Department of Mechanical and Aerospace Engineering

Integrating Renewable Energy Systems for Off-grid Electric Vehicle Charging Station on Motorway

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A thesis submitted in partial fulfilment for the requirement of the degree

Master of Science

Sustainable Engineering: Renewable Energy Systems and the Environment

2016

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Signed: Date: 25th August 2017

Abstract

The carbon emission has been rising in recent years. The government and global organizations attempt to fix the problem by creating the amazing technologies, such as carbon capture. One of the main reasons that cause problems is from current traditional vehicles, which emit carbon monoxide. Thus, people are more interested in clean power. So, electricity generators via renewables from wind, solar, and waves were invented to compete and eventually replace the use of coal and gas.

This is a significant change that spurs humanity to developing a sustainable world. Electrical vehicle is one of the more recent technologies that people currently take an interest in, due to the engine use of clean energy with little to no toxic emissions. For example, electrical, hybrid, and hydrogen cars. However, there is a problem with charging electrical vehicle (EV) through the grid, especially when the energy demand has reached the peak load.

Thus, this thesis primary focus is on the off-grid system with the placement of charging point in the existing service station that divided into 3 groups, small, medium, and large service stations with the 3 demand cases, light, medium, and aggressive energy demand. The power for recharging EV's battery is from renewables, such as wind turbines and solar panels. The systems were situated beside the motorway and looked at the number of renewables needed to supply the demand for the whole year. To make the simulations more accurate, they were separated into 3 scenarios: that the charging points were supplied by wind turbines only (assumed that it was cloudy), solar panels only (assumed that it was claim wind), and the combination of them. Also, the situation of the EV battery performance reduction during the winter.

The simulations were done with the modeling tool; Merit, which was created by the University of Strathclyde. The results from Merit were analyzed mainly from the number of renewables needed, and the area for the renewables farms. Also, the use of maps was to create a comparison, with already existing service stations beside the M8 motorway and around the UK. From the simulations, they show the acceptable systems for all demand cases and scenarios. However, there are the factors that cannot be overlooked that presented in the discussion section.

Acknowledgements

I would take this opportunity to acknowledge the professors who enabled me to accomplish this thesis. Firstly, my individual advisor, Dr. Joe Andrew Clark, who always guided me to work hard and to be cautious about conducting the simulations and writing the report, including the motivation to learn more in the study area. Secondly, Dr. Paul Tuohy, who advised my proposal project and simulations. Lastly, Dr. Jaemin Kim who educated me about the software Merit that was used in the thesis as a modeling tool.

I would take this opportunity to acknowledge my classmates and friends due to the sharing of knowledge and ideas, including the enjoyment of studying a master degree. Especially, Mr. Tongpong Sriboon and Ms. Tharaya Poorisat who studied their master degrees in 2015 and 2016, who shared the experiences of doing a good thesis. Moreover, I would like to thank Mr. Andrew Renfrew who checked my language and grammar through the whole report.

Finally, I would take this opportunity to acknowledge my family who always supported and inspired me until the completion of this thesis.

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Chapter 1: Introduction

1.1 Electrical vehicles in the UK

The car is one of the most important modes of transportation. More than that, it highlights the status and provides the opportunity for personal control and autonomy (European commission, 2017). However, The UK government has announced a plan to ban the new selling of diesel and petrol cars from 2040 (Craig, 2017). That means the number of electrical vehicles (EV) tends to be higher than the number at present and will be the main transportation in the UK as it shown in the figure 1.1.

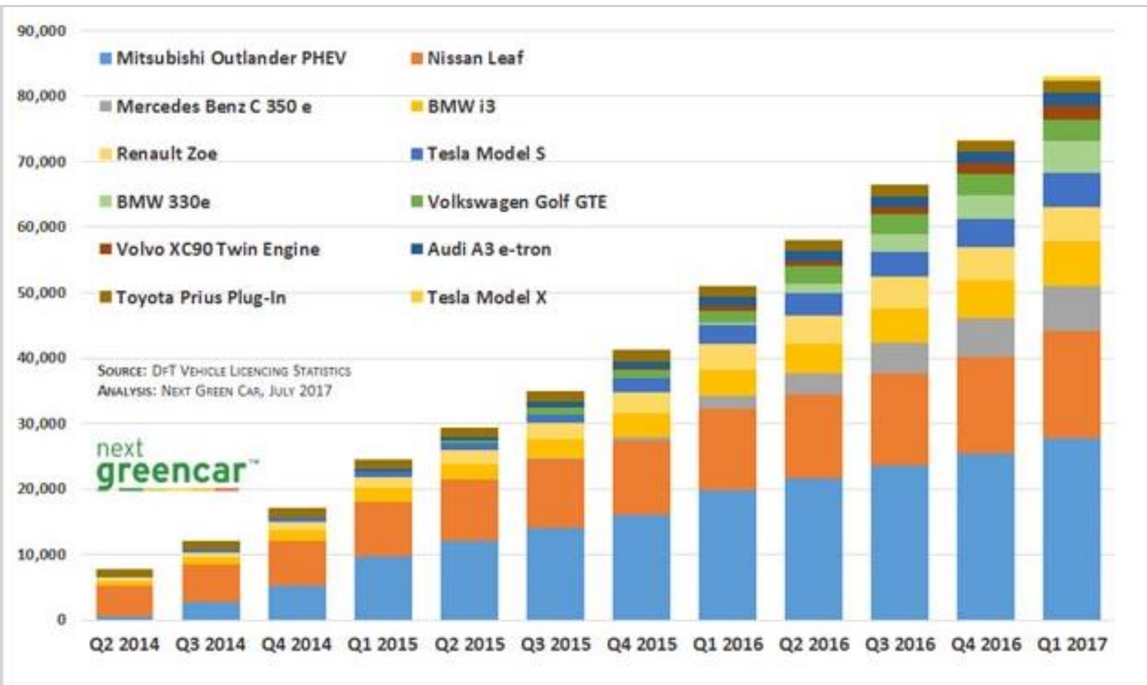


Figure 1.1: vehicle licensing statistics by model in the UK 2014 - 2017

The figure 1.1 is a bar chart that shows the up-trend of the number of registered EV in the UK. Surprisingly, the number of all EV brands are going up from 2014 to 2017.

However, the most 2 popular EV brands in the UK are the Nissan Leaf and Mitsubishi Outlander (Lilly, 2017). The technical data from those 2 brands will be used for the demand profiles.

However, there is a problem with the grid when the demand of charging EV's has been rising, especially when car owners charge their cars at the same time as the peak energy demand (Autovista Group, 2017). Scottish and Southern Electricity Networks (2017) reported that the most popular charging time is immediately after the owners return home from their work places. It is at the same time before the energy demand reaches the peak point of the day. That means the grid ability to supply power is threatened and can cause a lack of energy running in the grid. Having a smart charge in the charging point, it can defer the maximum charging power during the peak load period and stop the process when the battery capacity is full.

Another way of reducing the problem occurring in the grid is avoiding them. Having an off-grid system would have zero effect to the grid. That means, the power supply must come from renewable energy technologies. The charging point can be at home, work, or the car parks. Due to the limited area of individual house and the charging time e.g. at night, it will rely on wind turbine only because there is no solar direct at night. Also, having the charging point at work place or car park around the city center, it requires a higher number of renewables depends on the number of cars, which means a larger area for the renewable farm as well.

Thus, the renewable farm can be situated either side of the motorway, such as wind turbines, because they are the unused area, unattractive, and only few people live there, claimed by Baroness Brown, the UK's green energy ambassador (Bawden, 2016). That leads to this project of situated renewable farms beside the motorway with the charging points on the existing petrol stations. The detail of the project will be present in the following section throughout the thesis.

1.2 Aims and objectives

The project was mainly aimed to further human lives towards the sustainable way of using natural resources, taking the advantages of them, and negating harm towards the earth. The aims of the project were listed as following:

- To mitigate the effects of dump charging causing grid problems via simulation of off-grid systems.
- To create a model of charging stations on the motorway by using renewable energy systems only.
- To define the least surface area required for renewables farms for wind turbines and solar panels.

To meet the aim of the project, the objectives of the project were listed as following:

- Define the scenario for EV charging, such as charging time at the charging stations.
- Simulate the system by creating the demand profiles with the power from renewables e.g. wind turbines and solar panels.
- Study additional effects, such as: climate, renewables, additional technologies e.g. battery storage.

1.3 Scope

The project has been scoped via the following: EV, renewable technologies, and charging stations.

- The electrical cars were analyzed in the project are household electrical cars, which are Mitsubishi Outlander and Nissan Leaf.

- The charging stations will be situated on the M8 motorway between Glasgow and Edinburgh.
- The power charged into the EV's batteries from the electricity that was generated from renewables e.g. wind turbine and solar panel.

However, this project focuses on specific aspects due to sensitivity in creating demand profiles, including the other factors that are uncontrollable. This is a list that is out of scope of the project as following:

- The other models of sustainable cars, for example, hybrid and hydrogen cars.
- The model systems that are off-grid (grid-to-vehicle: G2V) and neglect the system of vehicle-to-grid: V2G.
- The position of charging stations and permission.
- Financial cost.

1.4 Methodology

To get the suitable systems for charging stations on the motorway, the project was followed step-by-step as presented below.

First of all, the electric cars in the UK were examined to create the demand profile by using technical specifications, such as battery capacity and charging duration. To supply the demand, the potential of renewables in Scotland were used for generating power, including battery storage.

The position for charging stations will be on the M8 motorway in Scotland. The length, the existing petrol stations, and area around the route were examined to define the maximum area that can be used for the charging stations. From the aforementioned details, the maximum number of wind turbines and solar panels will be estimated.

Thirdly, the scenarios were defined to create the completed demand profile, which includes the data from the first and second step.

Finally, the area needed for the renewables farms were defined whether they are the acceptable areas beside the M8 motorway. Furthermore, to apply the charging points into the service stations around the UK were considered.

Chapter 2: Literature review

2.1 The potential of renewables in Scotland

Scotland is one of the country that has high potential of renewable energy because of the climate and its geology said by the Scottish Government (2017). From the figure 2.1, it shows the increase of renewable electricity capacity in Scotland over 8 years from 2008 to 2016. The average annual capacity increase over 660 MW since 2008.

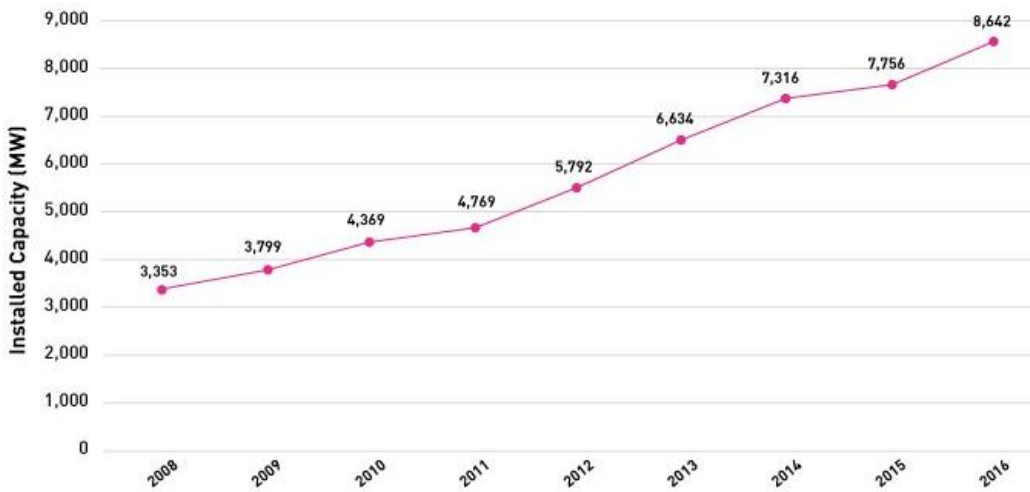


Figure 2.1: total installed capacity of renewable electricity in Scotland 2008 -2016

Renewable Renewables (2017) reported that the current mix of installed capacity of renewable electricity is 9,309 MW by 2017. The biggest capacity was from onshore wind turbine, which is over 72% of the total capacity. The other main sources are hydro, solar photovoltaics, and bioenergy respectively.

Thus, it is clear that onshore wind turbine is the major renewable technology in Scotland that supply to the national grid. However, there has been used for the smaller scale such as for generating electricity in the household or the charging stations for EVs. Especially wind turbine and solar panel that were used widely.

2.2 The significant motorway in Scotland

Traveling by vehicles, motorway is a choice of the driver for the travelling in long distance or in rush hour. The M8 motorway is one of the most significant motorway in Scotland (Baird, 2015). The total distance is around 60 miles, which links between Glasgow and Edinburgh via Renfrewshire, Lanarkshire and West Lothian. This motorway is used in the rush hour in the morning from 07:00 – 09:00 and again at evening from 16:00 – 18:00. Thus, it made the M8 motorway is one of the busiest in Europe with the number 180,000 vehicles running on the motorway every day as shown in the figure 2.2.

Figure 2.2: the M8 motorway near Glasgow

The motorway in Glasgow is contained in the boundaries of the former Strathclyde Regional Council area. It is counted roughly from Harthill Services near Junction 5 to Junction 31 near Bishopton.

2.3 The existing wind farm beside motorway in the UK

From the section 2.1 of the potential of renewables in Scotland, it shows that wind turbine is one of the most effective renewable technology. Also, it has a project of situating wind farm beside motorway, which called Clyde Wind Farm. The wind farm is can be seen easily from the A74(M) motorway as shown in the Figure 2.3.

Figure 2.3: Clyde wind farm view on A74(M) motorway

The Clyde wind farm was created for powering around 200,000 homes, which consists of total 152 wind turbines. The wind farm project was approved in July 2008 by the Scottish Parliament after getting a planning permission to build a wind farm on either side of the motorway by Scottish and Southern Energy (SSE). It was under construction in in early 2009, finished in 2012, and opened in September 2012 at a ceremonial ribbon cutting by First Minister of Scotland Alex Salmond (Dixon, 2014).

The wind farm is currently one of the biggest single consented wind farms in Europe, which is situated between Biggar and Moffat in the total area around 47 square kilometers.

However, SSE Renewables was granted consent in July 2014 by the Scottish Government to extend the existing 152 turbine Clyde Wind Farm by operating a 54-turbine extension. It is currently constructed by expecting to complete by mid-2017. Allison (2016) said that after the extension is commissioned, the equity stake jointly owned by UKW and GLIL will be diluted to 30% with SSE retaining 70%.

The Clyde Wind Farm after an extension will has a maximum generating capacity of 172.8MW from 54 Siemens 3.2MW direct drive turbines. There are two permanent met masts on site and 35km of access tracks. The final rotor will be lifted into place be the project team by July 2017. With the new 54 turbines, it continues to towards completion of the wind farm.

2.4 The existing solar farm beside motorway in the UK

From the section 2.1, solar panel is one of the main sources of renewables in Scotland. Wessex Solar Energy (2014) has constructed the Park Wall 5 MW Solar Farm beside the M5 motorway about 0.5 km to the east of Bridgewater. A planning application were submitted to Sedgemoor District Council for the permission for the construction in May 2017 as shown in the figure 2.4.

Figure 2.4: the top-view Park Wall 5 MW Solar Farm

The figure 2.4 shows the whole solar farm from the top-view and presents the total solar panels in the farm, which over 20,000 solar panels in the area of 8 hectors or 0.08 square meters. The solar panels are placed on top of the panel table, makes the PV tile angle is between 20 and 35 degrees from the horizontal, and up to the ground 3.5 meters to reach the panel tables.

The solar farm generates the electricity around 5,000,000 kWh per year to support over 1,000 homes. Moreover, it has been accounted that the solar farm can prevent the carbon emission up to 4,500 tons. However, the electricity is exported through the existing underground network called tee-in, which is operated by Western Power Distribution.

2.5 Software review

To simulate the scenarios about using the renewables to produce electricity, there's a multiplicity of software that can be used, for example, ESP-r, Merit, EnergyPLAN, and Homer. The aforementioned software's will be reviewed for defining the most suitable software for the simulation in this project.

ESR-r is a software that was created in 1974 by the University of Strathclyde, United Kingdom. It allows to focus the energy and environmental performance in the building. It works in a manner of the realistic and actual physical systems by using the design of the building for an integrated performance. The building designs, which are: the building form, the material such as fabric, airflow, and shading.

Merit is a software for evaluation of tools and determines the relationship of the climate such as wind speed and direct solar, with the renewable supply and battery storage. By matching demand and supply with the certain technologies. It aims to meet the electrical and thermal (heat and hot water) demand via renewable energy systems and low carbon energy system such as photovoltaic (PV) components, wind turbines, fuel cells, CHP, heat pump.

EnergyPLAN is a software for the national energy systems in every hour of all sectors such as electricity, heating, cooling, industry, and transport. It also helps in decision making for an energy system strategy on a future national scale with relation to environmental and economic impacts (Ostergaard, 2015)

Homer (Hybrid Optimization Model for Multiple Energy Resources) is a global standard software for optimizing microgrid design of all sectors from the small scale, such as village power, to the national grid (HOMER Energy LLC, 2014). To meet the demand, Homer can be customized via 9 individual modules, for example, the renewable sources like hydro, biomass, and hydrogen, and the thermal demand of combined heat & power, and the advance systems such as Advanced Load, Advanced Grid, and Advanced Storage, and the other sources from Multi-Year and MATLAB Link.

From the research, Merit is a software that meets the aims of the project. Because Merit allows creation of a model for the mix supplies from the renewables for the demand, which is the power required for charging the EV's battery as shown in section 3.4 demand profiles. Then calculate the area needed by the number of renewables that required in each scenario to meet the demand. The process of the software is shown in figure 2.5.

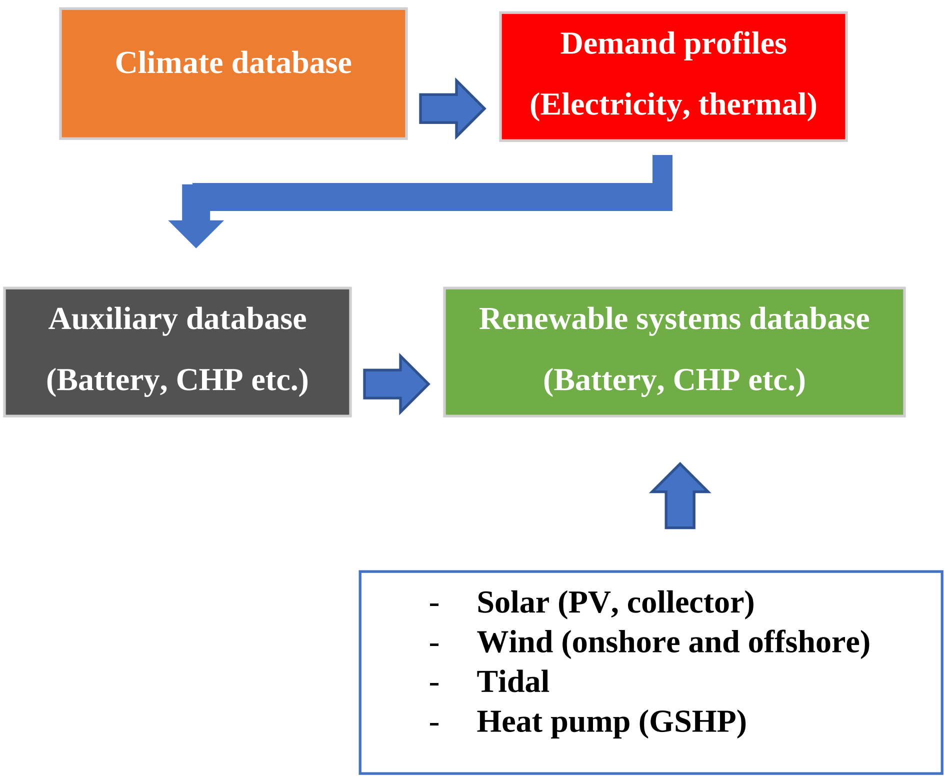


Figure 2.5: the process in the modeling tool Merit

The process of the modeling tool of the project, Merit software, is presented in figure 2.5. It starts at the climate profile step, which needs to be devised where the system is going to be situated. The systems in this project focus on the M8 motorway, which links between Glasgow and Edinburgh. So, the focused climate will be in Glasgow. The next step is demand profiles, which are shown in the sector 3.4 demand profiles. The auxiliary database was used due to the intermittent power generated from the renewables, which was explained at the beginning of section 3.5 renewable required. Finally, the renewable system step. There are multiple choices of renewables that can be used for both electricity and thermal demand. However, this project will be focused on electricity demand by providing the power from solar panels and wind turbine onshore.

The technical analysis is shown in section 3, which has the explanations about the modeling tool that will be used for the simulations in this project.

Chapter 3: Technical analysis

3.1 Scenario definition

The charging stations will be situated beside the M8 motorway which links between Glasgow and Edinburgh. The traditional process is for the EV to be driven to a station, the driver charges their car (EV's battery) and wait until it has reached full capacity, once full, the car will vacate the station. From that process, it takes between 1.5-14 hours to fully recharge, depending on the charging duration of each EV brand. Consequently, most owners prefer to recharge their EVs overnight.

Instead of spending the time, in this project, the station has a set of EV's battery. The battery from EV will be charged via the use of renewables throughout the day and night. Thus, the process is as follows: the EV is driven to the station, the EV's battery is changed to a full capacity, and the car drives out of the station. Due to this project being based on a future scenario, the changing EV's battery step can be done by a robot. So, the whole process would be done in a few minutes.

There are many kinds of renewables, but only wind turbine and solar panel were used for simulation in this project. Due to the 2 renewables are the most suitable technologies for applying beside motorways, where there's a limited area. Moreover, the critical point is the surface area needed for the system. Wind turbine and solar panel appear to be suitable sources for producing power as well as the system is not connecting with the national grid (off-grid).

Thus, it has been divided into 3 scenarios. The first 2 scenarios are the systems, which have power supplied via 1 kind of renewables, wind turbine is for the first scenario and solar panel for the second scenario. They are created to consider the worst-case scenario, that there is no wind or sun to produce the power. Finally, the last scenario is the combined technologies of wind turbine and solar panel.

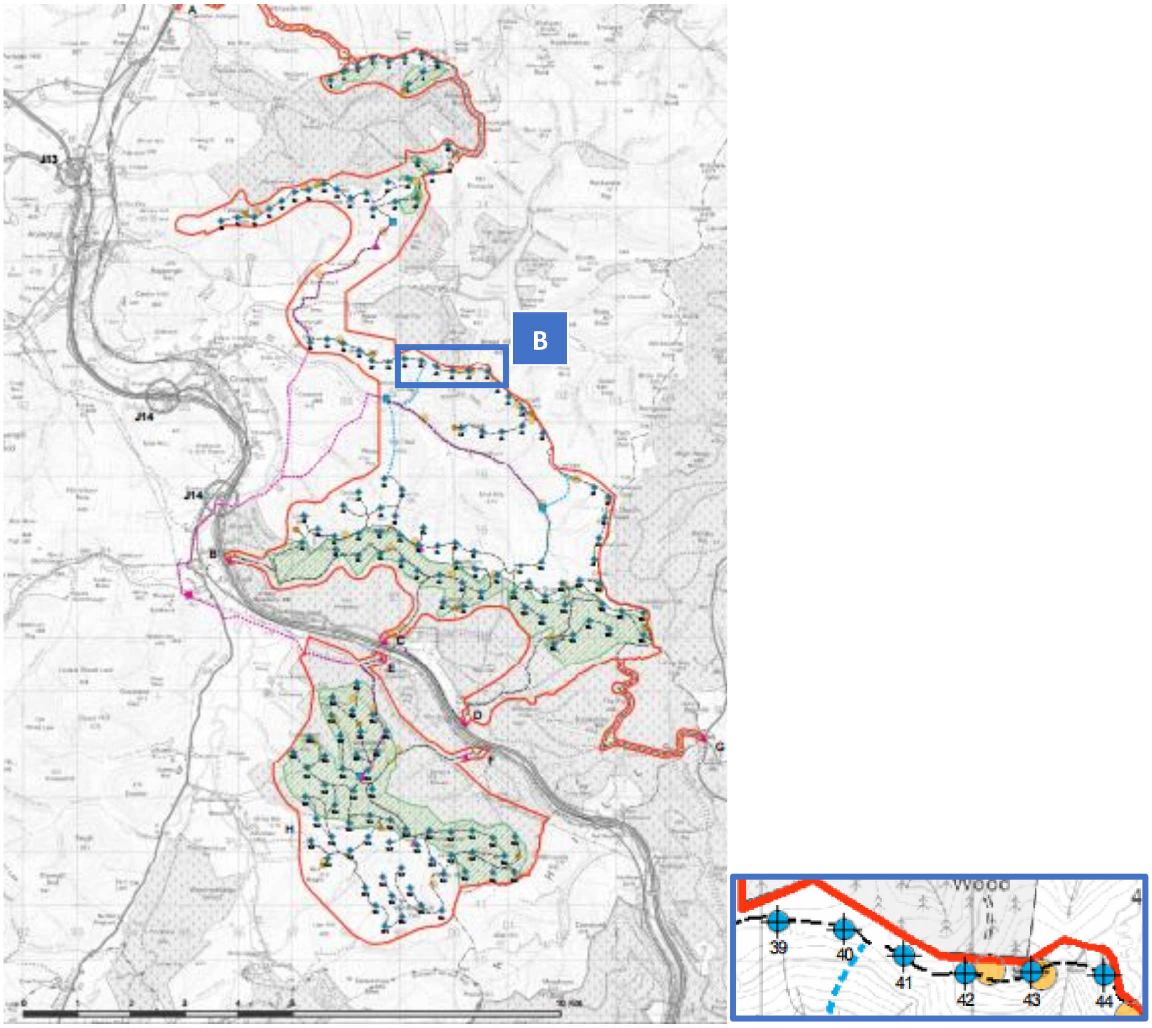
However, there is another one simulation considering about the effect of EV's battery during the winter. Also, the scenario of applying the charging point into the existing petrol stations around the UK, might happen in the future.

Before conducting the simulation, it is important to define what is the assumption of the simulation, which will be explained in the section '3.2 simulation assumption'.

3.2 Simulation assumption

To do the simulation, assumption of the project need to be set before. The scenario was created to find the maximum number of renewables as well as the area needed for the renewables farms. To determine the maximum number of renewables that is acceptable for situating the farms on either side of the motorway, the number of renewables were taken from the existing wind farm and solar farm which has been used in the real situation.

Determinizing of the area needed for the wind farms, it will be defined by referring to the Clyde Wind Farm map as shown in the figure 3.2.



A: top-view of the whole wind farm B: the distance of 1 kilometers

Figure 3.2.1: Clyde Wind Farm map

From the figure 3.2A, it shows the whole map of 152 wind turbines in the area of 47 square kilometers. While figure 3.2B shows the 6 turbines arranged in a single column which require the distance of 1 kilometer approximately. It can be assumed that wind turbines require a gap between them 0.28 kilometers.

Normally, wind farms will be designed by using the distance needed, for example, the wind turbines will be situated along the motorway with a distance such as 1km (figure 3.2.1B). However, the project will be focused on the area required for the renewables farms between wind and solar farms. To compare those 2 renewables sources, the unit needs to be the same. Due to solar farms are calculated by area needed, the wind farm will be calculated by area needed as well. It was assumed that the area of the wind farms is shaped as a square with equal sides as shown in the figure 3.2.2.

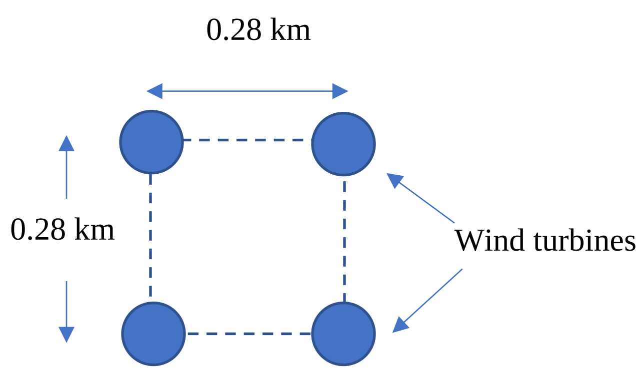


Figure 3.2.2: the wind farm assumption

The assumption of the area needed for the wind farm will be defined by referring to the Clyde Wind Farm as shown in figure 3.2.1. The square area of the wind farm consists of 4 wind turbines with an equal distance between them. Thus, the total area of 4 wind turbines requires 0.06 square kilometers. So, a single turbine requires 0.015 square kilometers.

Due to the off-grid system, the wind farm needs to be around the service station. To use the area of Clyde Wind Farm as a maximum area for wind farm for 1 service station, it takes too much land-use. So, the large service station beside M8 motorway will be used as a comparison for the maximum acceptable area for a wind farm. For example, Morrison shopping and petrol station (G34 9JJ), which is indicated as a large service station, can be used to determine the maximum area for the wind farm, as shown in figure 3.2.3.

Figure 3.2.3: Morrison shopping and petrol station

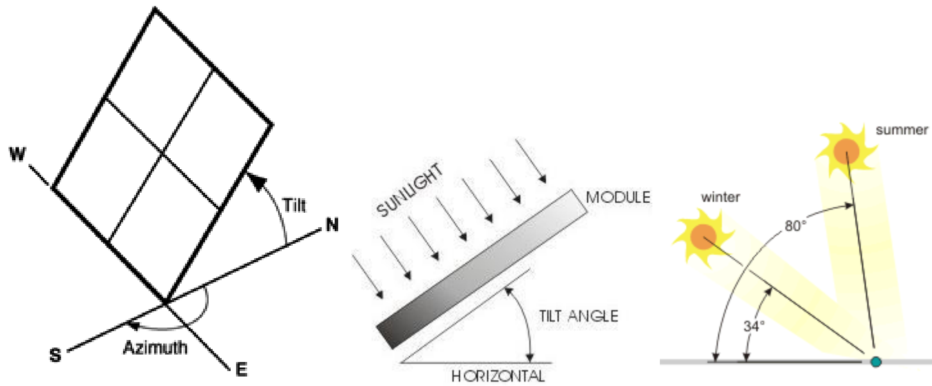
The example of the large service station on motorway is Morrison shopping and petrol station. It has the total area 0.045 square kilometers including a shopping mall, petrol station, and car park. Thus, it can be assumed that 4 times of the Morrison shopping and petrol station area is an acceptable size for the wind farm. So, the maximum area of the wind farm would be 0.18 square kilometers.

Next, the area required for solar farm will be defined in the same way as used for the wind farm. A good example of the solar farm in the UK is Park Wall Solar Farm.

Figure 3.2.4: Top-view of the whole Park Wall Solar Farm

The figure 3.2.4 shows the whole solar farm, which covers approximately 8 hectares or 0.08 square kilometers with 20,000 solar panels. Thus, an average of a single panel required is 4 square meters. It is an acceptable size due to the existing measurements of Park Wall Solar Farm, so it includes other parameters, such as PV shading, tilt, and azimuth angles. Also, the area of the Park Wall Solar Farm was assumed to be the maximum area for solar farm in the simulations.

Moreover, the simulation of power generating needs to be set for the angle of the PV for the maximum power output, as shown in the figure 3.2.5.



A: PV array fixed tilt B: PV tilt C: sun angle

Figure 3.2.5: PV factors

To get the maximum power output from the PV, there are other factors that need to be considered e.g. tilt, azimuth, and angle of incidence as shown in the figure 3.2.5. The type of PV from the modeling tool is a PV array fixed tilt as presented in figure 3.2.4A. The main parameter of the PV is tilt. Tilt (β) is the angle between the ground base and the horizontal, as presented in figure 3.2.5B. And the figure 3.2.5A shows the azimuth (γ), which is the angle of the planar rotation West or east. While figure 3.2.5C shows angle of incidence (θ), which is the angle between the vector perpendicular to the ground base and the projection of the sun to the PV (Brownson, 2016). The relationship between those 3 factors is as follows in the equation below.

$$\cos\theta = \sin\phi \sin\delta \cos\beta - \cos\phi \sin\delta \sin\beta \cos\gamma + \cos\phi \cos\delta \cos\beta \cos\omega$$

$$+ \sin\phi \cos\delta \sin\beta \cos\gamma \cos\omega + \cos\delta \sin\beta \sin\gamma \sin\omega$$

The suitable angle was calculated in different climate based in Glasgow during winter, spring/ autumn, and summer. The results are the tilt angles in different climate, which are 80, 56, and 32 degrees respectively. (The Solar Electricity Handbook, 2017).

Furthermore, the other factor that needs to be considered is azimuth. The experiments from the private organization called the EEM Energy has presented that PV operates the most effective with the angle of azimuth about 0 degrees and tilt 30 degrees.

Thus, simulating the whole year scenario, the angle 32 degree was used as a tilt (degrees from horizontal) due to the fact that power is generated maximumly during the summer and less during winter. So, PV tilt should be at 32 degrees, which is the optimal angle during winter. Thus, the PV systems are set at 32 and 0 degrees of tilt and azimuth respectively.

In addition, battery storage was used in the simulation. Because of the intermittent power generated from the renewables, battery storage needs to be added in the system to discharge when renewables produce inefficient power. Thus, the high quality of 145Ah 6Volt battery storage was used in the simulations.

To sum up, the assumptions of the simulations were defined. The critical point of the project is the number of renewables for supplying the demand. That means the area needed for the renewables farms both wind and solar farms can be summarized in table 3.2.1.

Table 3.2.1: the summary of the assumptions

Renewables Farms	The maximum number of renewables	The area of a single renewable (sq. m.)	The maximum area for the renewable farm (sq. m.)
Wind turbines	12	15,000	180,000
Solar panels	20,000	4	80,000

From the table 3.2.1, it shows the maximum number of the renewables and the amount of area needed, and the area for each wind turbine and solar panels. The numbers were taken from the existing wind and solar farms: Clyde Wind Farm and Park Wall Solar Farm. It is clear that from the table, that the acceptable number of renewables between wind and solar farms is totally different. Due to the area needed for a single solar panel is only 4 square meters, while a wind turbine required is 15,000 square meters. The wind turbine requires that much area because it needs the space for the length of the turbine and the turbulence of the wind between the wind turbines. So, the maximum number of wind turbines is less than the number for the solar panels. Thus, the total acceptable area for the wind farm is higher than solar farm.

After defining the assumptions, the modeling tool needed to be validated to get the accurate results from the simulations. The validation is presented in section 3.3 Validation.

3.3 Validation

From the software review section, Merit is the modeling tool that will be used for the simulation, by following the scenario definition and simulation assumption as shown in the section 3.1 and 3.2 respectively.

To make sure that the modeling tool is working accurately. The power output of renewable technologies, wind turbine and solar panel, need to be validated. In this project, 800 kW, 15 kW, 10 kW, and 1kW wind turbines and 167W, 100W, and 30W solar panels were used as the renewable power supplies.

The 4 sets of power output from 4 different wind turbine capacities are shown in the table 3.3.1 in the unit of kilowatt (kW) by an increased wind speed.

Table 3.3.1: power output for various capacity of wind turbine from modeling tool

wind speed	Power output (kW)			
	800 kW	15 kW	10 kW	1 kW
1	0	0	0.00	0.00
2	0	0	0.00	0.00
3	0	0.4	0.10	0.01
4	0	1.2	0.30	0.03
5	23	2.2	0.55	0.10
6	57	4	0.90	0.15
7	90	5.2	2.50	0.23
8	165	7.8	4.00	0.36
9	257	10	6.00	0.49
10	359	12.8	7.50	0.62
11	470	14.8	9.00	0.70
12	572	16	9.80	0.75
13	668	16	10.00	0.80
14	747	15.6	10.00	0.82
15	805	15.6		0.82
16	838	14.8		0.82
17	842	14.8		
18	840	14.8		
19	827	14.8		
20	808	14.8		
21	785	14.8		
22	757	14.8		
23	728	14.8		

From the table 3.3.1, it is clear that the data is not for a linear line but will be a curve that can be separated into 3 parts: at the cut-in wind speed, rated wind speed, and cut-out wind speed.

The cut-in speed depends on the wind turbine capacity. That means the higher capacity of the wind turbine, and the strength of the wind force to get the first lowest power from the wind turbine. For example, it requires a wind speed of at least 5 m/s to get the cut-in power at 23 kW for 500-kW wind turbine. While a 15 kW, 10 kW, and a 1 kW capacity wind turbine would require only 3 m/s wind speed, to get the cut-in power. Similarly, to get the rated power, over 15 m/s wind speed would be required for an 800-kW wind turbine, but other capacity wind turbines requires a lower wind rate. Moreover, the cut-out power is controlled by the limitation of generating power.

The power output from the modeling tool was compared with the data from the manufacturers, which is shown in appendix 5, in each capacity by plotting into a graph, which is shown as a power curve. To make sure that the power that generates from the wind turbine is acceptable, the comparison graphs from the data from the modeling tool and the manufacturer are shown in the figure from 3.3.1 to 3.3.4. The different percentage should not go over 10%, so it is indicated as an acceptable wind turbine that can be used for the simulations.

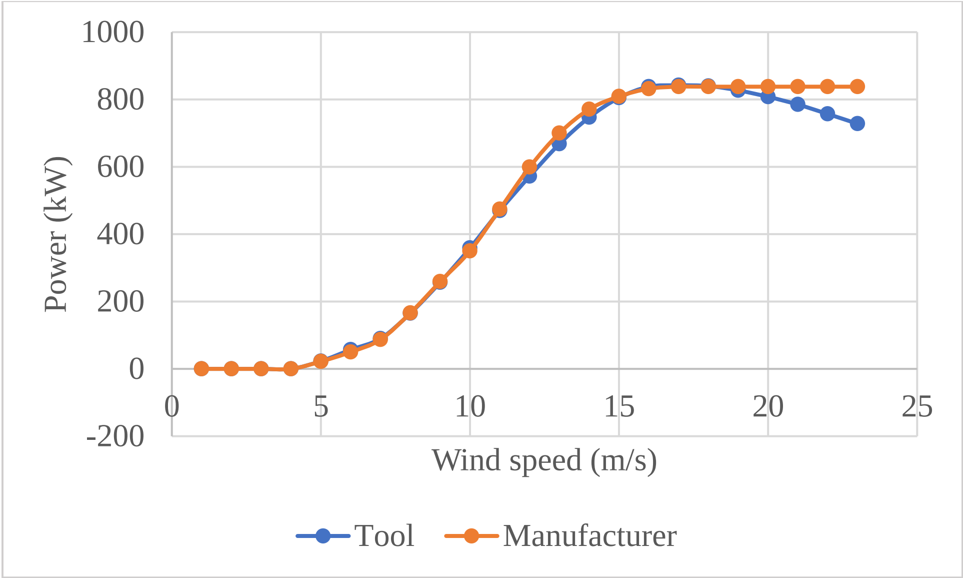


Figure 3.3.1: power curve for 800 kW wind turbine

The figure 3.3.1 shows a set of power out-put of the 800-kW wind turbine from the modeling tool and manufacturer. It is clear that the most different between 2 sets of data is at the high wind speed or at out-put wind speed. The rest of data is almost the same and shows with almost the same line. However, the different percentage is 3.26%, which is lower than 10% (the maximum different percentage that is acceptable), so the 800-kW wind turbine is acceptable to use in the simulations.

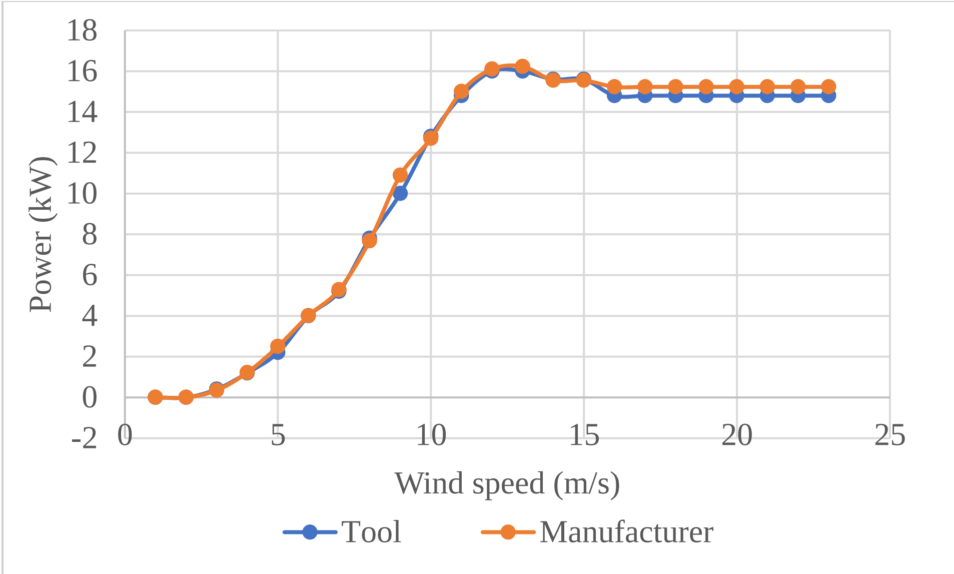


Figure 3.3.2: power curve for 15 kW wind turbine

The figure 3.3.2 shows a set of power out-put of the 15-kW wind turbine from the modeling tool and manufacturer. The 2 power curves show the peaks of the power out-put at 13 m/s wind speed, then decreased to the rated wind speed before coming to the cut-out wind speed at 16 m/s. The overall graph is not much different with only a 2.91% difference. Thus, the 15-kW wind turbine is acceptable to use in the simulations.

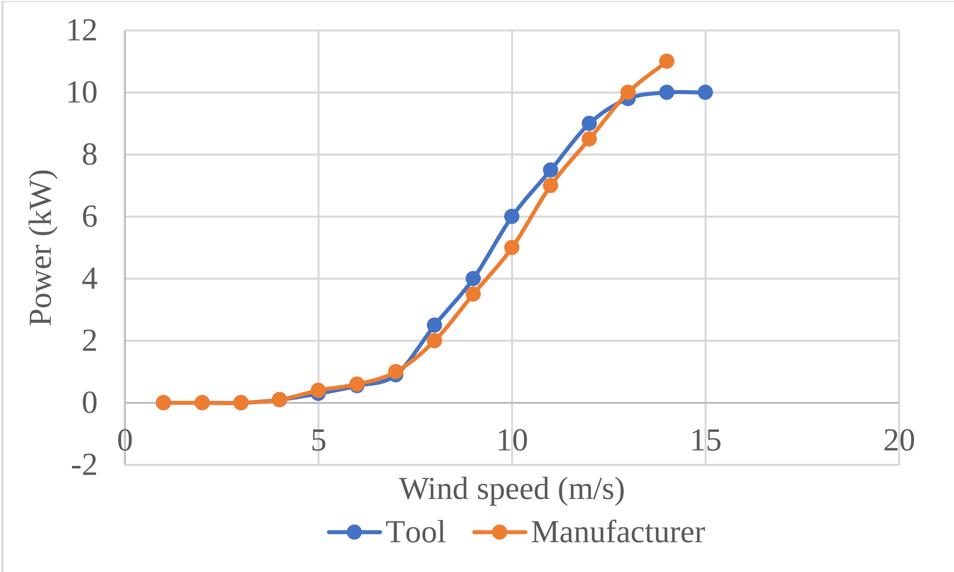


Figure 3.3.3: power curve for 10 kW wind turbine

The figure 3.3.3 shows a set of power out-put of the 10-kW wind turbine from the modeling tool and manufacturer. It is clear that the significant difference between the 2 sets of data is that before the rated wind speed, where there's a noticeable slope, and after the rated wind speed at 13 m/s. Thus, it gave the high different percentage of 9.70%. However, it is lower than the maximum acceptable different percentage of 10%. So, the 10-kW wind turbine is acceptable to use in the simulations.

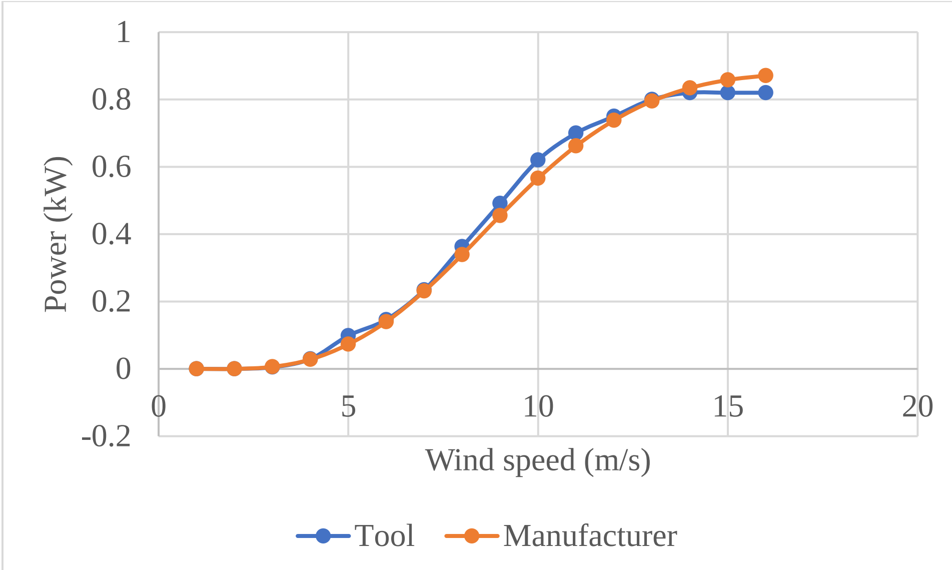


Figure 3.3.4: power curve for 1 kW wind turbine

Figure 3.3.4 shows a set of power out-put of the 1-kW wind turbine from the modeling tool and manufacturer. It is clear that the most noticeable difference between 2 sets of data is before the rated wind speed, where it slopes, and after the rated wind speed at 14 m/s. Thus, it gave the high different percentage of 6.70%. However, it is lower than the maximum acceptable different percentage of 10%. So, the 1-kW wind turbine is acceptable to use in the simulations.

The wind turbines have been validated and got the acceptable percentages. After that the 3 sets of the electronics characteristics from 3 different solar capacities were used for the validation of solar panel. The electronics characteristics are shown in table 3.3.2.

Table 3.3.2: The electronics characteristics for various capacity of solar panel from modeling tool

Electronics characteristics	Solar panel		
	167 W	100 W	30 W
V_{mp} (V)	25.00	17.00	17.40
I_{mp} (A)	6.70	5.90	1.87
I_{sc} (A)	7.30	6.30	2.03
V_{oc} (V)	30.00	21.00	21.2

Table 3.3.2 shows the current – voltage (V-I) characteristics of the 167W, 100W, and 30W solar panels, which are voltage at maximum power (V_{mp}), current at maximum power (I_{mp}), short circuit current (I_{sc}), and open circuit voltage (V_{oc}), To get the maximum power, it is the combination between the particular current and voltage at I_{mp} and V_{mp}, which is used for the ideal operation of the maximum power point (MPP), as shown in the equation below:

$$P_{maximum} = V_{mp} \times I_{mp}$$

From the table 3.3.2, its clear that the highest maximum output is from the 167W, 100W, and 30W solar panels respectively. The relationship between the 4 parameters is shown in figure 3.3.5, which shows the comparisons of each solar panel capacity including the comparison between the modeling tool and manufacturers.

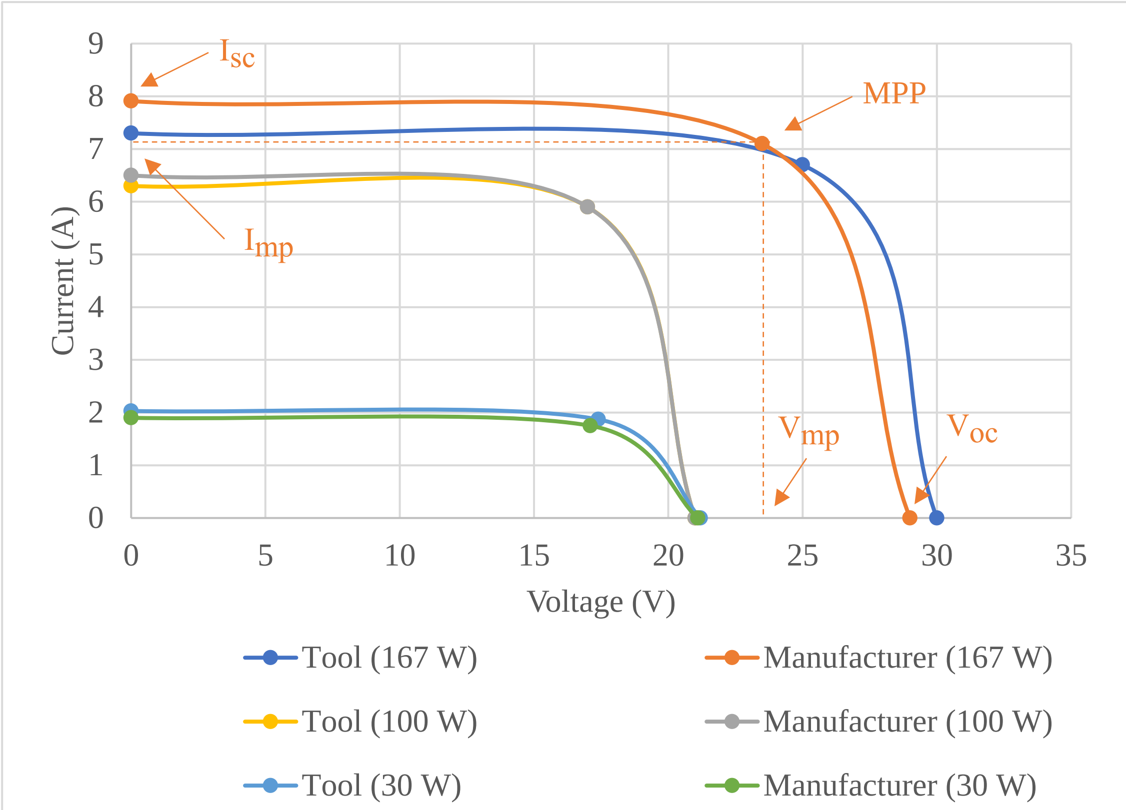


Figure 3.3.5: V-I characteristics for the solar panels from modeling tool and manufacturer

Figure 3.3.5 shows the V-I characteristics of the 167W, 100W, and 30W solar panels. The graphs were plotted by using the data from the modeling tool and manufacturers. The 167W solar panel has the highest maximum power output with the highest V_{mp} and I_{mp}. Moreover, 100W and 30W solar panels have a similar amount of voltage at the maximum power point at around 17 volts. However, 100W has a higher maximum power output than 30W solar panels. Similarly, V_{oc} of the 100W and 30W are approximately 21 volts.

The different percentages between the data from modeling tool and manufacturers were defined for 167W, 100W, and 30W solar panels. For 167W solar panel, it has the highest percentage with 7.71%. Then, the lower percentages for 30W and 100W solar panels are 6.84% and 3.07% respectively. From the different percentages for all 3 types of solar panels, it is clear that solar panels are acceptable to use in the simulations by using the data from the modeling tool due to the different percentages is lower than 10%.

In brief, the modeling tool Merit, has been validated and showed the different percentages that they are acceptable. So, it is almost ready to simulate the scenario. Before that, the demand profiles needed to be created as shown in section 3.4.

3.4 Demand profiles

Demand profiles were created by using the power for full charge for the number of cars that come to the existing petrol stations, because the number will be taking into account of the total number of EVs that come to the charging stations. It has been researched by Adzuna (2010) that in busy petrol stations, it gets a customer approximately twice in a minute or 120 cars per hour. A normal station has an average of 40 customers per hour, while a quite station has a customer once every 10-15 minutes or around 4 cars per hour. Thus, the power demand can be established into 3 cases. The first case is the smallest amount of power required for charging EVs for 4 cars per hour. In the other cases number 2 and 3 there’s a higher power demand needed by 40 customers per hour and 120 customers per hour respectively.

Before creating the demand profiles, Setting the duration of customer coming to the stations needs to be done. Referring to the petrol stations around M8 motor, most of them open 24 hours and a few open in the morning between 7:00-8:30 and close around 22:00. However, the rush hours on M8 motorway are 7:00-9:00 in the morning and 16:00-18:00 in the evening (Baird, 2015). So, the opening time of the charging stations was assumed to be between 07:00 and 22:00 on weekdays.

Moreover, the power needed in each case is created by using the technical data of the EV’s battery, which are: battery capacity, charging duration, and range. In this project, Mitsubishi Outlander and Nissan Leaf were used as the most popular EV brands in the UK as shown in the table 3.4.

Table 3.4: technical specification for the most popular EV brands in the UK

EVs	Battery capacity (kWh)	Charging duration (hrs)	Distance range	
			(miles)	(km)
Mitsubishi Outlander	12.0	3	32.5	52.3
Nissan Leaf	24.0	7	124.0	38.6

(Energy Saving Trust, 2017)

From the table 3.4, Nissan Leaf seems to be the most difficult to charge their battery, due to requiring double the amount of power in comparison to a Mitsubishi Outlander. However, the longer charging time reduces the hourly power needed. Nissan Leaf requires around 3.43 kW per hour of charging, which is lower than Mitsubishi Outlander that requires 4 kW per hour of charging. In addition, Mitsubishi Outlander has a lower distance range, which is 32.5 miles or 52.3 kilometers, while Nissan Leaf has almost 4 times higher, which is 124 miles or 38.6 kilometers.

George and Kershaw (2016) reported that the average distance people travelled by cars in 2016 was 18.25 miles per day. From the table 3.4.1, it can be assumed in the demand profiles, that drivers use their EVs on weekdays, so Mitsubishi Outlander and Nissan Leaf require daily and weekly charges with almost full charging. Moreover, it was assumed that there are 2 EV brands running on the M8, half being Mitsubishi and the other being Nissan Leaf.

After garnering required data, the 3 demand profiles have been created and have the same trend as shown in the figure 3.4.1.

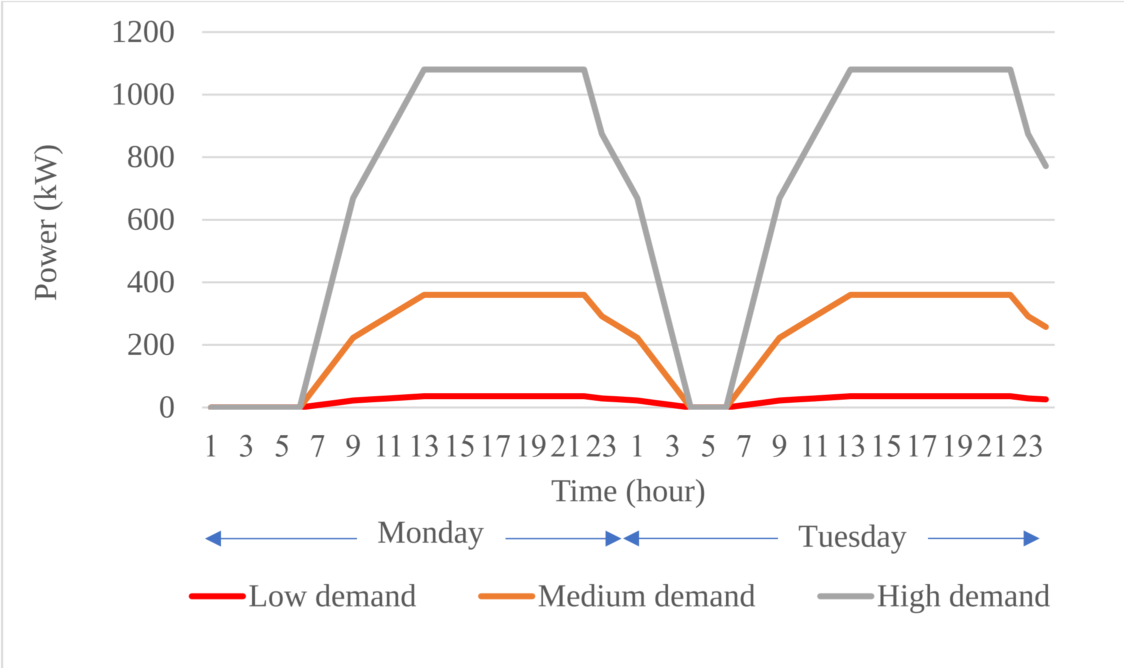


Figure 3.4.1: 2 days demand case 1, 2, and 3 profiles

The figure 3.4.1 presents a non-linear line of the low, medium, and high demand profiles on Monday and Tuesday. They present that there is no power needed between 01:00-06:00 on Monday because charging stations close at this time. During 07:00-12:00, the line has the same slope as the time between 23:00-04:00 the next day, because the EVs arrives and vacates the station with the same ratio that it has 4 cars comes to the station in each hour. So, the power needed in the high demand goes higher until 1080.3 kW at 13:00 until 22:00. The figure runs in the same loop during the weekdays but no power required during weekends. Because the last set of the EV's battery is at 22:00, due to the longest charging duration in this project, it requires 7 hours to reach full capacity. That means at 05:00 on the next day has no battery for charging until the stations open again at 07:00.

The other 2 demands, which is low and medium demands, have the same profile but lower magnitudes, due to the assumption that demand case 1 and 2 has 4 and 20 EVs in the station per hour. Thus, the maximum demands are 36.01 kWh and 360.1 kWh for low and high demand respectively.

Now all the data is enough to do the simulation, to define how many renewables are needed for the specific demand, only 1 source of renewables or both of wind turbines and solar panels is required, and how size of the area needed for the renewables farms. The renewables required is shown in the section 3.5.

3.5 Renewables required

To recap, Merit will be used as a modeling tool to simulate demand, find the number of renewables required under 3 scenarios, and adjust whether the systems are acceptable.

Due to the fact that renewables are intermittent of producing power, the simulations of showing the matching percentages of demand and supply will be done before doing the simulations with the 3 demands under the 3 scenarios.

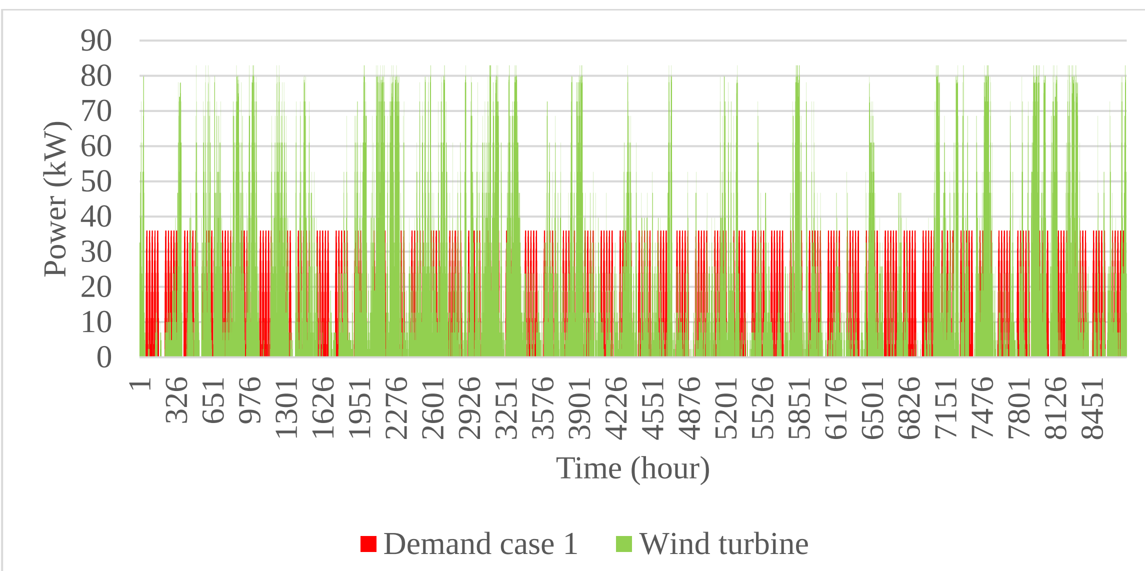


Figure 3.5.1: the year demand case 1 supplied by wind turbine

The figure 3.5.1 shows that 5 wind turbines of 15 kW generated power fluctuated, causing multiple gaps between demand and supply throughout the year. There was very low power from the supply that didn’t match the demand in some period of time, while some went more than double from demand. To justify that this is not suitable, it can be judged by the matching percentage.

Table 3.5.1: matching result between demand case 1 and wind turbine

Demand	Total demand (MWh)	Renewables	Energy supply (MWh)	% Match	Energy deficit (MWh)
Case 1	153.81	5 wind turbines of 15 kW	207.84	50.26	67.09

From the table 3.5.1, it is clear that the system of using only wind turbine as a supply is not acceptable due to the match percentage being too low and indicated as a poor match. Because the total power from wind turbines is higher than the demand, it shows that there is an energy deficit, which was around half of the demand that was supplied. Thus, to supply demand, power generated from only 1 source, such as a wind turbine is not enough.

The simulation of matching demand and supply of solar only presented using wind turbine only, would be more suitable.

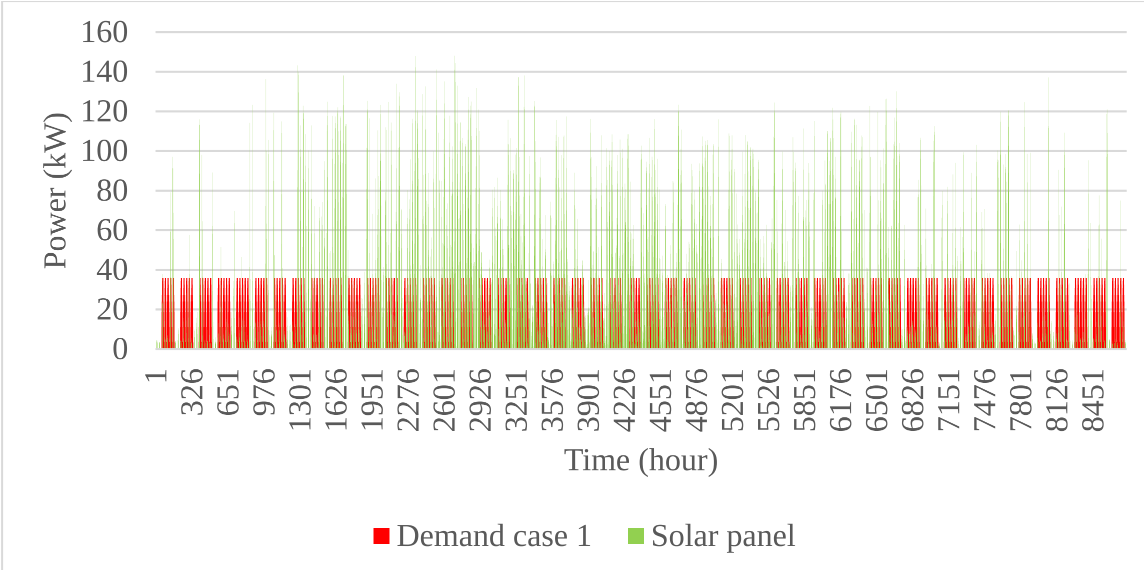


Figure 3.5.2: the year demand case 1 supplied by solar panel

The figure 3.5.2 shows the similar matching that the power generated from 167 kW 1,000 solar panels fluctuated throughout the year, which caused many gaps throughout the year. Moreover, solar panels can produce power only during daytime due to the lack of direct sunlight at nighttime. The majority of Power from solar panel was 3 times higher than demand at some points, except at the beginning and last period of the year that minimal power was generated. Also, percent match needs to be considered for justifying the acceptance of the system.

Table 3.5.2: matching result between demand case 1 and solar panel

Demand	Total demand (MWh)	Renewables	Energy supply (MWh)	% Match	Energy deficit (MWh)
Case 1	153.81	167W 1,000 solar panels	154.35	46.27	93.99

The table 3.5.2 presents the match between demand case 1 with solar panel only. It is clear that this system has low rate matching of 46.27, which is indicated as a very poor match. The energy supply is almost equal to the demand but because of the intermittent of solar panel, there was the high amount of deficit. Thus, solar panel is not acceptable for supplying power for demand as its own.

From matching demand with sources of renewables as a supplier as their own, it is clear that the system cannot be without battery storage, which charges when there is energy surplus and discharges when there is not enough power delivered for demand. To find the most suitable systems for all demand under the scenarios. They will be presented by the number of wind turbines or solar panels needed, which means the area needed. The demand cases and scenarios will be simulated followed by the table 3.5.3.

Table 3.5.3: the simulations in this project

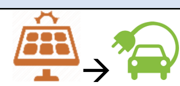
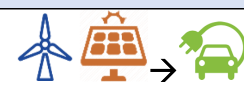
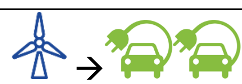
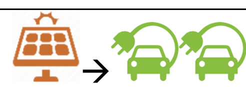
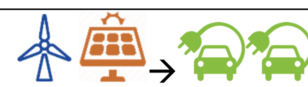
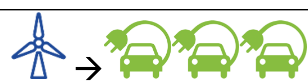
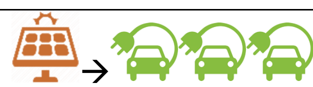
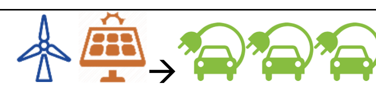
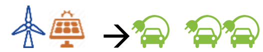
Demand case	Scenario		
	1	2	3
1			
2			
3			

Table 3.5.3. shows the demand cases and scenarios that will be simulated in the following section. The symbols were used to present the renewables and the demand of charging power to the EVs. For example, demand case 1 under scenario 1 was used as the symbol  , which means the power generated from wind turbines only, as it was assumed that no solar direct from the sun and rely on 1 source of renewables, is supplied for the light number of EVs in the charging stations (4 cars per hour). While 

represents the power generated from solar panels only, as it was assumed that there's no wind and rely on 1 source of renewables, is supplied for the higher number of EVs in the charging stations (40 cars per hour). However,  means the power generated from both wind turbines and solar panels is supplied for the highest number of EVs in the charging stations (120 cars per hour).

In this project, the simulations of demand case 1 under the scenario 1 will be done first, to show the least demand with the fewest number of renewables required, and followed by scenario 2 and 3, with the different kinds of renewable supplier. Then consider the higher demand in case 2 and the most aggressive demand in case 3 under the different scenarios. All of the simulations will be connected with battery storage because of the intermittent of renewables, as shown above in the figure 3.5.1 and 3.5.2, and tables 3.5.1 and 3.5.2.

3.5.1 Demand case 1 under the scenario 1

The first simulation is demand case 1, which has a total demand of 153.81 MWh, supplied by wind turbines only. To consider in the case that has no direct solar energy and which system is the most suitable by relying on wind turbines only. It will be justified by the area needed for the wind farm.

Table 3.5.1.1: the area needed for the simulation of demand case 1 under the scenario 1

Demand case	Wind turbine		Area needed (square kilometers)	Acceptable
	Capacity (kW)	The number of turbines		
1	800	1	0.015	✓
	15	5	0.07	✓
	10	10	0.15	✓
	1	150	2.25	×

From the table 3.5.1.1, the variety of wind turbine capacity from 800 kW to 1 kW were simulated with the light demand. The number of areas needed in the unit of square kilometers is varied by the number of wind turbines. From the section 3.2, it shows the acceptable maximum area for a charging station, which is around 0.18 square meters. The system which has a 1-kW wind turbine requires 150 turbines for supplying demand and required 2.25 square meters, which is unacceptable size, due to being over 12 times of the maximum area of the station. While the other capacity is acceptable, due to the areas exceeding the assumption.

However, an 800-kW wind turbine is more than enough for supplying the demand for the whole year but causes a lot of energy surplus due to its high capacity. That means it is not a suitable system because of costs of higher capacity of wind turbine. Even it was required for the least area needed, in terms of financial cost, it would be too much to pay for. On the other hand, instead of applying the high capacity and cost of the wind turbine, take a bit more of space for more low-capacity wind turbines would be a more rational approach.

Thus, in the first scenario of demand case 1 under the scenario 1, there are 2 systems that are suitable to build. The first system is supplying demand by using 5 turbines of 15 kW wind turbine capacity, which takes around half of the total maximum area. And the other system used 10-kW wind turbine with the number of 10 turbines, which required under the maximum acceptable area for a charging station beside M8 motorway.

The next simulation is still in the demand case 1 but under the scenario 2, which is supplied by solar panels only.

3.5.2 Demand case 1 under the scenario 2

The second simulation is the demand case 1 supplied by solar panel only. That means it is the worst situation of no wind, so no power generated from the wind turbine. In this project, solar panels were divided into 3 levels, high, medium, and low capacity. The high capacity is 167 W, 100 W and 30 W were indicated as medium and low capacity respectively. Each capacity level of solar panel supplied to the demand case 1. To justify which capacity level of solar panel is suitable for demand, it needs to be considered by the area needed for the solar farm.

Table 3.5.2.1: the area needed for the simulation of demand case 1 under the scenario 2

Demand case	Solar panels		Area needed (square kilometers)	Acceptable
	Capacity (W)	The number of solar panels		
1	167	2,000	0.008	✓
	100	4,000	0.016	✓
	30	8,500	0.034	✓

The table 3.5.2.1 shows that every system is acceptable to use as a supplier to produce power for demand, because the area needed in each system is lower than the total area of the solar farm, which is 0.08 square kilometers. However, the lowest capacity of the solar farm required surface area over 4 and 2 times of the area required for the 167-W and 100-W solar farms respectively. However, the area required for those systems is a significantly smaller area compared with the maximum area.

Thus, using only 1 source of renewables, it is enough to supply the whole year for demand case 1. In the next simulation, both wind turbines and solar panels will produce power for supplying the demand. That means it might require less area.

3.5.3 Demand case 1 under the scenario 3

To supply demand case 1, using only wind turbine and solar panel has been simulated in section 3.5.1 and 3.5.2. Both scenarios show that it is possible to build the farm. However, to supply power from 2 sources of renewables, wind turbine and solar panel, might require less area for wind turbine only or solar panel only.

To reduce the area needed, this simulation was aimed to reduce half of the number of turbines in the scenario 1 and replace the power loss with solar panels. Then justify the system whether or not they are suitable for supplying demand.

Table 3.5.3.1: the area needed for the simulation of demand case 1 under the scenario 3

<table>
<tr><th rowspan="2">Demand case</th><th colspan="2">Wind turbine</th><th colspan="2">Solar panel</th><th rowspan="2">Area needed (square kilometers)</th><th rowspan="2">Acceptable</th></tr>
<tr><th>Capacity (kW)</th><th>The number of turbines</th><th>Capacity (kW)</th><th>The number of panels</th></tr>
<tr><td rowspan="6">1</td><td rowspan="3">15</td><td rowspan="3">3</td><td>167</td><td>150</td><td>0.0456</td><td>✓</td></tr>
<tr><td>100</td><td>300</td><td>0.0462</td><td>✓</td></tr>
<tr><td>30</td><td>650</td><td>0.0476</td><td>✓</td></tr>
<tr><td rowspan="3">10</td><td rowspan="3">5</td><td>167</td><td>250</td><td>0.0760</td><td>✓</td></tr>
<tr><td>100</td><td>450</td><td>0.0768</td><td>✓</td></tr>
<tr><td>30</td><td>1,000</td><td>0.0790</td><td>✓</td></tr>
</table>

From the table 3.5.3.1, it is clear that to combine wind turbines with solar panels is to reduce the area needed compared with the scenario 1 and 2. The more capacity of the wind turbine and solar panel, the less area needed. Under scenario 3, the system that requires the least area needed is 3 turbines of the 15-kW wind turbine with 167-W 150 solar panel. However, the total area needed for the system that has the same capacity of wind turbines but the different capacity of solar panels has no significant difference between them. In addition, all the system under this scenario is acceptable due to the area needed is less than the maximum area from the assumption.

To sum up, there was no problem with applying wind farms or solar farms or both, beside M8 motorway for the light demand. Also, the combination of wind turbines and solar panels (scenario 3) is the most suitable way. Because it requires less area than the other scenarios and reduces the risk of relying on only 1 source of renewable. For example, in the cloudy or no wind. Moreover, the average area needed is shown in figure 3.5.3.1.

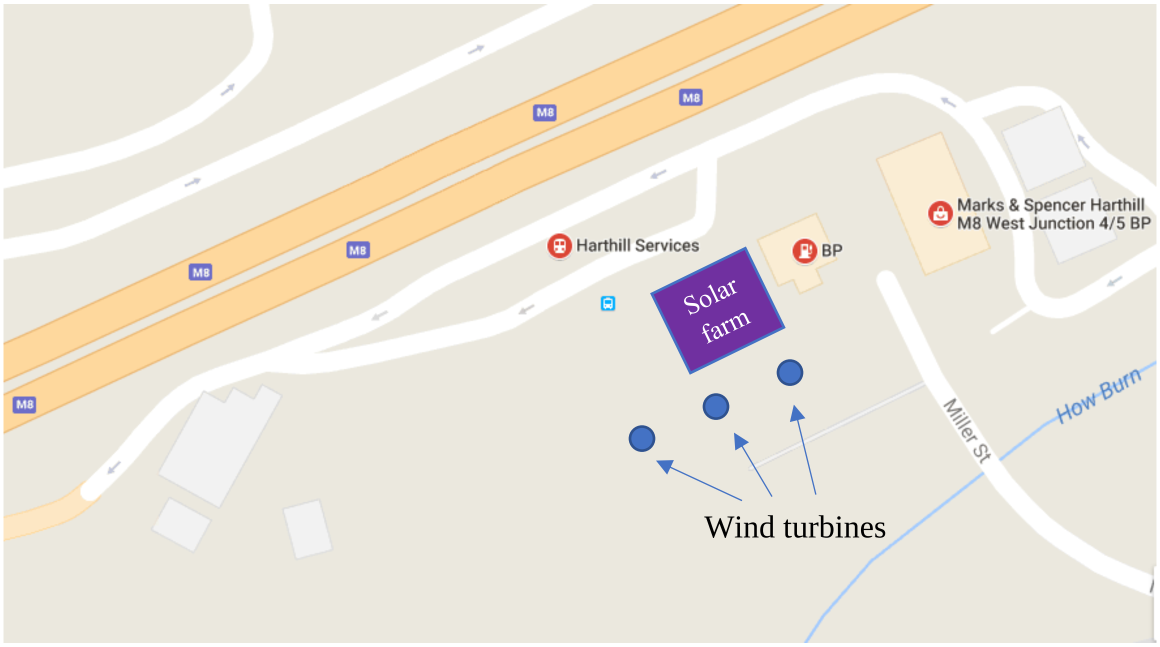


Figure 3.5.3.1: the map for renewables farm for demand case 1

For the demand case 1, it can be compared with the small service station on the M8 motorway, such as BP petrol station, ML7 5TT. As the area of the station is around 400 square meters, while the solar farm required 600 square meters, which is approx. 1.5 times of the small station, plus the 3 wind turbines. However, the solar farm can be applied to be as a solar rooftop, which almost reduces all areas for on-ground solar farm.

The simulation of the demand case 1 is done under all scenarios. It was no problem because of the light demand, so the system requires a little number of wind turbines and solar panels. In the higher demand, demand case 2 and 3, might show some problems with situating renewables beside the motorway.

3.5.4 Demand case 2 under the scenario 1

The simulation for higher demand, which supplied power from wind turbines, only will be present in this section. The total demand, in this case, is 1.54 GWh from the customers that come to the station, totaling at 40 cars every hour. The area needed for renewable supply is presented in table 3.5.3.1.

Table 3.5.4.1: the area needed for the simulation of demand case 2 under the scenario 1

Demand case	Wind turbine		Area needed (square kilometers)	Acceptable
	Capacity (kW)	The number of turbines		
2	800	2	0.03	✓
	15	50	0.75	×

Table 3.5.4.1 shows that the capacity of the wind turbine that used to be a suitable supply for demand case 1 is not for demand case 2. Due to the higher demand, it requires more power from renewable sources, in this case, wind turbines. Thus, the 15-kW wind turbine is not acceptable for supplying power for demand case 2. Because it needs a surface area of 0.75 square kilometers, which is over 4 times higher than the defined maximum area.

However, 800-kW is more suitable to be a supplier in this system, while it was not for demand case 1.

To look at another scenario, which is the renewables, is solar panel only. It would be compared to the demand case 1 in the same scenario again.

3.5.5 Demand case 2 under the scenario 2

Supplying demand case 2 by using power from solar panel only. It is definitely clear that the area needed will be higher than the second simulation for demand case 1 under the same scenarios as shown in the table 3.5.2.1. In this simulation, the area needed for solar farm is presented in the table 3.5.3.1.

Table 3.5.5.1: the area needed for the simulation of demand case 2 under the scenario 2

Demand case	Solar panels		Area needed (square kilometers)	Acceptable
	Capacity (W)	The number of solar panels		
2	167	6,500	0.026	✓
	100	15,000	0.060	✓
	30	35,000	0.140	×

From the area needed for solar farms as shown in the table 3.5.3.1, there is a system that is not suitable for supplying power, which is the 30-W solar panel. Due to a smaller capacity, so it can produce less power. That means it requires a huge area of situating 35,000 panels, which is almost 2 times the maximum area that was assumed, to generate power for the whole year in demand case 2.

Similarly, 100-W solar panels required the area of 0.06 square kilometers, which almost reaches the maximum area 0.08 square kilometers. However, the high capacity solar panels are under the given measurement of the maximum areas required.

Thus, there are only 2 systems that can be used. There are 6,500 solar panels of 167 W and 15,000 panels of 100 W that can be used as a supplier for generating power for demand case 2.

To reduce the area needed for the wind and solar farms, the combination of them between wind turbine and solar panels is a good simulation to do. Especially the higher demand, using both wind turbines and solar panels is a more rational system.

<u>3.5.6 Demand case 2 under the scenario 3</u>

In this simulation, wind turbines and solar are both provided power to demand case 2. The capacity of the 80-kW wind turbine was used in the project. Because of the wind turbines, which have low capacity, such as 15 kW and 10 kW required the area more than the given maximum area. Also, the number of wind turbines was reduced to be 1 turbine. As suggested from the results in table 3.5.4.1, the system requires 2 turbines. Thus, if the system needs to use both wind turbine and solar panel, the number of wind turbine would be reduced from 2 to 1 turbine. To consider the area needed from the system of the 800-kW wind turbine and high capacity of solar panel, it is shown in the table 3.5.6.1.

Table 3.5.6.1: the area needed for the simulation of demand case 2 under the scenario 3

Demand case	Wind turbine		Solar panel		Area needed (square kilometers)	Acceptable
	Capacity (kW)	The number of turbines	Capacity (kW)	The number of panels		
2	800	1	167	1,500	0.011	✓
			100	3,000	0.027	✓

As shown in table 3.5.6.1, the area needed is reduced from the scenario 1 and 2 as presented in table 3.5.4.1 and 3.5.5.1. To supply power for demand case 2, the 2 systems required surface less than the maximum area, which is 0.08 square kilometers.

To sum up, generating power from 2 sources of renewables, wind turbine and solar panel is suitable to supply for the demand case 2. Due to the system required less land use of 0.011 square kilometers with 800-kW wind turbine and 167-W solar panel. Moreover, the average area needed is shown in figure 3.5.6.1.

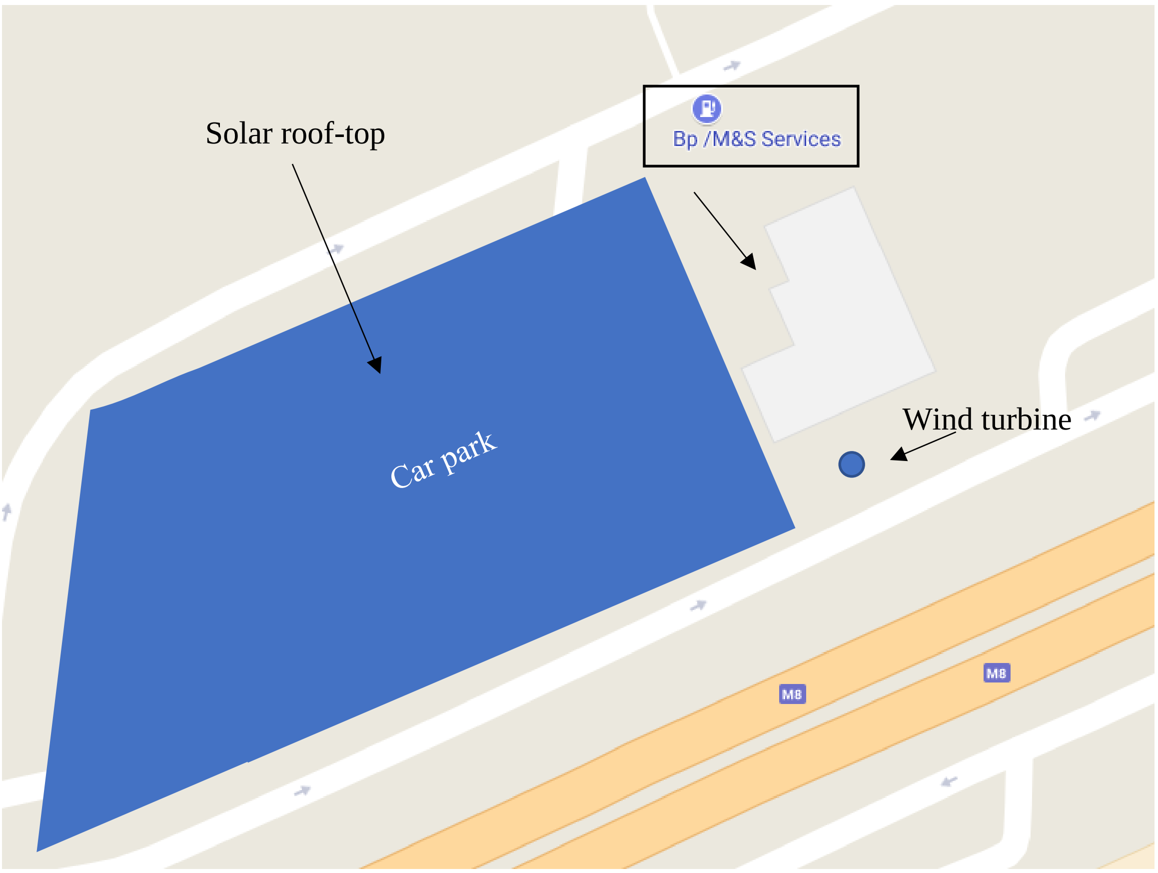


Figure 3.5.6.1: the map for renewables farm for demand case 2

For the demand case 2, it can be compared with the medium service station on M8 motor way, such as the M&S Service Station, ML7 5SB. As the area of the petrol station is around 1,333.20 square meters and the car park almost 8,800 square meters, while the solar farm requires 6,000 square meters plus 1 wind turbines. It is approximately 4.5 times the area of the petrol station to be an area for solar farm but around 1.5 times lower than the area of the car park. So, the solar farm can be applied to be the solar rooftop e.g. on top of the car park, instead of an on-ground solar farm.

The most aggressive demand was simulated under the 3 scenarios in the next section.

3.5.7 Demand case 3 under the scenario 1

The demand case 3 was indicated as the most aggressive demand due to customers using the charging station 120 cars every hour. The power from renewables under 3 scenarios was generated and supply to demand. The first scenario of demand case 3, which wind turbine produces the power, is presented in table 3.5.7.1.

Table 3.5.7.1: the area needed for the simulation of demand case 3 under the scenario 1

Demand case	Wind turbine		Area needed (square kilometers)	Acceptable
	Capacity (kW)	The number of turbines		
3	800	4	0.06	✓

Even the simulation is the highest demand, the 800-kW wind turbine is still the wind turbine that can be used as shown in the 3.5.7.1. The area for the wind farm is 0.06 square kilometers, which is lower than the maximum area assumed. That means wind turbines are the supply technology that can generate enough power for the most aggressive demand. Moreover, it requires an acceptable area for the wind farm.

To look at the other technology, the simulation of the demand with the producing power from solar panel only is shown in the following section.

3.5.8 Demand case 3 under the scenario 2

To justify that solar is the technology that can support the whole year for an aggressive demand. The simulation of demand case 3 and power supplied by solar panel only is shown in table 3.5.8.1.

Table 3.5.8.1: the area needed for the simulation of demand case 3 under the scenario 2

Demand case	Solar panels		Area needed (square kilometers)	Acceptable
	Capacity (W)	The number of solar panels		
3	167	20,000	0.08	✓
	100	40,000	0.16	✗

From the table 3.5.8.1, there are 2 systems in this simulation. One is 167-W solar panel generated the power and the other being a 100-W solar panel. It is clear that the 100-W was not acceptable as a supply for the demand. This is because of the low capacity of the solar panel, so 100W solar panels needs a greater area to reach the sufficient power demand. It required the area double of the maximum area for the solar farm, which is 0.16 square kilometers.

On the other hand, the area that is needed for the high capacity 167W solar panels is the same area as the maximum assumption area for the solar farm. It is acceptable because it is not higher than the maximum space solar farm.

Thus, the capacity of 100 W for a solar panel is too low to generate power and supply demand in the limited area. So, the other option, being a 167 W capacity solar panel, is more suitable for generating power in the system that has solar panel only as a supply.

Otherwise, a combination of 2 renewables of wind turbine and solar panel will be seen in the next section.

3.5.9 Demand case 3 under the scenario 3

Under the scenario 3, there is only 1 system for demand case 3, which is a combined supply renewable between the 800-kW wind turbine and 167-W solar panel. Due to the highest demand in case 3, it requires lots of power for charging EV's battery. The other capacity of both renewables in the previous demand cases and scenarios is not enough to supply power for the demand.

To use a combination system, the number of turbines will be half of the number of turbines from table 3.5.7.1. Replacing the lost power with solar panels. So, the area needed for this system is shown in table 3.5.6.1.

Table 3.5.9.1: the area needed for the simulation of demand case 3 under the scenario 3

Demand case	Wind turbine		Solar panel		Area needed (square kilometers)	Acceptable
	Capacity (kW)	The number of turbines	Capacity (kW)	The number of panels		
3	800	2	167	10,000	0.06	✓

Figure 3.5.9.1 shows the system of demand case 2 with wind turbines and solar panels, covers an area of 0.06 square meters. This system is acceptable from the total area needed, which is lower than the maximum area. It would have the 2 wind turbines and 10,000 solar panels in the area. Moreover, the average area needed is show in the Figure 3.5.9.1.

Figure 3.5.9.1: the map for renewables farm for demand case 3

For the demand case 3, it can be compared with the large service station on the M8 motorway, such as Morrison shopping and petrol station, G34 9JJ. As the area of the shopping mall is around 22,500 square meters and the car park 47,500 square meters, while the solar farm required 40,000 square meters plus the 2 wind turbines. So, the solar farm can be applied to be a solar rooftop design, instead of an on-ground solar farm.

To make a comparison between demand cases and scenarios, the bar chart in figure 3.5.3 was created. The amount of area needed will be taken from the system that requires less space.

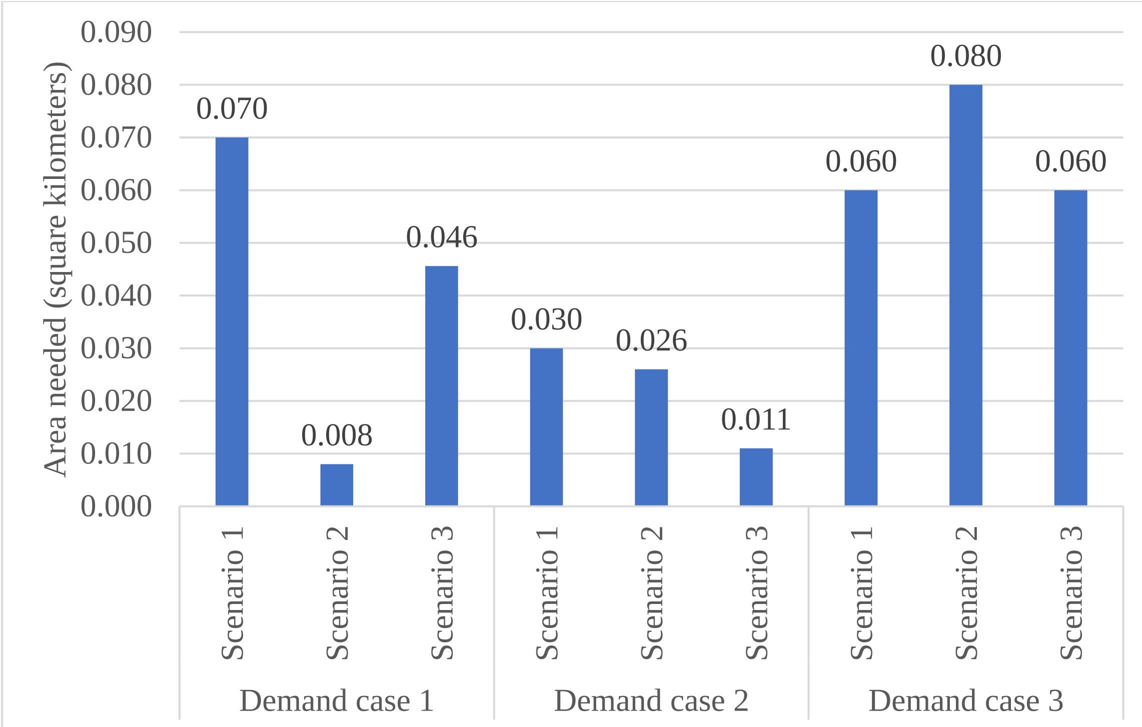


Figure 3.5.3: the comparison of area needed

Figure 3.5.3 shows the area needed in the unit of square kilometers for the wind and solar farms in each demand case and scenario. In each demand case, scenario 3 required the least space for the renewable farms, both of wind and solar farms, except for the demand case 1. It required a large area in demand case 1 under scenario 1 and 3 because the system has a supplier in the form of a 15-kW wind turbine, indicated as a low capacity turbine. So a high number of turbines are needed for generating sufficient power for demand case 1. The rest of the systems are 800-kW wind turbines and 167-W solar panels, which are high capacity technologies. From the figure 3.5.3, the area needed varies to the demand case compared to the same scenario. That means the higher demand of the system, the more area needed for renewables farm. Also, the scenario 3 required the least area.

In other words, the system of combined supply between the 800-kW wind turbine and the 167-W solar panel is the most suitable system for generating power to supply the EV's battery. That would be under the scheme of EV's battery charged outside of the body-car and the ratio of low, medium, and high number customers in the charging station 4 cars, 40 cars, and 120 cars every hour.

The modeling tool simulated another situation to look at the impact of EV's battery during the winter. Due to the fact that electric vehicle performance tends to be reduced during the winter. Reichmuth (2016), a senior engineer in the Clean Vehicles Program, reported that the car range will be dropped by 25% under the freezing condition from the maximum range under the normal condition.

This simulation was created by using the worst condition in January as indicated is a winter month. This is due to the lack of direct sunlight, which means to get the same amount of power generated from solar panels in other months; it would need a higher number of solar panels. The demand profile was taken from the demand case 3, which is the most aggressive demand, and added the power required 25% more to reach the full charging of the EV battery. So, the total demand is 745.40GWh. The renewable required is shown in the table 3.5.4.

Table 3.5.4: the area needed for the simulation of demand case 3* under during winter

Demand case	Wind turbine		Solar panel		Area needed (square kilometers)	Acceptable
	Capacity (kW)	The number of turbines	Capacity (kW)	The number of panels		
3*	800	3	167	20,000	0.125	×

* The power required was added more 25% from the demand case 3

The table 3.5.4 shows the worst conditions of less solar direct and higher demand by adding 25% more required power. The combination system was used due to the least area needed for the renewable farm and not a risk system to rely on 1 source of renewables. As shown in table 3.5.4, it required only 3 wind turbines, but a large area for a solar farm, which is not acceptable. Due to the greater than the maximum area the solar farm required.

From the simulations, it can be applied into the national scale for the whole UK by applying charging points into existing petrol stations. There are around 8,460 petrol station in the UK (Statista, 2017). Assuming from the total number of the UK petrol stations, there are the quiet, medium, and busy petrol stations for 25%, 50%, and 25% respectively referring to the ratio of the size of the business, which is 1:2:1 of small, medium, and large business (Merigó and Gil-Lafuente, 2016).

Thus, there are 2,115, 4,230, and 2,115 stations that have demand case 1 for small, demand case 2 for medium, and demand case 3 for large service stations respectively. To consider the least area needed for renewables farms for the whole UK, 800-kW wind turbine and 167-W solar panel were used in the simulations by taken the number of renewables from the scenario 3 in the table 3.5.6.1 and 3.5.9.1, apart from the small service stations that will be taken from the scenario 1 in the 3.5.1.1 of the system 800-kW. Because it required the least area needed.

The simulations for the charging point in the service stations around the UK is presented in the 3.5.5.

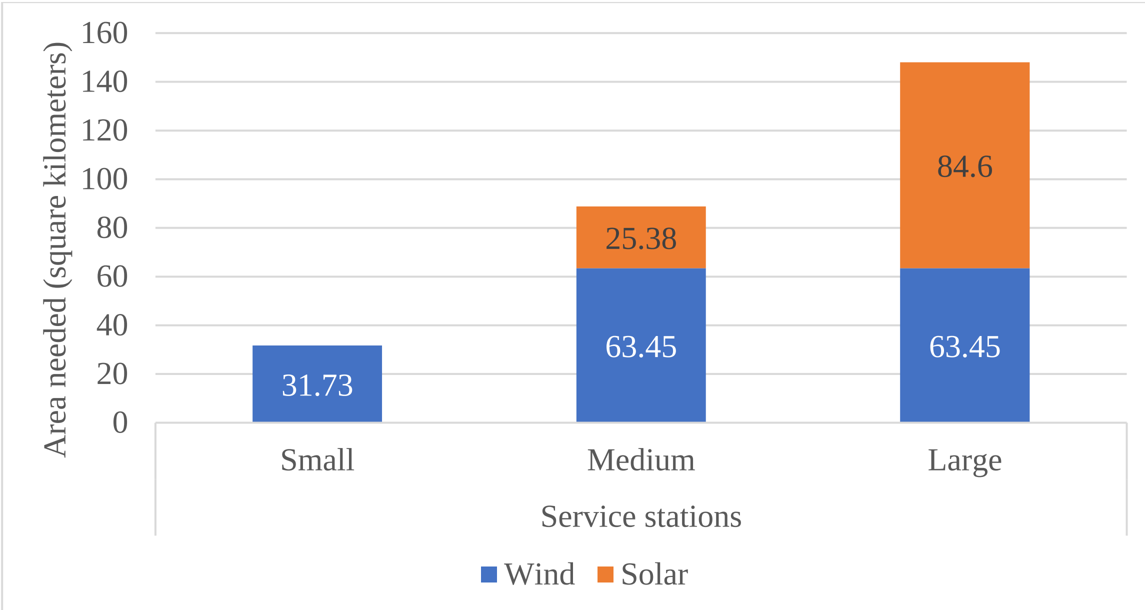


Figure 3.5.5: area needed for the whole UK

To apply the charging point into existing petrol stations in the UK by using power via renewables, the total area needed for wind and solar farms in the different types of service stations are shown in figure 3.5.5. It is no doubt that the total number of 2,115 large service stations requires the largest areas of about 148.05 square kilometers. It is almost double from the renewables farms areas in medium stations, which is 88.83 square kilometers, while small stations required only 31.73 square kilometers.

However, only 1 wind turbine is enough for charging EV's battery for a small service station, which requires half of the total area for wind farms in medium and large stations. While the other service stations need 2 sources of supply, from both of wind turbines and solar panels. They required the same area for wind farms for the medium and large service stations. Because the number of wind turbines needed for a large station is twice as higher than for a medium station. But the number of the medium stations is double of the large stations.

Solar farms can be installed in medium and large service stations. With the high capacity of the wind turbine, it required a few number of solar panel for producing power. However, the large stations have large solar farms. Because of the aggressive demand from the customers, theirs to much risk to rely the power generated from only 1 source of renewables, especially when it is a cloudy or not windy day.

Overall, it is acceptable to build the renewables farms that required the amount of areas as shown in figure 3.5.5.

To sum up, the land beside M8 motorway is acceptable to be used for renewables farms for generating power supply the service stations on M8. Applying the charging points in the existing petrol stations in the UK, it can be done with the limited areas beside the stations.

Chapter 4: Discussion

Renewables are clean and sustainable sources for the production of power and electricity. However, due to its intermittence and reliance on nature, for example, wind, solar, and wave, it can be unpredictable and inconsistent. Figure 3.5.1 shows the intermittence of the wind turbine, while figure 3.5.2 shows the discontinuity of the solar panel. They present the fluctuated power generated that sometimes produced very high power, while sometimes there can generate minimal or no power. Also, the energy deficit caused by the discontinuous power generation from renewables is shown in the table 3.5.1 and 3.5.2. However, they can produce the high amount of power but didn't match with demand and caused the energy surplus. That means the systems need to have a baseload such as: gas, coal, or nuclear power. As well as additional technologies e.g. battery storage for keeping energy surplus and discharging when there is not enough power.

In this project, battery storage also plays an important role, because of the intermittence of power generated from the renewables for charging the EV's battery to full capacity and on time for the next EV coming to the station.

Also, some renewable technologies, such as wind turbine, which generates high power but the power fluctuates on an hourly basis, which causes the problem with the grid stabilization. Having an off-grid system, it needs battery storage. To make a comparison, connecting battery storage with solar panels is more effective than with wind turbines. Because when power was generated, it is very high but on a non-windy day, it can produce zero power from the wind turbine. In contrast, power from solar panel is produced every day, but not at night, so battery storage can be charged for storing power and discharge power when it needs. That is one of the reasons that the system prioritizes the use of solar panels with a few wind turbines.

It has more conditions about setting up for some renewables, for example, solar panels. There are many controlled variables, tilt and azimuth. In this project, the angle was defined to get more power primarily during winter. Because there is less power than other seasons, due to during the winter is very cloudy or less solar direct. To make the system more efficient, the adjustable solar panels is more suitable to apply. However, the area for solar farm needs to be calculated in every climate due to the different angle of the sun.

The area needed for wind turbine in the simulation was calculated from the high capacity of the wind turbines in the Clyde Wind Farm. In contrast, the lower capacity was used in this project. That means the area needed for the wind turbine for the charging stations would be lower than defined. Moreover, after the wind rotates the turbines, it will cause turbulence, which can affect another wind turbines behind it. So, the gap between the wind turbines need to be calculated more accurately. However, it was acceptable areas for the wind farm. Thus, when applying to real situations, the area would be lower than it was required in the simulation.

In this project, it has total of 9 simulations, which are the 3 demand cases and 3 scenarios of renewable supply. It is an explanation about the simulation between demand and supply in table 3.5.3. As the reason of the intermittent renewables, all of the simulations were connected with battery storage as well. For the first demand, which is the least power required from the 4 customers in every hour in the station. It shows that only 1 wind turbine with 800 kW capacity is enough for the light demand and required the least area as shown in table 3.5.1.1. However, to reduce the risk of using 1 source of renewables, table 3.5.3.1 presents the system can be a mix of 3 wind turbines of 15 kW capacity and 150 solar panels of 167 W capacity. However, this required around 3 times of the area for an 800-kW wind turbine farm as shown in the figure 3.5.3.1.

For the medium rate of 40 EVs arriving at the station per hour, it was defined as the demand case 2. Table 3.5.6.1 shows the least area required for the renewables farm, which included an 800-kW wind turbine and 1,500, 167-W solar panels. The area was compared on the map with the medium size of the service station beside M8 motor way, as shown in figure 3.5.6.1.

The most aggressive demand was case 3, where 120 customers arrive the station every hour would require 2, 800-kW wind turbines and 10,000, 167-W solar panels to supply the power generated as shown in the table 3.5.9.1. This system is the most suitable for the demand case 2, due to the smallest required area for the renewables farms being 0.06 square kilometers, as shown in figure 3.5.9.1.

To sum up, the combination of 2 sources of renewables, which are 800-kW wind turbine and 167-W solar panel, is the most suitable systems for charging stations beside the motorway with an acceptable area needed in each demand cases. However, due to the lowest demand of case 1, only 1 wind turbine is enough to supply power to the demand for the whole year. Also, figure 3.5.3 presents the area needed for each demand and scenario, which highlights which system required the least area.

However, the first 2 scenarios were created for the worst situations for no solar direct from the sun and no wind to generate power in scenario 1 and 2 respectively. For the demand case 1, it is acceptable to use only 1 wind turbine for scenario 1, as shown in table 3.5.1.1. Similarly, the scenario 2 was acceptable by using 2,000 solar panels. Due to the light demand, the area needed for the renewable farm is not high and under the maximum area as shown in table 3.5.2.1. The comparison between the area of the existing small petrol station, which is 400 square meters, it is perfect to apply 1 wind turbine beside the station. However, it might not suitable for the solar farm as an only renewable supply. Because the solar farm required equal to 20 stations small petrol stations, which would use an unnecessary amount of land to be the sustainable.

For the second demand case, it required 2 wind turbines when cloudy, but 6,500 solar panels when it has no wind, as shown in table 3.5.5.1 and 3.5.6.1. To compare the area for the renewable farms with the size of the medium petrol station, it is perfectly fine too use 2 wind turbines. However, it required almost the area of 20 medium petrol stations, which is not acceptable.

For the highest demand case, when it is cloudy or theirs no wind, it required 4 wind turbines and 20,000 solar panels for the worst situations respectively, as shown in table 3.5.7.1 and 3.5.8.1. It is acceptable to apply the wind farm beside the large station due to the area needed is little. Also, it requires the area of 2 more large stations for the solar farm, which is acceptable. Also, the solar farm can be fit on the roof of the car park instead of ground-mounted as shown in figure 3.5.9.1. That means no area needed for the solar farm.

From the simulation of the worst situation of relying on 1 renewable source, it requires too much area for solar farms. However, it is acceptable for the demand of case 3 due to the large area of the petrol station. For scenario 1, which was assumed for the cloudy situation, it is perfectly fine due to the wind turbine requires less area than solar panels, compared with the power generated and the number of renewables, including the area for the renewable farms.

However, the car range of the EV tends to be reduced by 25% during the winter. As shown in table 3.5.4, it is unacceptable for providing power to the demand case 3, which has 120 EVs in the station every hour, and added 25% increase in power demand. Because of the lack of solar direct during the winter, it required higher number of solar panels than other months. Thus, the maximum area for solar farm were needed. So, the 3 wind turbines were unacceptable, but they were needed to generate power. In short, the situation of the EV's battery performance for driving the engine is reduced during winter, it is not suitable for recharging via renewables, due to the land use for the renewable farms are required too much to accept as the sustainable way.

The solar farms in this project were mentioned both ground-mounted and rooftop solar. They have different factors that need to be considered before making a decision on using ground-mounted and rooftop solar.

Ground-mounted solar is the traditional way of the solar farm. Because it is easier to be created and less initial cost, but requires higher land-use and time for the installation of underground wiring and the stabilization of the panels. While rooftop solar has no need for on ground area, and the cost of installation is cheaper, if it already has a roof. However, this project primarily focuses on solar farm where there is plenty of unused land. Thus, it is not a verdict on which option is better, but it depends where the solar farm is going to be situated.

Moreover, solar panels can be more than a technology for generating power, but can be worked as a noise barrier or bike lane on the motorway. For example, the A13 motorway in Switzerland, solar panels are situated along the motorway and cover an area of 968 square meters. They also have another purpose to be a noise barrier from vehicles on the motorway. Moreover, the 20-mile highway in South Korea between Daejeon and Sejong. There is a bike lane between inbound and outbound road on the highway. The point is the roof of the bike lane is covered by solar panels. Thus, instead of being situated as a ground-mounted solar panel, it can be created in the form of solar roof-top either on carpark or bike lane or a solar noise barrier to reduce the land used.

In the national scale, the charging point can be added into the petrol stations around the UK. Figure 3.5.5 presents the area needed for wind and solar farms for each kind of the service stations, which are quiet, medium, and busy service stations. Only the quiet station that only has 1 turbine was needed. While there’s a mixed system of wind turbine and solar panel, which were required to support the charging point in the medium and busy station.

From all the simulations, the system of wind turbine and solar panel is the most suitable supply for the charging stations. Because they work better together and reduce the risk of reliance on 1 source of renewables. For example, when 1 source is not available, there is another source that can produce the power for the demand, especially when cloudy or a non-windy day. In contrast, when there’s strong wind and strong sunlight at the same time, the battery can charge even faster.

In term of financial cost and land use, it is cheaper to have both of wind turbines and solar panels. Due to the price per watt, but solar panel remains more expensive than wind turbine. Also, solar panels require more area to reach the same power generated than wind turbines. Thus, having 2 sources of renewables is more suitable than relying on 1 source of renewables.

However, in consideration of a combination system, it is important that placement of wind turbines does not cast a shadow over the solar panel. The impacts of each renewables are still appearing. The reflection of the solar panels is the direct impact of situating them beside the road. When the solar direct has a specific angle with the solar panel, the glistening light can be reflected to the driver's eyes, which is very dangerous and can cause the road accident. Although wind turbines produce noises, due to the rotation of the blades in a strong breeze. In this project, it was situated beside the motorway where no one lives, so there's no significant impact on that factor. However, some area either side of M8 motorway has small towns, villages, and factories, which can be a point to consider before creating a wind farm.

Due to the EV's battery efficiency, it tends to be reduced in the winter. Because the electricity is not only used for driving the engine, but also the heating system. That means the demand of charging EV's battery will increase during the winter.

Although it seems to be possible to recharge the EV's battery via renewables, the simulations are for the idealize scenarios. There are unpredictable factors in real situations that need to be considered, especially the demand profiles and the intermittent renewables.

Chapter 5: Conclusion

According to the renewables required in section 3.5 and discussion in section 4, the charging stations for the electric cars by renewable sources is possible to happen, due to the area needed for the renewable farms in each demand case or size of the service station, and the supply scenario is acceptable. From figure 3.5.3.1, 3.5.6.1, and 3.5.9.1, they show the area of the existing service stations beside the M8 motorway compared with the renewable farms.

However, the demand might be higher during the winter, due to the performance of EV's battery is reduced. Thus, they need to be recharged more often. Moreover, it has less solar direct, which is the main parameter for generating power from solar panels. That means, the demand during winter tends to be higher but with a low power supply.

To apply in a real situation, it can be done via the application of charging points into existing petrol or service stations. Using the space around the station for the renewables farms, or application of rooftop solar, it is still acceptable by ignoring the car range in the winter.

From all of the simulations, wind turbine and solar panel work better together. Because of factors like: area needed, financial cost, the difficulty of the installation, and the risk of relying on 1 source of renewables.

Having an off-grid system for charging the EV's battery reduces the problem of dump charging that causes problems to the grids stabilization. In term of commercial perspective, it increases the employment rate, which can aid in unemployment issues.

Chapter 6: Future work

The majority of the project is to show the possibility of using renewable technologies for charging stations for electric cars. It shows the number of renewables required, including the area for installation. Moreover, study the impacts of relying on 1 source of renewables and use the battery storage as a back-up when there's minimal or no power generated from the renewables.

There is another way to store the energy instead of using traditional battery storage, which is called green gas or gas energy storage. From the higher performance, it might reduce the number of renewables required. For the future work, it is what I'm interested in studying.

Having a new farm of renewables needs permission before construction. Environmental impact assessment (EIA) plays an important role before giving permission. It is necessary to look at the place where the renewable farms are to be situated. For example, the noise from wind turbine and the light reflected from the solar panels.

The system in the project is not connected to the grid, which is called the off-grid system. Because to provide the electricity from the grid to the charging station is more complex and has many factors that can cause the problem such as the grid stabilization, especially the electricity from the wind turbine. If the systems were connected to the national grid, it can support the charging stations for the Scotland or even the whole. Thus, the energy surplus can be used for other purpose such as for thermal demand or export to another country from a financial perspective. Also, it has back up from the traditional power supply, for example, gas and nuclear power plants. Currently, the small charging points connected to the grid, which call grid-to-vehicle (G2V). However, the government has been looking at the process of returning power from vehicle-to-grid when its lacked power supply. Thus, to study the impacts of both V2G and G2V can be potential future research.

List of references

Adzuna, 2010. *The 8 Toughest Interview Questions. Adzuna.co.uk Job blog*, [blog] 22 November. Available at: https://www.adzuna.co.uk/blog/2010/11/22/the-8-toughest-google-job-interview-questions-with-answers [accessed 16 August 2017].

Allison, P., 2016. *Clyde Extension*. Glasgow: Scottish and Southern Energy (SSE)

Autovista Group, 2017. *EVs risk serious damage to UK power network if just a handful charge on one street, report warns*, [blog] 21 April. Available at: https://www.autovistagroup.com/news-and-insights/evs-risk-serious-damage-uk-power-network-if-just-handful-charge-one-street-report [accessed 21 August 2017].

Baird, S., 2015. *The M8 Motorway*. Glasgow: The Glasgow Motorway Archive

Bawden, T., 2016. *Baroness Brown: Line our motorways with wind turbines, says Government's adviser on green energy*. [online] Independent. Available at: http://www.independent.co.uk/environment/baroness-brown-line-our-motorways-with-wind-turbines-says-government-s-adviser-on-green-energy-a6828436.html [accessed 21 August 2017].

Brownson, J., 2016. Collector Orientation, *EME 810: Solar Resource Assessment and Economics*. [online], The Pennsylvania State University, Available at: https://libweb.anglia.ac.uk/referencing/harvard.htm [accessed 16 August 2017].

Craig, J., 2017. *New petrol and diesel cars banned in UK from 2040*, [Newspaper] 26 July. Available at: http://news.sky.com/story/petrol-and-diesel-cars-banned-from-uk-roads-by-2040-10962075 [accessed 20 August 2017].

Dixon, D., 2014. *NS9914: A74(M) Clyde Wind Farm*. Dumfries: The geograph

Energy Saving Trust, 2017. *Electric cars and vehicles*. London: Energy Saving Trust

European commission, 2017. *The importance of the private car*. Belgium: European commission, Mobility and Transport

George, N. and Kershaw, K., 2016. *Road Use Statistics Great Britain 2016*. London: Department of Transport

Google Maps, 2017. *The petrol stations on M8 motorway*. Available at: https://www.google.co.uk/maps?hl=en&tab=ll&authuser=0 [Accessed 21 August 2017].

HOMER Energy LLC, 2014. *Our products: The Homer Pro*. [online] HOMER Energy LLC. Available at: http://www.homerenergy.com/HOMER_pro.html [accessed 20 August 2017].

Kerecman, J., 2010. *Airdolphin Marine Wind Turbine 1000 Watt*. Florida: Marine Energy Solutions

Lilly, C., 2017. *Electric car market statistics*. Bristol: Next Green Car Ltd

Merigó, J.B., Gil-Lafuente, A.M. and Gil-Lafuente, J., 2016. *Business, Industrial Marketing and Uncertainty*. Journal of Business & Industrial Marketing, 31(3), 325.

Ostergaard, P. A., 2015. *Reviewing EnergyPLAN simulations and performance indicator applications in EnergyPLAN simulations*. Applied Energy, 154, p. 921-933.

Proven Energy, 2014. *Technical Specification Sheet MODEL Proven 15 (15kW),* [online], Available at: http://www.cellenergy.ie/pdf/Proven%20folder.pdf [accessed 13 August 2017].

Reichmuth, D., 2016. *Do Electric Cars Work in Cold Weather? Get the Facts*, [blog] 16 February. Available at: http://blog.ucsusa.org/dave-reichmuth/electric-cars-cold-weather-temperatures [accessed 20 August 2017].

Renewable Renewables, 2017. *Renewables in numbers*. Glasgow: Renewable Renewables

RENUGEN Limited, 2010. *Aeolos Aeolos-V 10kW 10kW Wind Turbine*, [online], Available at: http://www.renugen.co.uk/aeolos-aeolos-v-10kw-10kw-wind-turbine [accessed 18 August 2017].

Scottish and Southern Electricity Networks: SSE, 2017. *Get to know your new Smart kit*, [online], Available at: https://sse.co.uk/help/energy/meters/smart-meters?source=search [accessed 21 August 2017].

Scottish Government, 2017. *High Level Summary of Statistics Trend Last update: Thursday, December 22, 2016.* Edinburgh: Scottish Government

Siemens, 2000. *Solar module SM110/SM100.* [online], Available at: http://svsoggypaws.com/images/forsale/SM110_Solar.pdf [accessed 21 August 2017].

Solarex, 1998. *MSX-Lite Photovoltaic Modules*. [online], Available at: https://www.solarpanelsaustralia.com.au/downloads/solarex_msxlite.pdf [accessed 21 August 2017].

Statista, 2017. *Petrol station sites in the United Kingdom (UK) from 2000 to 2016.* London: The Statistics Portal

The wind power, 2017. *N50/800 (Nordex).* [online], Available at: http://www.thewindpower.net/turbine_en_148_nordex_n50-800.php [accessed 13 August 2017].

Wessex Solar Energy, 2014. *Park Wall 5 MW Solar Farm*. [online], Available at: http://wessexsolarenergy.com/parkwall-solarfarm.html [accessed 21 August 2017].

Appendix

Appendix 1: Technical specification of Nordex N50 800kW wind turbine

THE WINDPOWER
Wind Energy Market Intelligence

www.thewindpower.net
August 13, 2017

N50/800 (Nordex)

Main data

Rated power: 800 kW
Rotor diameter: 50 m
Old model
Offshore model: no
Commissioning: 1999

Rotor

Number of blades: 3
Type: Stall
Swept area: 1963.5 m^2
Power density: 2.45 m^2/kW
Maximum speed: 23,6 rd/min

Tower

Minimum hub height: 46 m
Maximum hub height: 70 m

Weights

Nacelle: 23,4 t
Rotor + hub: 15,7 t
Tower: 89 t
Total: 128,1 t

Gearbox

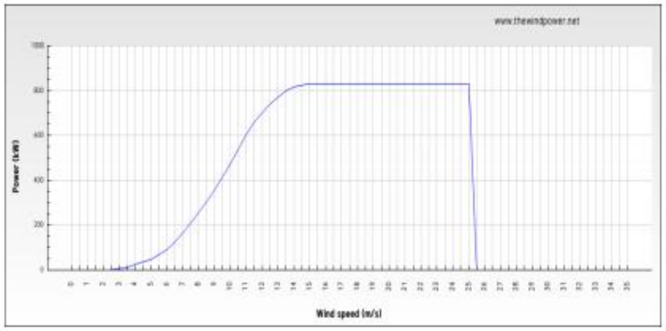
Gearbox: yes
Stages: 3
Gear ratio: 1:42,3

Generator

Type: ASYNC DF
Number: 1
Maximum speed: 1510 rd/min
Voltage: 690 V

Wind speeds

Cut-in wind speed: 3 m/s
Rated wind speed: 15 m/s
Cut-off wind speed: 25 m/s



Appendix 2: Technical specification of Proven 15kW wind turbine

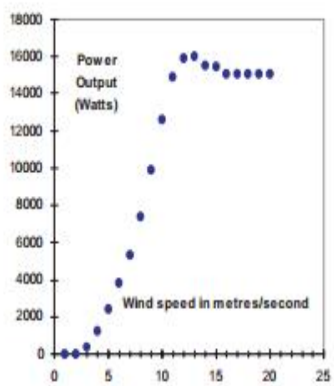
Technical Specification Sheet

MODEL	Proven 15 (15kW)
Cut In (m/s)[1]	2.5
Cut Out m/s)	None
Survival m/s)	70
Rated (m/s)	12
Rotor Type	Downwind, Self Regulating
No. of Blades	3
Blade Material	Glassthermoplastic Composite
Rotor Diameter(m)	9
Generator Type	Brushless, Direct Drive, Permanent Magnet
Battery charging	48V DC
Grid connect with Windy Boy Inverter	230Vac 50Hz or 240 Vac 60Hz
Direct Heating	240V ac
Rated RPM	150
Annual Output[2]	15,000-30,000 kWh
Head Weight (kg)	1100
Mast Type	Tilt-up, tapered, self-supporting, no guy wires (Taller guyed towers also available on request)
Hub Height (m)	15 or 25
WT Found (m)	3.7x3.7x1.2 or 5x5x2
Winch Found (m)	1.5x1.5x1.2 (no anchor foundation for 25m)
Tower Weight (kg)	1478 or 2794
Mechanical Brake	Yes
Noise[3] @ 5m/s	48 dBA
Noise @ 20m/s	65 dBA
Rotor Thrust (kN)	26
Sample of commercial customers	British Telecom Scottish Youth Hostel Association British Rail Irish Lighthouse Authority UK Lighthouse Authority T-mobile Orange Shell Exploration Saudi Aramco

Proven Patented Furling

In winds of above 12m/s or 25mph, the Proven's blades twist to limit power in response to high rpm

Low Speed Equals Durability



Marine Build Quality

All machines are manufactured with galvanised steel, stainless steel & plastic components

Appendix 3: Technical specification of Proven 10kW wind turbine

Aeolos-V 10kW

AEOLOS

Specification

Generator Type:	Three Phase Permanent Magnet
Rotor Height:	5.3m (17.38 ft)
Rotor Width:	4.2m (13.77 ft)
Turbine Weight:	385kg (848.8 lbs)
Blades Material:	Fiber Glass
Blade Quantity:	3 pcs
Working Temperature:	-30 ℃ to 60 ℃
Design Lifetime:	20 years
Working Humidity:	≤95%
Protection Class:	Ip55

Performance

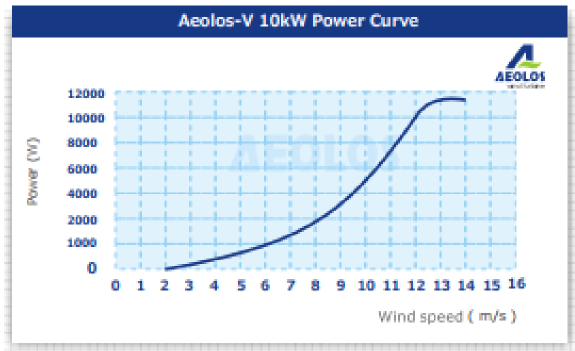
Rated Power:	10 KW
Max Output Power:	12 KW
Cut In Wind Speed:	2.5m/s (5.6 mph)
Rated Wind Speed:	12m/s (26.8 mph)
Survival Wind Speed:	55m/s (122.65 mph)
Generator Efficiency:	96%
Noise Level:	< 45 dB(A)
Warranty:	5 year

Safety

Blades RPM Limitation:	150 RPM
PWM Dump Load:	15 kW Box
Mechanical Brake:	Manual/Auto

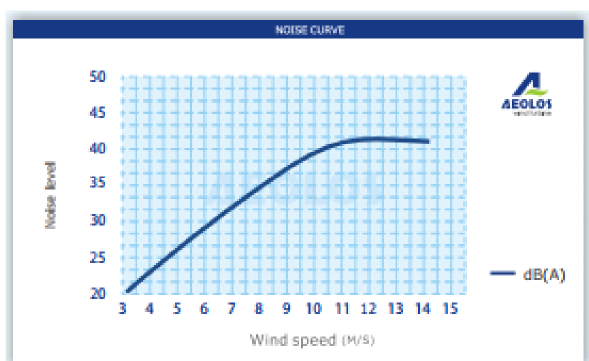
Optional

Remote Monitoring System	(Internet/Wireless)
Auto Hydraulic Brake System	(Unattended Site)
Off Grid :	96V or 240 V
Grid Tie :	380 V



Aeolos-V 10kW Wind Turbine Annual EnergyOutput

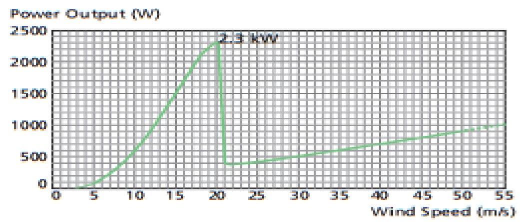
Wind Speed(m/s)	Annual Energy Output (KWh)	Wind Speed(m/s)	Annual Energy Output (KWh)
3 m/s	2278 kWh	8 m/s	26280 kWh
4 m/s	4380 kWh	9 m/s	35741 kWh
5 m/s	6657 kWh	10 m/s	42924 kWh
6 m/s	11386 kWh	11 m/s	68328 kWh
7 m/s	17958 kWh	12 m/s	89352 kWh



Appendix 4: Technical specification of Airdolphin 1kW wind turbine

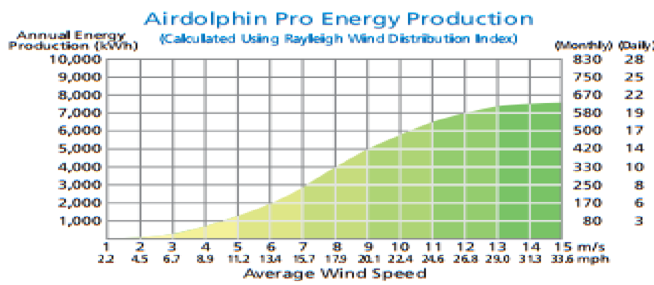
AIRDOLPHIN PRO 48V
AIRDOLPHIN Mark-Zero 24V

Power Output Characteristics



Intelligent Power Management System

A truly seamless power generation can be achieved from wind speeds ranging from 2.5 m/s (5.6 mph) and over, never cutting out. The system instantly responds to wind speed fluctuations for optimal power point production. At peak, Airdolphin Mark-Zero and Pro can deliver 2.3 kW output in 20 m/s (44.7 mph) winds, then shift to a gradual output as the wind intensifies.



Wind Speed m/s (mph)	Per Hour (Wh)	Per Day (Wh)	Per Month (kWh)	Per Year (kWh)	Wind Speed m/s (mph)	Per Hour (Wh)	Per Day (Wh)	Per Month (kWh)	Per Year (kWh)
2 (4.5)	6	144	4	53	9(20.1)	566	13,584	408	4,958
3 (6.7)	28	672	20	245	10(22.4)	662	15,888	477	5,799
4 (8.9)	73	1,752	53	639	11(24.6)	738	17,712	531	6,465
5 (11.2)	140	3,360	101	1,226	12(26.8)	795	19,080	572	6,964
6(13.4)	231	5,544	166	2,024	13(29.1)	834	20,016	600	7,306
7(15.6)	339	8,136	244	2,970	14(31.3)	858	20,592	618	7,516
8(17.9)	455	10,920	328	3,986	15(33.5)	871	20,904	627	7,630

Specifications

Model Name	Airdolphin Pro / Airdolphin Mark-Zero
Model Number	Z-1000-48 / Z-1000-24
Wind Turbine Type	Horizontal axis, up-wind
Rotor Diameter	1,800 mm (5'10-7/8")
Mass	17.5 kg (38.5 lbs)
Tower Diameter	48.6 mm (1-15/16")
Number of Blades	3
Blade Construction	Carbon fiber laminate over solid foam core
Blade Mass (per piece)	380 g (13 oz)
Blade Method	Interlock hub mounting
Body Material	Aluminum diecast
Body Construction	Screw-less joints (based on traditional Japanese craftmanship)
Product Finish	Anti-corrosion Teflon-based paint
Generator	Synchronous-type, three-phase power generator with permanent neodymium iron boron magnet
Control Systems	Built-in original Intelligent Power Management with: 1. Power Assist Function 2. Seamless Power Control Functions 3. Safety Control 4. Battery Charge Management 5. Data Communication
Protection Circuit	Built-in
Data Logger	Built-in (Total energy production)
Yaw Control	Free yaw (360 degrees)
Direction Control	Original Swing-Rudder System
Start-up Wind Speed	0 m/s (Power Assist Function)
Cut-in Wind Speed	2.5 m/s, 5.6 mph
Peak Power	2.3 kW (20 m/s, 44.7 mph)
Maximum Rotor Speed	1,000rpm (20 m/s, 44.7 mph)
Mass per Watt	17.5 g (1 oz)/W (at rated power)
Output Voltage	50V DC (Z-1000-48) / 25V DC (Z-1000-24)
Braking System	Regenerative electromagnetic braking system
Communication System (Signal Output)	RS-485
Recommended Battery Capacity	Deep cycle lead acid battery 500 Ah or more Off-grid: Deep cycle lead acid battery, 500 Ah or more

Appendix 5: Power curve of wind turbines from manufacturers

Wind speed (m/s)	Power output (kW)			
	800 kW	15 kW	10 kW	1 kW
1	0	0	0.00	0.00
2	0	0	0.00	0.00
3	0	0.35	0.10	0.01
4	0	1.22	0.40	0.03
5	0	2.50	0.60	0.07
6	22	4.01	1.00	0.14
7	50	5.28	2.00	0.23
8	87	7.68	3.50	0.34
9	166	10.9	5.00	0.46
10	259	12.70	7.00	0.57
11	350	15.00	8.50	0.66
12	474	16.10	10.00	0.74
13	599	16.23	11.00	0.80
14	700	15.55	11.00	0.83
15	771	15.55		0.86
16	809	15.23		0.87
17	832	15.23		
18	838	15.23		
19	838	15.23		
20	838	15.23		
21	838	15.23		
22	838	15.23		
23	838	15.23		

Appendix 6: Technical specification of 167W solar panel

167 WATT

A DURABLE MODULE FOR LARGE ELECTRICAL POWER NEEDS

FEATURES

- High-power module (167 W) using 125mm square multi-crystal silicon solar cells with 12.84% module conversion efficiency
- Photovoltaic module with bypass diode minimises the power drop caused by shade
- Textured cell surface to reduce the reflection of sunlight and BSF (Black Surface Field) structure to improve cell conversion efficiency: 14.84%
- White tempered glass, EVA resin and a weatherproof film, plus aluminum frame for extended outdoor use
- Nominal 24 DC output, ideal for grid connected systems
- Output terminal: Lead wire with waterproof connector
- Certifications: IEC 61215 & IEC 61730
- SHARP modules are manufactured in ISO 9001 certified factories

MULTI-SILICON PHOTOVOLTAIC MODULE WITH 167W MAXIMUM POWER

A safe, clean, reliable source of energy, Sharp's **NE-Q7E3E** photovoltaic module is designed for large electrical power requirements. Based on the technology of crystal silicon solar cells developed since 1959, this module has superb durability to withstand rigorous operating conditions and is suitable for grid connected systems.

Common applications for the Sharp NE-Q7E3E include residences, office buildings, solar power stations, solar suburbs, radio relay stations, beacons and traffic lights. As one of the world's leading manufacturer of photovoltaic modules, Sharp produces an extensive line of high power modules for every electrical power requirement.

SHARP

NE-Q7E3E – MAXIMUM POWER

ELECTRICAL CHARACTERISTICS

Cell	Multi-crystal silicon solar cells
No. of Cells and Connections	72 in series
Open Circuit Voltage (Voc)	43.1V
Maximum Power Voltage (Vpm)	34.6V
Short Circuit Current (Isc)	5.33A
Maximum Power Current (Ipm)	4.83A
Maximum Power (Minimum Power) (Pm)[1]	167.0 (158.7)
Encapsulated Solar Cell Efficiency (ηc)	14.84%
Module Efficiency (ηm)	12.84%
Maximum System Voltage	DC 1000V
Series Fuse Rating	10A
Type of Output Terminal	Lead Wire with MC Connector

[1](STC) Standard Test Conditions: 25°C, 1 kW/m², AM 1.5

MECHANICAL CHARACTERISTICS

Dimensions (A x B x C below)	1575 x 826 x 46mm
Weight	17.0kg
Packing Condition	2 pcs - 1 Carton
Size of Carton	1700 x 970 x 130mm

ABSOLUTE MAXIMUM RATINGS

Parameters	Rating	Unit
Operating Temperature	-40 to +90	°C
Storage Temperature	-40 to +90	°C
Dielectric Voltage Withstood	3000 max.	V-DC

IV CURVES

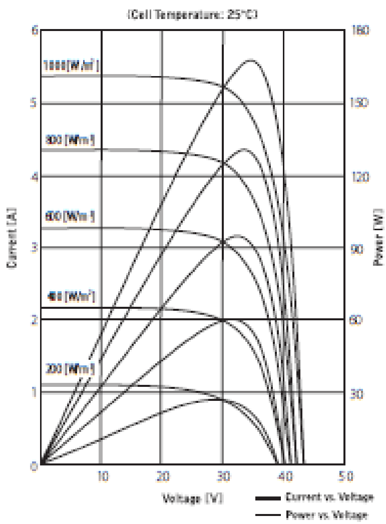
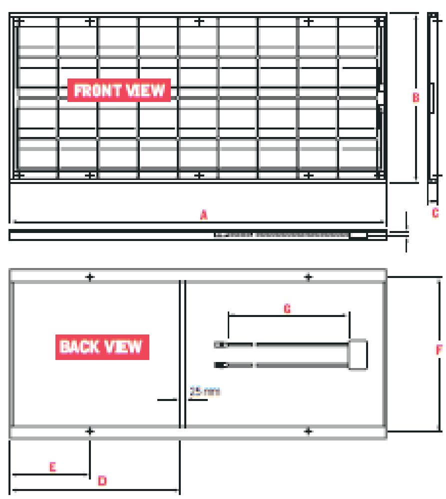


Fig. 1-2 Current, Power vs. Voltage Characteristics

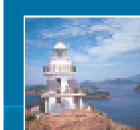
DIMENSIONS



A	B	C	D	E	F	G
1575mm	826mm	46mm	712.5mm	340mm	790mm	900 +/-50mm

In the absence of confirmation by device specifications sheets, Sharp takes no responsibility for any defects that may occur in equipment using any Sharp devices shown in catalogues, data books, etc. Contact Sharp in order to obtain the latest device specification sheets before using any Sharp device.

- Design and specifications are subject to change without prior notice.
- Colour variations to products may occur due to printing.
- All information and technical details are correct as at product release date.



SHARP

SHARP CORPORATION OF AUSTRALIA PTY LTD
ABN 40 003 039 405
1 Huntingwood Drive, Huntingwood, NSW 2148
PO Box 6827, Blacktown, NSW 2148
Tel: (02) 9830 4600 Fax: (02) 9672 1208
www.sharp.net.au

SHARP Solar

Appendix 7: Technical specification of 100W solar panel

SIEMENS

Solar module SM110/SM100

When it comes to reliable and environmentally-friendly generation of electrical power from light, solar modules from Siemens Solar provide the perfect solution. Manufactured in compliance with the most stringent quality standards, they are designed to withstand the toughest environmental conditions and are characterized by their long service life. Siemens Solar power solar modules are covered by a 25-year limited warranty on power output – your guarantee of trouble-free solar power generation.

PowerMax® technology
Siemens Solar proprietary PowerMax® technology optimizes the cells and modules for energy production in all types of environmental conditions. This includes the growing of single crystalline silicon ingots, wafer processing under clean room conditions and the multistage proprietary TOPS™ (Texture Optimized Pyramidal Surface) process. The most striking features of the TOPS™ process are the special textural etching system which creates a pyramid-shaped surface, combined with surface passivation and an anti-reflective oxide coating.

This means that light absorption is especially high, even at low light levels. Siemens Solar PowerMax® solar cells deliver maximum energy throughout the day.

Certifications
The following certificates and approvals confirm the high quality of the Siemens Solar SM110/SM100:

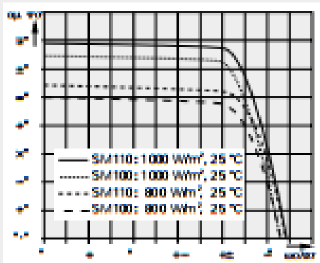
- IEC61215
- TÜV safety class II
- CE mark

Solar module SM110/SM100

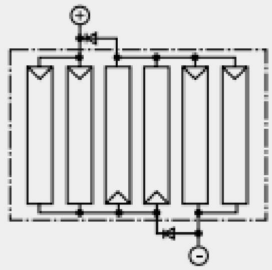
- Power rating SM110: **110 W ± 5 %**
  SM100: **100 W ± 5 %**
- Available in 12 V or 24 V versions and as framed module or laminate
- Single crystalline PowerMax® solar cells for maximum *operational* efficiency
- Used in grid-connected systems and for grid-independent rural/stand-alone power supply systems
- 25-year power output warranty

Technical Data

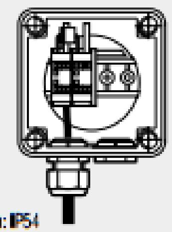
Voltage-current characteristic 12 V



Internal interconnection 12 V

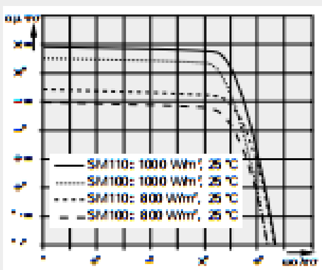


Sp terminal box 12 V (qty. 2)

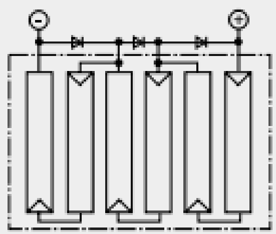


Maximum cable diameter: 4 mm²
Degree of protection: IP54
Cable gland: PG11

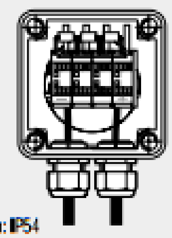
Voltage-current characteristic 24 V



Internal interconnection 24 V

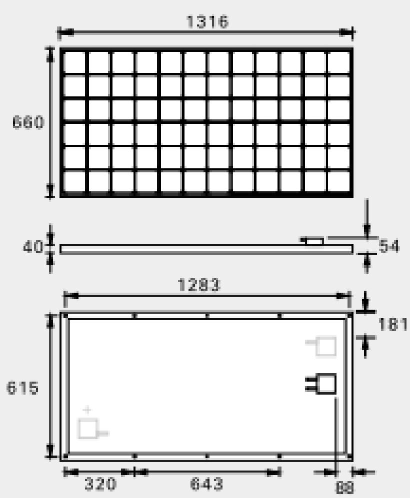


Sp terminal box 24 V



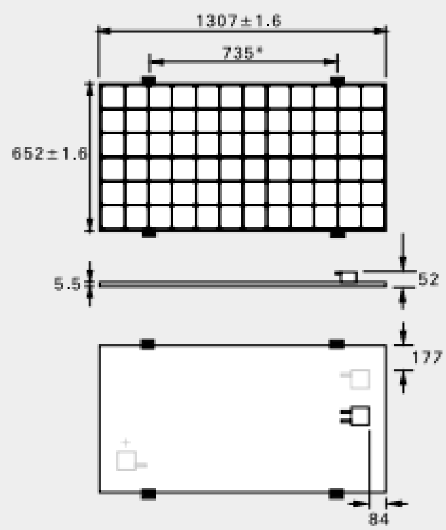
Maximum cable diameter: 4 mm²
Degree of protection: IP54
Cable gland: PG11

Module dimensions SM110/SM100



Hole diameter 7 mm (8 x) or 4 mm (2 x).
Hole dimensioning referred to hole center.
12V terminal boxes drawn in grey.

Module dimensions SM110-L/SM100-L



* Spacing between attachment clips.
Only use Siemens LCS/LCV clamps.
Only transverse mounting allowed.
12V terminal boxes drawn in grey.

Technical Data

Options
Modified versions of the solar module are also available, with MC plug-in contacts for example or a special version for integrated building solutions. You can obtain information about these versions from your Siemens Solar dealer or directly from Siemens Solar.

High Quality
Siemens Solar has established very high quality standards. Thus, our main production plants are certified to ISO 9001. Constant checks and inspections guarantee uniformly high quality. Each module which leaves the production line is subjected to thorough visual inspections as well as mechanical and electrical tests.

Performance warranty
The high quality of the modules results in an expected service life of well over 30 years. The SM110/SM100 is covered by a 25-year Siemens Solar warranty on power output.

You will find further information on modules, solar power generation principles and applications in the Siemens Solar product catalog.

Solar module SM110/SM100

Electrical parameters		SM110	SM110-24	SM100	SM100-24
Rated power P_{max} (± 5%)	$[W_p]$[1]	110	110	100	100
Configuration		12 V	24 V	12 V	24 V
Rated current I_{MPP}	[A]	6.3	3.15	5.9	2.95
Rated voltage U_{MPP}	[V]	17.5	35.0	17.0	34.0
Short circuit current I_{SC}	[A]	6.9	3.45	6.5	3.25
Open circuit voltage U_{OC}	[V]	21.7	43.5	21.0	42.0
Thermal parameters					
NOCT[2]	[°C]	45 ± 2			
Temp. coefficient of the short-circuit current		$+4 \times 10^{-4}$/K			
Temp. coefficient of the open-circuit voltage		-3.4×10^{-3}/K			
Limit values / Qualifications					
Max. permitted module temperature	[°C]	-40 to +85			
Max. permitted ambient temperature					
Module under solar irradiation	[°C]	-40 to +50			
Module shaded (storage temperature)	[°C]	-40 to +85			
Maximum permitted system voltage[3]	[V]	1000			
Surface pressure	[N/m²]	2400			
Maximum distortion[4]	[°]	1.2			
Humidity at 85 °C	[%]	85 relative			
Hailstorm/hailstones	[mm]	ø 25			
	[m/s]	v = 23			
Weight (with/without frame)	[kg]	11.5 / 9.5			

1) W_p (Watt peak) = Peak power under standard test conditions:
(minimum power 104.5 W_p/95 W_p)
Air Mass AM = 1.5
Irradiance E = 1000 W/m²
Cell temperature T_C = 25 °C

2) Normal Operating Cell Temperature at:
Irradiance E = 800 W/m²
Ambient temperature T_A = 20 °C
Windspeed v_W = 1 m/s

3) Protection class II 820 V

4) Diagonal lifting of the module plane

Your address for photovoltaics from Siemens Solar

Siemens modules are recyclable.

Internet: www.siemenssolar.com

Siemens Solar GmbH
A joint venture of
Siemens AG and E.ON Energie AG
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D-80915 München
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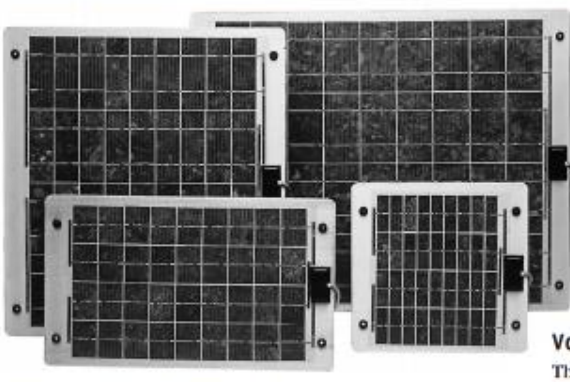
Order No. A95002 D1045 E 104CK

Appendix 8: Technical specification of 30W solar panel

MSX-Lite Photovoltaic Modules

MSX-Lite™ modules, part of Solarex's Megamodule™ series, are designed for applications requiring a combination of light weight, compactness, and ruggedness. They are particularly useful as 12VDC power sources for expeditions, mobile communications, recreational vehicles and railroad signaling devices.

Four models of MSX-Lite are available, the MSX-5 Lite, MSX-10 Lite, MSX-20 Lite and the MSX-30 Lite, delivering typical peak power of 4.5, 10, 20, and 30 watts respectively at Standard Test Conditions (STC). They are intended primarily for use in single-module power systems, but may be interconnected—up to a 30V nominal limit—to provide increased voltage or current.



Individually Tested, Labeled and Warranted

As part of the final inspection procedure, every MSX-Lite module is tested in a solar simulator and labeled with its actual output—voltage, current, and power at maximum power point (P_{max})—at Standard Test Conditions and Standard Operating Conditions. Furthermore, Solarex guarantees:

- that no module will generate less than its guaranteed minimum P_{max} when purchased;
- at least 90% of the guaranteed minimum P_{max} for five years.

Contact Solarex's Marketing Department for full terms and limitations of this warranty.

Proven Materials and Construction

The materials used in these modules reflect Solarex' two decades of experience with solar modules and systems installed in virtually every climate on Earth.

- Polycrystalline silicon solar cells: efficient, attractive, stable.
- Modules are rugged and weatherproof: cell strings are laminated between sheets of ethylene vinyl acetate (EVA) with a stainless steel substrate and Tedlar™ cover.
- Proven cell interconnection technique and moisture-resistant metallization ensure electrical integrity in severe climates.

Light, Rugged, Easily Mounted

Although extremely rugged, MSX-Lite modules are compact and lightweight. The largest, the MSX-30 Lite, weighs only 6 1/2 pounds (3 kg). The modules may be mounted from front or back through four grommet-finished holes which accept fasteners up to 0.2" (5mm) diameter. Total module thickness is only 16 mm, including the mounting grommets and the low-profile output termination box. The termination box is on the module's front, facilitating mounting on flat surfaces. MSX-Lite modules can also be mounted on curved surfaces: they will conform to curvature up to 1 inch per foot.

Ample Charging Voltage

With 36 cells in series, MSX-Lite modules generate sufficient voltage to charge 12V batteries in virtually any climate, as shown by the electrical characteristics on the reverse of this sheet.

Solarex Quality

MSX-Lite modules are tested and inspected in our ISO 9001-certified factories to demanding specifications.

Variables Affecting Performance

The performance of typical MSX-Lite™ modules is described by the I-V (current/voltage) curves and electrical characteristics table on the reverse side. Each module's actual, tested output characteristics are printed on its label.

Options

MSX-Lite modules may be ordered with an integral blocking diode, which prevents battery discharge at night or during periods of poor insolation.

More than 20 years ago, Solarex made the first polycrystalline silicon solar cell, advancing photovoltaics beyond the first-generation monocrystalline technology developed for electronics. Developed specifically for photovoltaics, polycrystalline silicon is used in Solarex's Mega™ series to provide a wide range of attractive, efficient modules. They require substantially less energy to manufacture and generate substantially more energy per rated watt than other crystalline silicon modules.

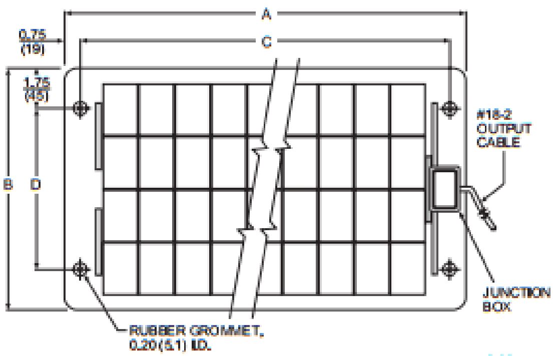
630 Solarex Court, Frederick, MD 21703 USA • PHONE (301) 698-4200 • FAX (301) 698-4201 • www.solarex.com • info@solarex.com

Mechanical Characteristics

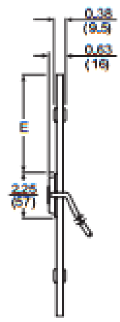
	MSX-30 Lite	MSX-20 Lite	MSX-10 Lite	MSX-5 Lite
Weight in pounds (kg)	6.5 (3.0)	4.5 (2.1)	2.5 (1.1)	1.6 (0.7)
Dimension (see dwg)		Inches (millimeters)		
A	24.25 (616)	17.5 (445)	17.5 (445)	10.75 (273)
B	19.5 (495)	19.5 (495)	10.5 (267)	10.5 (267)
C	22.75 (578)	16.0 (406)	16.0 (406)	9.25 (235)
D	16.0 (406)	16.0 (406)	7.0 (178)	7.0 (178)
E	8.63 (219)	8.63 (219)	4.13 (105)	4.13 (105)

Output cable: 3 meters long, AWG #18-2.

Dimensions: Dimensions in brackets are in millimeters. Unbracketed dimensions are in inches. Overall tolerances ±1/8" (3mm)



FRONT VIEW



SIDE VIEW

	DIM. A	DIM. B	DIM. C	DIM. D	DIM. E
MSX-5 LITE	10.75 (27)	10.50 (27)	9.25 (23)	7.00 (18)	4.13 (11)
MSX-10 LITE	17.50 (44)	10.50 (27)	16.00 (41)	7.00 (18)	4.13 (11)
MSX-20 LITE	17.50 (44)	19.50 (50)	16.00 (41)	16.00 (41)	8.63 (22)
MSX-30 LITE	24.25 (62)	19.50 (50)	22.75 (58)	16.00 (41)	8.63 (22)

Download CAD

Download MSX-20 & MSX-30 XLS

Download MSX-5 & MSX-10 XLS

For more information, contact:

Typical Electrical Characteristics*

	MSX-30 Lite	MSX-20 Lite	MSX-10 Lite	MSX-5 Lite
Maximum power (P_{max})	30W	20W	10W	4.5W
Voltage @ P_{max} (V_{mp})	17.1V	17.1V	17.1V	16.8V
Current @ P_{max} (I_{mp})	1.75A	1.17A	0.58A	0.27A
Guaranteed minimum P_{max}	27W	18W	9W	4W
Short-circuit current (I_{sc})	1.90A	1.27A	0.60A	0.29A
Open-circuit voltage (V_{oc})	21.1V	20.8V	21.1V	20.6V
Temperature coefficient of I_{sc}	(0.065±0.015)%/°C			
Temperature coefficient of V_{oc}	–(80±10)mV/°C			
Approximate effect of temperature on power	–(0.5±0.05)%/°C			

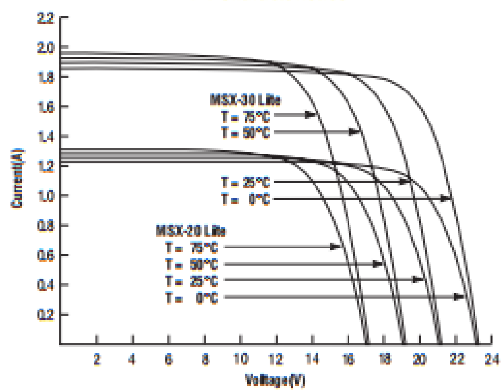
NOTES

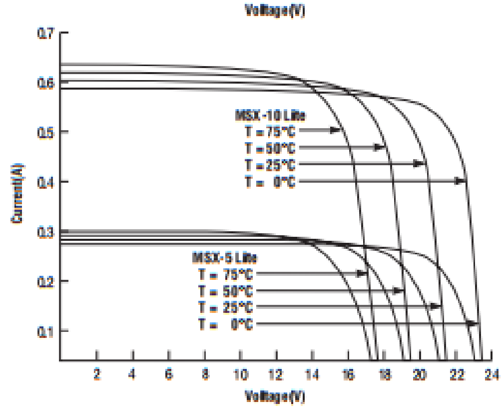
*These data represent the performance of typical modules as measured at their output cable terminations, and do not include the effect of such additional equipment as diodes. The data are based on measurements made in a solar simulator at Standard Test Conditions (STC), which are:

- Illumination of 1 kW/m^2 (1 sun) at spectral distribution of AM 1.5
- Cell temperature of 25°C or as otherwise specified (on curves).

Operating characteristics in sunlight may differ slightly.

I-V Characteristics





SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE

6061-8 11/98

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Appendix 9: Technical specification of 145Ah 6volts battery storage

Rolls AGM Series

S6-460AGM 6V 415Ah (C20)

CONSTANT CURRENT DISCHARGE (AMPS)

CUT OFF VOLTAGE V/CELL	30M	45M	1H	2H	3H	5H	8H	10H	12H	20H	24H
1.75V	386.6	285.0	231.5	123.4	93.9	65.9	45.1	37.4	31.8	20.8	17.4

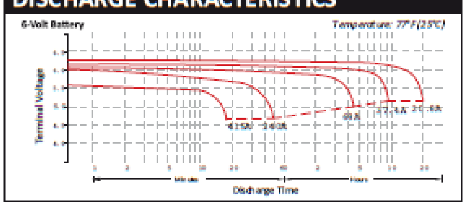
RESERVE CAPACITY

@25AMPS	@75AMPS
885 Minutes	229 Minutes

SPECIFICATIONS

Nominal Voltage		6 Volt
Rated Capacity (20 Hour Rate)		415AH
DIMENSIONS	Total Height (inc. Terminals)	424mm
	Height	404mm
	Length	295mm
	Width	179mm
Weight		56.0Kg

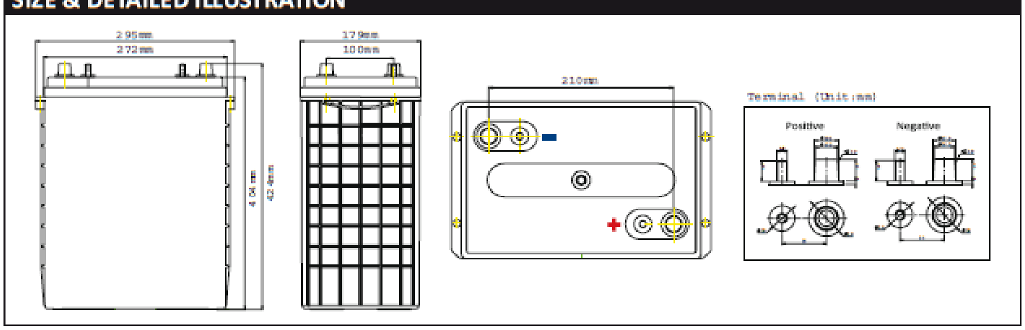
DISCHARGE CHARACTERISTICS



CHARACTERISTICS

Capacity 25°C (77°F)		20 Hour Rate (20.8A to 5.25 Volts)	415AH
		10 Hour Rate (37.4A to 5.25 Volts)	374AH
		5 Hour Rate (68A to 5.1 Volts)	340AH
Internal Resistance		Full Charged Battery 25°C (77°F)	1.6mΩ
Capacity Affected by Temperature (20 Hour Rate)		40°C (104°F)	102%
		25°C (77°F)	100%
		0°C (32°F)	85%
		-15°C (5°F)	65%
Self-Discharge 25°C (77°F)		Capacity after 3 Month Storage	91%
		Capacity after 6 Month Storage	82%
		Capacity after 12 Month Storage	64%
Max. Discharge Current 25°C (77°F)		2000A (5s)	
Terminal	Standard	DT	
Charging (Constant Voltage)	Cycle	Initial Charging Current ≤ 0.2 x C20 7.25V ~ 7.45V/25°C(77°F)	
	Float	6.8V ~ 6.9V/25°C(77°F)	

SIZE & DETAILED ILLUSTRATION



This information is generally descriptive only and is not intended to make or imply any representation, guarantee or warranty with respect to any cells and batteries. Cell and battery designs/specifications are subject to modifications without notice. Contact Rolls Battery for the latest information.

CAUTION ONE MEAN BATTERY

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