Department of Mechanical and Aerospace Engineering

A Study of the potential to use the Department Stores' outdoor Parking Space as a Solar Farm and EV Charging Stations in Thailand

A Case study at The Megabangna Shopping Centre

Author: Peetapat Supanich

Supervisor: Dr.Paul Tuohy

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Copyright Declaration

Signed: Peetapat Supanich   Date: 19th August 2020

Abstract

Carbon emission from road transportation is the most critical environmental issue in Thaiand. PM 2.5 is also a serious problem. The government has tried to employ all means available to manage the challenges. EV technology has been brought up in consideration. National policies and measures have been implemented to reduce the emission and promote the EV' use. Yet, using EVs will enlarge the electricity demand, the power generation, and the carbon intensity level.

The study aimed at designing the most suitable model that enhances the EV charging stations' renewable energy system installed in the shopping centres' parking to achieve the maximum electric power and the carbon saving. The parking in the Megabangna Shopping Centre has been deployed as charging stations and a solar farm. The simulations performed using the existing ten EV charging points, 1,380 cars/month. Four models are employed for the simulation. Each model represents each battery-size: S, M, L, and XL. Five cases have been defined: S, M, L, XL, and mixed-size. Each case has been simulated under two conditions: on the bright day and the cloudy day. HOMERpro software and Thai modelling are applied to study the system's potential and the obtained electricity's capacity.

The results signifies that it is feasible to apply the parking area of Thailand's shopping centres as a solar farm for the EV charging stations via an off-grid system. The simulation of the unmet electricity load scenario reveals that the installation of the designed-solar panel is viable. The gained electricity is adequate for the EV charging stations. The CO2 and the PM2.5 savings are higher than 20,691,189 kgCO2 per year and 790 kg PM/year.

Plenty of the high-density solar irradiation is available in Thailand all year round. Thailand can make the most of the enormous existing renewable energy resources for environmental sustainability.

Acknowledgements

This dissertation has been accomplished with precious advice and assistance from many parties. Please permit me to take this opportunity to convey my gratitude to all those who encouraged and guided me in carrying out the study.

First and foremost, I wish to extend my heartfelt gratefulness to Dr. Paul Tuohy, my advisor and supervisor. I feel thankful for his in-depth engineering advice. His mentoring and valuable encouragement is a great help. Without his guidance, the dissertation would not have been attained.

I feel most grateful to the Megabangna Shopping Centre for all professional assistance in providing the parking statistics' database and the electrical consumption of this project.

My special thankfulness goes to the Electricity Generating Authority of Thailand (EGAT) for sharing the national grid profile which allowed me to get insight into the electrical production, carbon intensity, and renewable energy generation.

I feel gratitude to the Electric Vehicle Association of Thailand (EVAT), for the statistical dataset of the EVs' profile, which let me go through the management of the EV demand.

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Chapter 1 : Introduction

1.1 Background

Thailand faces several environmental problems, especially the air pollution. The carbon emissions produced by the transport sector are the severe issue. The emission released from road transportation is the most critical subject. So far, the number of vehicles, most of which are the conventional internal combustion engine vehicles (ICEVs), has enlarged extensively. It results in a level of high carbon intensity (Govidhayawong, 2016). In addition, in the past four years Thailand has faced problems with the particulate matters (PM2.5) caused either naturally or by humans. One of the major sources is the diesel vehicle fuel exhaust emission. The PM2.5 is emitted throughout the combustion of solid and liquid fuels.

Since 2019, the Thai government has tried to apply all means available to sort out the problems. The issue has been made the national agenda. The electric vehicles (EVs) technology has been brought up in consideration. The adoption of EVs has been considered as the key solution. In 2020, policies and measures have been implemented to lower carbon emissions and promote the use of EVs. Price and tax are reduced to ease the load and support the clients. The government aims to limit the number of sales of the petrol and the diesel cars by the year 2050 (Thai Government, 2017). In the long term, the number of EVs will likely be greater than the one currently. EVs will become the main road vehicles in Thailand. The possibility can be seen in Figure 1.1.

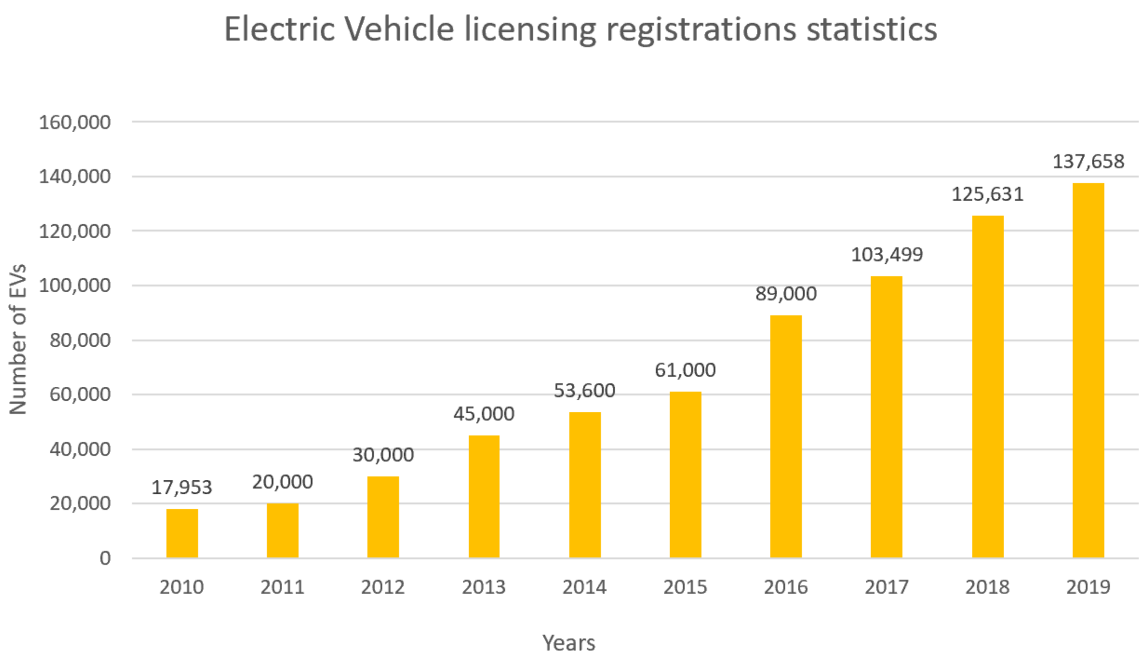


Figure 1.1 : EVs Licensing and Registration Statistics in Thailand 2010-2019 (Sources: Electric Vehicles Association of Thailand - EVAT)

Figure 1.1 demonstrates a bar chart of the EVs fleet. The number of the EVs licensing and registration has grown considerably from 17,953 in 2010 to 137,658 in 2019. EVs are considered as a choice of solution to lessen the environmental impacts affected by ICEVs (Selvakkumaran, 2018). Figure 1.2 shows that there are a total of 520 public charging locations, 793 outlets.

Electric Vehicle Association of Thailand - EVAT

SERVICE PROVIDERS	Number of Locations	Number of Outlets: AC Normal Chargers	Number of Outlets: DC Fast Chargers	Number of Outlets: ALL Total Chargers
EA ANYWHERE	376	573	240	573
CHARGING STATION	68	48	32	80
ptt	17	25	0	25
ChargeNow	16	38	1	39
MEA EV	13	7	9	16
PEA EV	11	13	13	26
EGAT EV	10	15	12	27
EVOLT	6	10	2	12
PROMPTCHARGE	3	7	0	7
TOTAL	520	726	69	793

Figure 1.2 : Thailand Registration EV Model Specification (Source: Land Transport Department)

As depicted in Figure 1.2, the main service provider holding the highest number of charging stations is Energy Anywhere (EA) (376 stations), followed by Volt charger (68 stations), PTT (17 stations), Charger now (16 stations), MEA EV (13 stations), PEA EV (11 stations), EGAT EV (10 stations), EVOLT (6 stations), and Prompt Charge (3 stations) respectively. There is a total of 520 charging locations in Thailand. 726 outlets are fixed with AC chargers, and 69 outlets are installed with DC chargers. The number implies that Thailand has been preparing for using EVs in the near future. The preparation considers both the efficient response to the needs of the EV users and the appropriate support for the service providers.

All parties concerned are aware of the weaknesses of the long battery recharing time, the range anxiety, and the pollution issues.

However, using EVs enlarges the electricity demand in supplying the EV's battery. The demand not only increases the national grid generation, but also results in a higher level of the emissions from coal, petroleum, and the others non-renewable energy production, which are the main resources of Thailand electricity production (Choma, 2015). The charging demand has enlarged as most of the car owners often have their batteries charged almost at the same time. The high demand influences on the grid generation which has different energy resources in the current energy mix. As a result, the electricity has to be produced as fast as possible to fulfil the need at the peak demand (Autovista Group, 2017).

Smart charging stations integrated with the internet of things technology (IOT) are considered to be one of the keys to resolve these difficulties. The charging time during the highest load time can be controlled, and the carbon content will be restricted when the carbon level is at a high level (Cutting, 2019). Another way to avoid the EVs fleet demand problem is to separate the system by installing an off-grid renewable energy system at the charging stations.

Due to the aforementioned technical difficulties, a case study was conducted to discover the technical solutions concerning the EVs fleet demand, the grid connection, and the high-level of the carbon intensity on the grid. The most suitable scale of model has been designed to optimise the renewable energy system of the EVs' charging stations to expose the highest achievable power and carbon saving. The parking space in the Megabangna Shopping Centre has been deployed as the charging stations and a solar farm. HOMERpro software has been employed to simulate Thai modelling to analyse the power response of the entirety of the electrical load served, full amount of the solar power output, the battery input power, and the grid power output. Through this, EVs will become a non-polluting technology, both its driving technology and its resources for driving.

1.2 Aims and Objectives

The aims of the study project were defined as follows:

1. Determine the highest achievable power of the EV charging stations using renewable energy technology by employing the demand analysis and the unmet-load scenario.
2. Alleviate the peak demand of the grid problems caused by fleet charging through renewable energy off-grid system's simulations, so that the high energy demand of the EVs in the future can be responded.
3. Define suitable area for a solar farm and design a model for the charging stations in the parking of the shopping centres which generates power via renewable energy system only.
4. Discover the carbon savings and surplus energy.

To meet the aim, the following objectives are determined.

1. Design the scale of the model of the renewable energy scheme which enables adequate electricity supply for the EV charging stations in the parking.
2. Simulate the modelling system via the EV demand profiles, under different cases and conditions.
3. Examine the highest achievable carbon savings and the surplus energy of the EV charging stations using renewable technology system.
4. Distribute the surplus amount (if any) to support the electricity of the shopping centres.

1.3 Scope of the Study

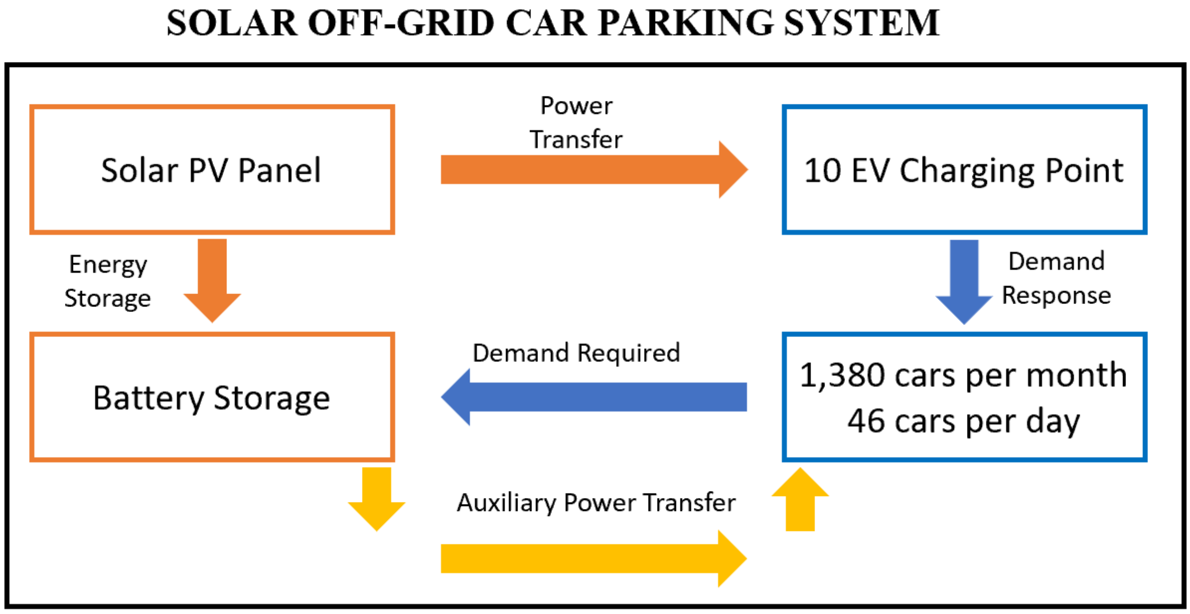


Figure 1.3 : The schematics of the solar off-grid parking system

The scope of the study has been outlined as follows:

1. Electric Vehicles Analysis (EVs): The study covers and focuses on the Battery Electric Vehicle (BEV), which uses power from the electric batteries, such as the batteries of Tesla Model S and Nissan Leaf.
2. EV Charging Stations (EVSE): The EV charging station in this study refers to the charging station at the Megabangna Shopping Centre's parking space, both indoors and outdoors. The simulations performed using the existing ten EV charging points, 1,380 cars/month.
3. Renewable Energy Technology: The renewable energy in this project refers to a solar energy off-grid system of the EVs charging stations in the Megabangna Shopping Centre's parking space.

The following issues are not included in the scope of the study due to some uncontrollable factors.

1. Other EVs types; Hybrid Vehicle (HEV) and plug-in hybrid (PHEV).
2. The technical analysis of the power circuit of EVSE; Bi-directional converter, battery storage selection.

3. The national grid feed-in tariff and policy, which involves in Thai politics.

1.4 Methodology

The methodology of the dissertation has been designed as follows:

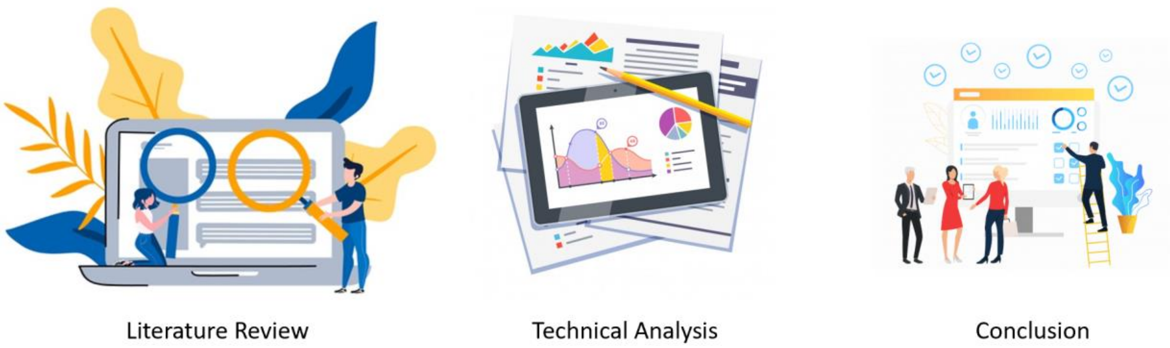


Figure 1.4 : Methodology Process

1.4.1 Literature Review

Literature review has been conducted in chapter two until chapter five.

Chapter Two provides general background knowledge and the principle of the EVs, the EVSE technology, and the charging stations. The EVs types, the EVs profiles, and the EVSE connectors, including the modes are specified. The details about the EV battery types and the technology are defined. The characteristics of the EVSE and the existing of the off-grid integrating with the EVSE in other countries are explained.

Chapter Three describes the current grid energy mix in Thailand, including the national grid profiles and the carbon intensity. The potential of energy resources; non-renewable energy and renewable Energy.

Chapter Four details the solar energy technology. The factor of solar panel installation, the solar irradiation at the site location, and the solar angle is explicated. The chapter provides the detailed information about the sizes and the types of the solar panel.

Chapter Five focuses on the potential assessment of the selected site location in the Megabangna Shopping Centre. The assessment relates to the four factors, namely the area, the electrical profile, the car parking statistics, and the charging behaviour.

1.4.2 Technical Analysis and Results

Chapter Six explains the simulation model and the software tool. The solar irradiation based on NASA laboratory has been applied as the input data. The electrical load of the EVs has been computed based on the EV battery sizes (S, M, L, XL), to examine the demand in each case. Fact findings of the power of the PV supply that meet the demand has been carried out to determine how much power can be saved over the year in each case, in the event that the shopping centre depends on the off-grid system only. This leads to the understanding of whether or not the demand and supply of the off-grid PV can be matched, or exceeded, or deficited. Comparison between the PV system and the non-installed PV system has been undertaken to examine how much carbon content can be saved during the EV charging process. The SOC analysis of the scenario that shows the battery potential in the PV energy for the charging EV is presented.

1.4.3 Conclusion and Future work

Chapter Seven concludes the study based on the simulation results in Chapter 6. The suitable model scenario giving the best energy matching percentage in the installation of the solar-farm in the shopping centre, is introduced. The proposed recommendations for future work to further develop the EVSE in Thailand is included in this chapter.

1.5 Project Timeline

Project Timeline				
Tasks	May	June	July	August
Literature Review				
Finding the Data				
Technical Analysis				
Result & Discussion				

Chapter 2 : Technology of Electric Vehicle and Charging Station

2.1 EVs' Technology

EVs' technology have existed for more than 170 years, but the vehicles were not widely commercialised at that time. The breakthrough's series on the EVs' technology has been carried on from time to time. Until 1900s, our world has faced critical climate change and a wide range of environmental challenges. One of the critical causes is the road-carbon emission released from the diesel vehicle fuel exhaust. EVs' technology, therefore, has been brought up and largely developed. Still, the difficulties about the electricity peak and the high level of the carbon intensity is to be concretely resolved in the EVs adoption.

An electric vehicle (EV) operates by applying one motor or a combination of the electric motors as a propulsion source, whereas a conventional internal-combustion engine (ICE) produces power by burning a mix of fuel and gases. EV deploys a large traction battery cell pack to run the electric motor, which has to be plugged into a charging station or the wall-outlet to recharge the power back to the battery, as it operates on electricity. Hence, there will be no emission from the EVs' exhaust system (AFDT, 2020). Different criteria can categorise the types of the EVs. In this study, the EVs are divided into three main categories based on their working standard system, namely Battery Electric Vehicle (BEV), Plug-in Hybrid Electric Vehicle (PHEV), and Hybrid Electric Vehicle (HEV). The diversity system of each type is shown in Figure 2.1.

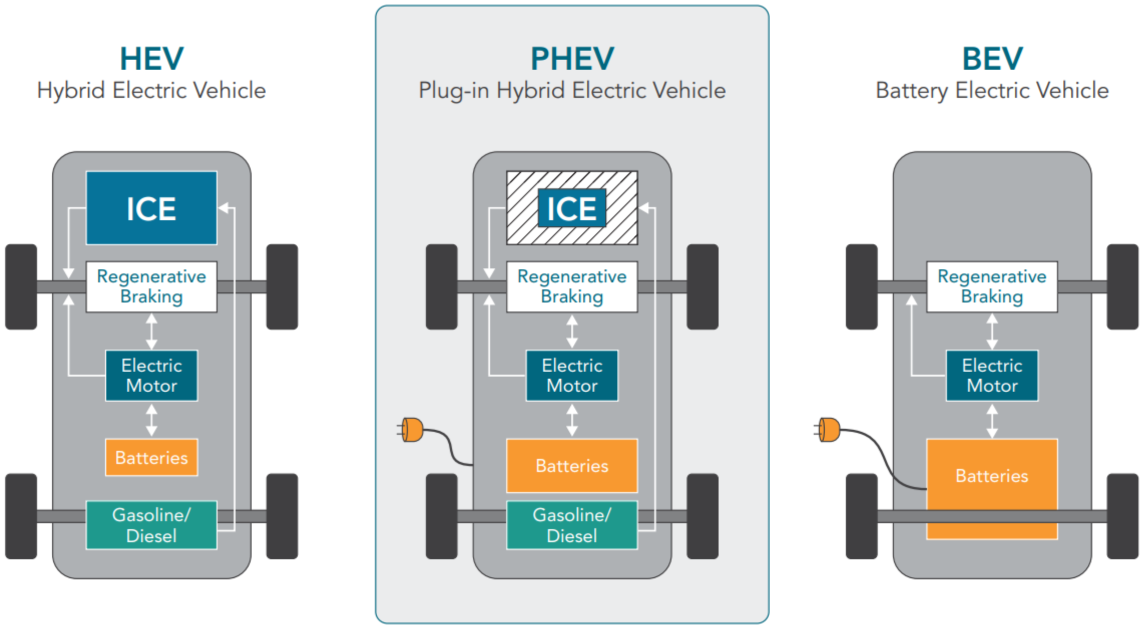


Figure 2.1 : Electric Vehicles System (Source: Courtesy of Gary Kendal, PhD.)

Battery Electric Vehicle (BEV)

The Battery Electric Vehicles (BEV) run the system using an electric motor only. The operational energy is delivered from the energy stored in the vehicle-mounted battery, which is charged by plugging into an external source of the electricity.

Plug-in Hybrid Electric Vehicle (PHEV)

The Plug-in Hybrid Electric Vehicle (PHEV) works according to two principles. The batteries activate an electric motor. Other fuels like diesel power an ICE, or other propulsion sources. The vehicles consume the electric power until the battery is empty. At that point, the system will be switched over to use the ICE automatically. The PHEV's battery can be charged either at the charging station or at the wall-outlet. Using electricity from the grid to drive the vehicle can decrease the operating costs and the fuels used in relation with the conventional vehicles.

Hybrid Electric Vehicle (HEV)

The Hybrid Electric Vehicles (HEV) are propelled by more than one energy sources. The first one is an internal combustion engine. The other one is an electric motor, which consumes the energy collected in the battery. The electric motor can be one or more. The HEV has been designed by bringing together the outstanding points as regards the power and range of the conventional vehicles, specifically the higher fuel economy and lower tailpipe emission. The HEV’s battery can be charged via the regenerative braking and the ICE only. Using a smaller-size engine is viable as the electric engine distributes extra electric power. The battery can also distribute the additional current and lessen the engine’s idle when it stopS. Such properties enhance the fuel economy without declining efficiency.

The study underlines the solar energy integration. The BEV has been focused as it is the type of EV that requires the highest electrical demands to assure the best practice, which will resolve the worst demand case sceario.

2.2 Electric Vehicles Charging Station Technology

The EV charging station technology (EVSE) plays a vital role in the success of the EVs and the grid integration. The architecture of the charging stations in each country varies according to the electrical grid connection, voltage, frequency, and standards. Time-consuming in the EV’s battery charge and the battery’s lifetime is associated with the features of the battery chargers. A good charger has high consistency and effectiveness. The power density should be at a high level. (Falvo, 2014).

The EVs, including its parts must comply with the standards formulated by the International Electrotechnical Commission (IEC), which is the organisation formulating and publishing the international standards for the entire electric-power, the electronics, and all involved technologies. The international standards comprise worldwide-related technical measurements and metrics that enable the electrical and electronic devices to operate proficiently, safely, and compatible with each other. The IEC 62196-1 and the IEC 62196-2 characterises the plugs and the sockets suitable for EVs’ charging. The IEC 62196-1 contains the wide-ranging requirement whereas the IEC 62196-2 determines the types of the core connecting systems, which are recognised as type1, type2, and type3. The standards as mentioned earlier comply with the IEC 61851-1, in which the charging of an EV from power sources has been classified into four modes (IEC, 2011). The essential components of the EVSE, according to the IEC standard, are defined as follows:

Electric Vehicle Supply Equipment Unit (EVSE)

The EVSE is also known as an EV charging station. The unit transfers the electrical energy to the EV during the battery charging process. It is a device attached to an electrical power source that delivers AC or DC supply to the EV, of which its traction battery needed to be charged. The charging speed is subject to the capacity options of the EVSE (Viana, 2017).

Connectors

Figure 2.2 demonstrates five types of sockets and the connectors for the pilot wire, which can be applied for the EV charging.

 J1772 (Type 1)	SAE J1772 / Type 1 connector: has five pins for the 2 AC wires, earth, and 2 signal pins compatible with IEC 61851-2001 / SAE J1772-2001 for proximity detection and for the control pilot function.
 Mennekes (Type 2)	Mennekes / Type 2 Connector: European standard, 7 pins and can withstand a maximum of 63 A.
 GB/T	GB / Type 3: Great Britain 7 pins and can withstand a maximum of 32 A.
 CHAdeMO	CHAdeMO / Type 4 : designed specifically for fast DC charging, 10 pins, and can withstand up to 200 A.
 CCS	Combined Charging System (CCS): 5 pins, can stand both fast, DC, and slow charge, AC.

Figure 2.2 : EV Connectors & Sockets (Source: evcharging.enelx)

Figure 2.2 displays the connectors and the sockets on the international EV's market. The connectors and the sockets can be grouped based on the electrical current as follows:

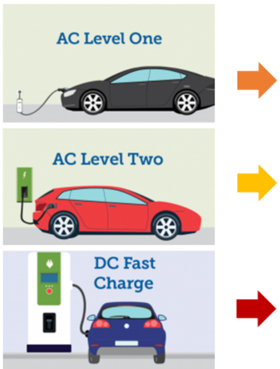
- Alternative Current (AC): SAE J1772, Mennekes, and GB
- Direct Current (DC): CHAdeMO, and CCS

Electric Vehicle Inlet (EV Inlet)

An EV inlet refers to a device on the EV that will be inserted by an EV connector, to establish the electrical connection between itself and the EVSE connector, so that the power can be transferred to the electric car.

Types of the Charging

The power level of the outlets specifies the types of charging. The battery recharging time is proportional to the amount of the remaining power. The charging types can be classified into 3 levels: level 1, level 2, and level 3 (Mary Land EV, 2020), as demonstrated in Figure 2.3.



EV CHARGING STATION

Charge Power (kW)	Charging Time	State of Charge	Maximum Current (A)
1.4	17 -18 hours	20% - 100%	12
1.9	12 - 13 hours	20% - 100%	16
3.3	6 - 8 hours	20% - 100%	16
7	3 - 4 hours	20% - 100%	32
10	2 - 3 hours	20% - 100%	16
22	1 - 2 hours	20% - 100%	32
43	20 - 30 min	20%- 80%	63
50	20-30 min	20% - 80%	100-125

Figure 2.3 : EV charging types (Source: Carolina country.com)

Level 1 (1.4-1.9 kW) is the slowest charging type. The charging process takes 17-18 hours with an approximate three to five electric miles of range per hour of charge. The charging requires a 120-volt outlet of the standard households through a single-phase alternative-current (AC). Thus, there is no charging equipment nor installation cost. Users can use the outlets at home or at any parkings.

Level 2 (3.3-22 kW) requires a 240-volt power to facilitate a quicker regeneration of the EV's battery system. It is generally installed in the public area, such as the shopping centres, downtown, and the public parking areas. The charging level is three to five times quicker than level 1, but gain more energy efficiency. It suits for commercial purposes at the public locations where people park their EVs for a few hours.

Level 3 (23-50 kW) is commonly known as a DC fast charging. It requires less than an hour to charge a battery. Most of the level-3 chargers can provide a depleted battery with an 80% capacity in circa 30 minutes. Thus, it is generally located in the high-traffic or rest areas, such as the gasoline stations. In winter, the cold weather may influence and lengthen the charging time.

This study focuses on the analysis of these three charging levels to define the suitable charging types for renewable energy integration.

Charging Mode

The charging mode explains a protocol for the EV and the charging station for clear and safety instruction. It can be divided into two main modes; AC charging and DC charging (RF Wireless World, 2019).

Figure 2.4 : EV charging Mode 1 (Source: Deltrix Chargers Company)

Mode 1: A standard power cord is plugged into a normal household socket. AC current will be converted to DC current through the vehicle-mounted charger. The battery charging is controlled by the vehicle charger. The lead cord will always live. Mode 1 charging does not comply with the safety standard requirement. Many countries, including Thailand, do not accept this mode. Thus, it is not in use anymore.

Figure 2.5 : EV charging Mode 2 (Source: Deltrix Chargers Company)

Mode 2: The lead is plugged into a normal socket (usually 15A). The vehicle-mounted charger is at one end, and a power cord is plugged on the other side. A power EVSE lead (electric vehicle supply equipment) is attached to the control box placed not more than 300 mm from the plug. The power lead is designed with automatic on/off switch, to ensure that the lead will not be live unless the car is being charged. The EV cannot be charged higher than the pre-set limit specified in the control box. The power will be disconnected automatically when the car is fully charged. In general, it is restricted to a maximum level of 2.4 kW 10A. A vehicle-mounted charger will convert AC to DC charging and control the battery charging process at the same time. The mode is certified with the safety standard.

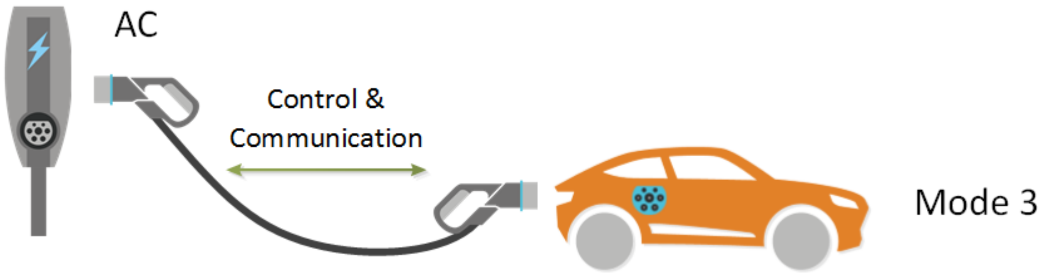


Figure 2.6 : EV charging Mode 3 (Source: Deltrix Chargers Company)

Mode 3: The mode operates with the EV multi-pin sockets, with on/off electronics functions equipped with a wall-mounted control box. This mode offers more choices of the charging rate sizes subjecting to appropriate criteria, such as EV charging capacity and EVSE. The alternatives are 3.6 kW 16A single phase to 22 kW 30A 3 phases, and even 40 kW 63A 3 phases. The vehicle-mounted charger will convert AC to DC charging and control the battery charging process at the same time. The mode is also endorsed with the safety standards.

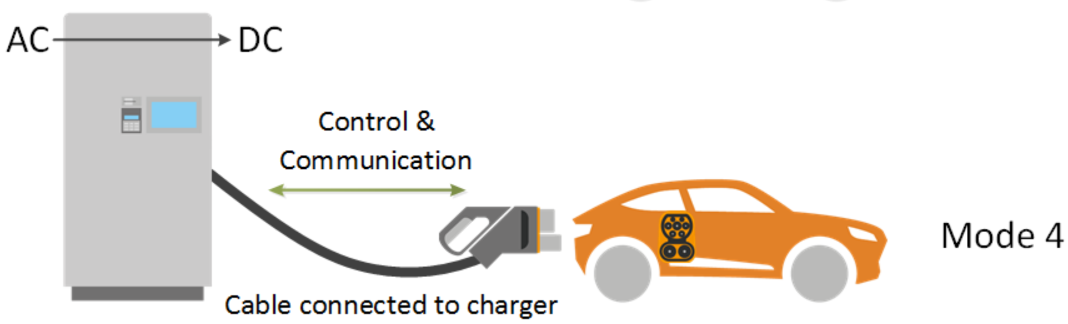


Figure 2.7 : EV charging Mode 4 (Source: Deltrix Chargers Company)

Mode 4: This mode refers to a DC fast charging. It is connected to the main power grid through an external charger. Users can connect via three different types of the sockets, depending on the standard accepted by the manufacturers. The mode offers broad ranges of charging rate, currently up to 50 kW (CHAdeMO), 120 kW (Tesla), or 150 kW (CCS). The charger is mounted to the wall box or a pillar converting AC to DC.

2.3 Electric Vehicle Battery

EVs' batteries are the energy sources that are extremely important for the EVs' performance. The EV battery powers the electric motor of the EVs. The EV battery can be classified into two main types. The first type is the lithium-ion (Li-on), which is used for the high-speed EV, e.g. Nissan leaf. The second type is the lead-acid, which is applied for the low speed EV, e.g. Mio mini EV. The Li-on batteries are expensive, but the efficiency is higher than the lead-acid batteries. As summarized by Sriboon (2015), the efficiency and the performance of the Li-on batteries are five times better than those of the conventional lead acid battery, which has existed for almost 100 years. Li-on is relatively light and compact. It has voltage per cell about 3.2 - 4.2V, high energy density of approximately 100–400 Wh/kg, high power density, low self-discharge, long lifetime, and high speed charging time.

Types of the EV Batteries

According to Hannan (2018), the positive electrode or the cathode is the most essential source of the energetic Li-on in a battery. The high quality battery contains a large amount of lithium.

Those kinds of cathode parts comprise LiCoO2: lithium-cobalt oxide, LiMn2O4: lithium-manganese oxide, LiFePO4: lithium-iron phosphate, LiNiMnCoO2: lithium-nickel-manganese-cobalt oxide, LiNiCoAlO2: lithium-nickel-cobalt aluminium oxide, and Li4Ti5O12: lithium -titanate.

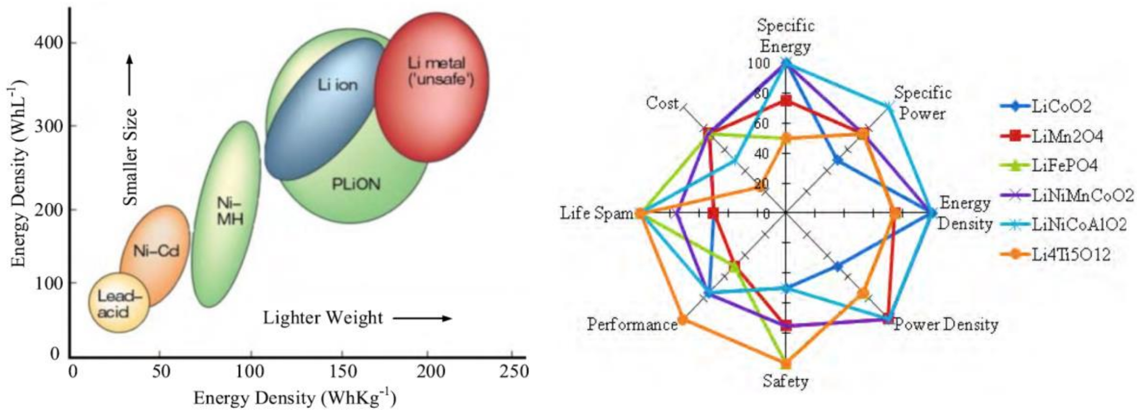


Figure 2.8 : The Comparison of Li-on Battery Types (Source: Special Section on Advanced Energy Storage)

Figure 2.8 demonstrates the comparison of various Li-on battery types. The features of the EV battery as defined ensure that the battery becomes a sustainable product in all aspects. The guideline for choosing the right EV batteries is identified below.

Lifespan - The battery longevity is subject to different factors, e.g. users' objectives, functional criteria, climates, and temperatures, etc. Presently, most of the EV battery's longevity is warranted for eight years or 160,000km (100,000 miles).

Safety - Safety is the major concern for EV batteries. Driving an EV consumes a large amount of power, thus; the safety of the battery plays a dominant role, specifically in the EV development. The safety standard specification and operation should be in place according to the battery management system (BMS). Users should apply and maintain the batteries correctly based on the defined protocol and manual.

Cost – The battery cost plays an essential role in the EV's success. The price is still a critical problem as it is as high as a small ICE car. The issue should be sorted out.

Performance – The operation and performance of the EV batteries are sensitive to the temperatures. The battery's life span will be shortened due to the high temperature. The battery's performance will significantly decrease at a low temperature.

Specific Energy – The energy density refers to the battery capacity in term of weight (Wh/kg), whereas the amount of energy is maintained per unit mass or by volume. The battery system is a substantial part of the EV's weight, the specific energy value is one of the most necessary factors of the EV batteries. EV needs high specific energy in the functions where a long runtime is demanded at a medium load.

Specific power - Power density refers to the loading capacity. The EVs' propulsion systems have much better torque than the ICE vehicles, with the same horsepower. The EVs, therefore, have a more excellent acceleration.

According to the aforementioned reasons, this study has selected the Li-on battery to store the power from the solar farm.

2.4 The Market Trend of the Future

In this decade, EVs are growing fast in the global market. In Thailand, the EVs with small-size batteries have the majority in the market segment, The capacity of the EVs with small-size batteries is about 10-29 kWh. This is because most of the urban people prefer a compact city car, easy for parking. In addition, the mini EVs are much cheaper than the big EVs. For example, a mini EV "FOMM ONE", of which the small-size battery capacity is around 11.8 kWh, costs only 15,000 pounds. The price of the EVs with a big-size battery "Tesla model S", of which the battery's capacity is 100 kWh, is 225,000 pounds. The different battery sizes make enormous difference in the price of around 210,000 pounds. The EVs batteries' standard according to the Electric Vehicle Association of Thailand (EVAT) are small-size battery (10-29 kWh), medium-size battery (30-59 kWh), large-size battery (60-89 kWh), and extra-large-size battery (90-120 kWh). The EVAT statistics, based on the battery sizes as shown in Figure 2.9, indicate that in 2019, there are the EVs with the small-size batteries 38%, followed by EVs with the medium-size batteries 34%, EVs with the large-size batteries 24%, and only 4% of the EVs are with the extra-large-size batteries. However, the EVs on the global market go the opposite direction. Tesla, which is a big size EV, has the best sale in 2020. According to these reasons and for a cleaner environment, the Thai government has provided support to promote the mini EVs so that the mini EVs can replace the conventional ICEs as fast as possible.

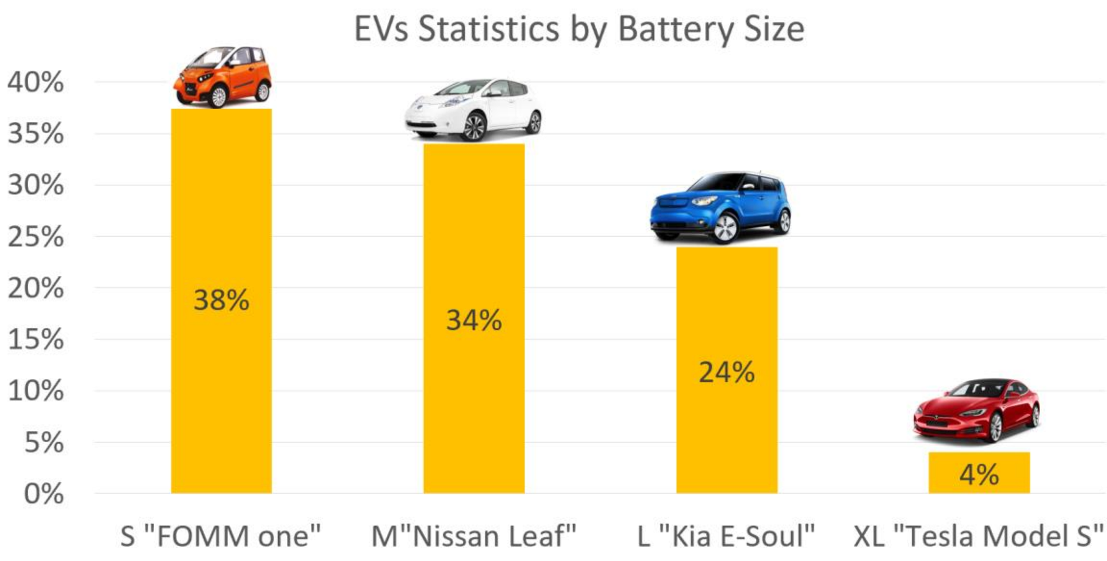


Figure 2.9 : The comparison of EVs by battery size (Source: EVAT)

With a view of the EV charging station market, both the AC and the DC chargers are available at most of the charging stations. Currently, the DC fast charging has been increased noticeably. According to Mordor intelligent - EVSE MARKET (2020), it is expected that the public fast chargers will be available worldwide soon.

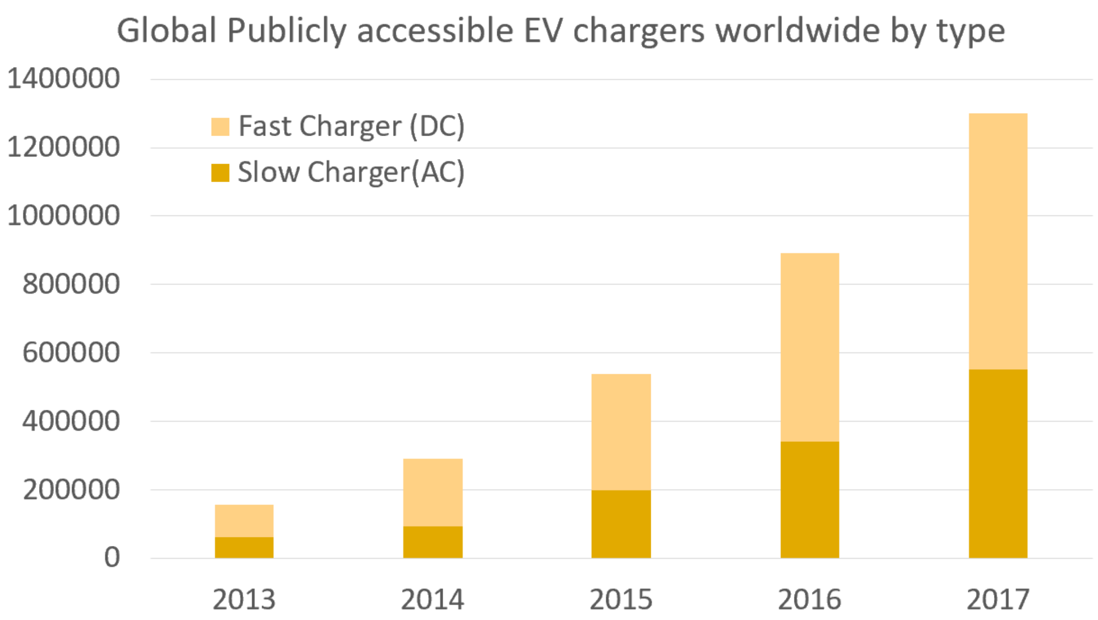


Figure 2.10 : The global publicly accessible EV chargers worldwide by type (Source: Statista IEA)

2.5 Existing EV Charging Station with renewable Integration

RE farm in the United Kingdom (U.K.)

As explained by Govidhayawong (2016), the project to situate the renewable energy farm along sideways of the motorway has existed. It's known as the Clyde RE Farm. People can see it from the motorway A74 (M). It implies that wind energy is one of the important renewable resources that can be converted and developed, as shown in Table 2-1.

Technology	Capacity for one charging point	Installation Cost	Note
Solar PV	10.35 kW	£50,000	Area to install the PV (10.35 kW) is approximately 80 m²
Wind Turbine	4.14 kW	£17,500	Under condition of wind turbine 6 kW and average wind speed is 5 m/s
CHP	1.23 kW	£ 2,200	Not only to sell back the electricity to third company but also supply direct to EV charging station

Table 2-1 : Clyde RE Farm along the A74(M) motorway, UK (Source: WESSEX University)

Table 2-1 displays the charging stations in the U.K. according to the types of renewable energy tehnology. The charging time is 2.75 hours/day on average. The consumption is around 8,300 kWh/year. In the U.K. the percentage of integrating the renewable energy resources in the EVs charging is low. If the installation expenses can be reduced, it will enlarge the number of EVs. Consequently, there will be more investment in renewable energy charging stations.

Solar Farm Systems in the U.S.A.

As detailed by Sriboon (2015), the existing renewable energy charging stations in the U.S.A. are mainly generated using solar energy. A lot of the EVs charging stations integrated with photovoltaic panel systems have increased in many states.

Location	Date installed	Cost of Construction (US $)	Number of Charging space	Daily power Generating (kwh)
University of Central Florida campus	Jan-2010	380,000	4	50
Saint Paul, Minnesota	Apr-2012	70,000	4	61
Eugene, Oregon	Sep-2010	800,000	18	106
Western Michigan University Campus	Feb-2012	700,000	15	168

Table 2-2 : Existing solar powered charging stations in U.S.A. (Source: International Energy Agency)

As depicted in Table 2-2, the charging space is quite small. The cost of the construction for the solar-powered charging stations is still high. Unless the price of the EVs, the battery system, and the PV equipment is lowered, people in the U.S.A. may drive more EVs. The capacity of the EVs charging stations will improve if the power at many charging stations can be produced from various types of the renewable energy resources, e.g. the solar-system, the wind turbine, and the tidal. In the U.S.A, the achieved solar radiation is around 4 kWh/m^2. It can produce energy about 5.7 kWh for a parking area with PV area 12 m^2. The efficiency is 12% efficient. Such scale can generate the energy around 64 kilometres for the EVs range.

Existing Systems in Thailand

By 2025, the Thai government targets to position the country as the EV hub. Meanwhile, relevant strategic plan and measures have been rolled out. The government has accelerated to implement the EVs charging stations' plans. Related laws and regulations regarding the transition of the ICE vehicles into the EVs have been reviewed, emphasising the air pollution and the better environmental system. Legal issues and promotional measures as regards the EVs, such as the privileges for the investment in the EVs, and cheaper cost of the imported batteries, will be either amended or newly issued, by taking into account the fairness to all parties.

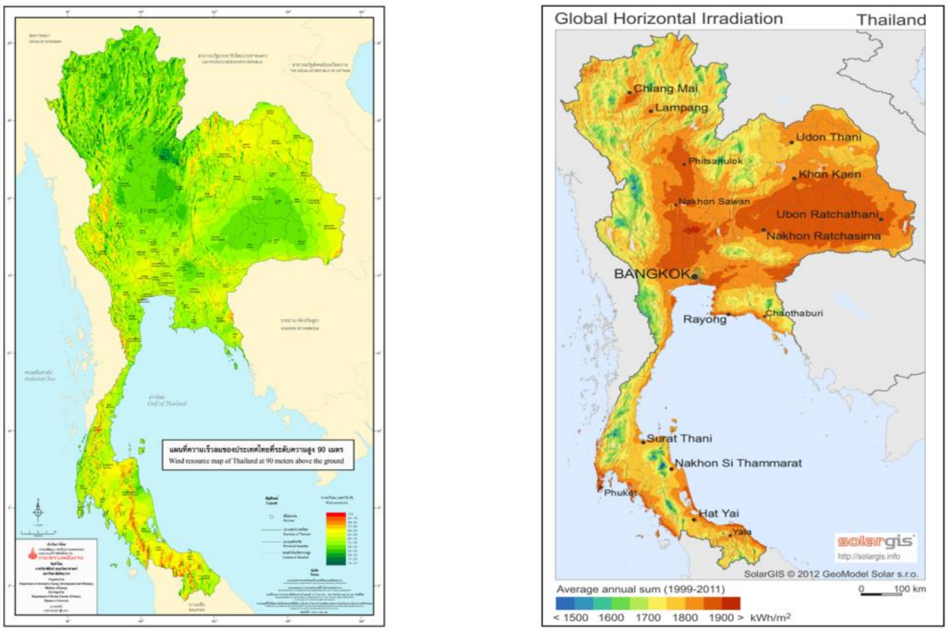
Such actions will encourage the expansion in the number of sales of EVs in Thailand. It will also promote the investment in public charging stations for the EVs. The Thai government subsidises this policy. The issue involves many organisation, e.g. the Ministry of Energy, the Provincial Electricity Authority, the Metropolitan Electricity Authority, and the Petroleum Authority of Thailand.

At present, the EVs demand in Thailand has increased gradually. It is expected that the demand in the EVs' charging energy will extend quickly within five years. Subsequently, it is necessary to prepare a proficient operational plan to ensure adequate resources to supply the power demand in the near future.

Currently, the EVs charging in Thailand is produced via the grid system using non-renewable sources, which harms the environment. If the EV demand increases quickly, as forecasted, the integration of the renewable energy resources into the EVs charging system is one of the methods that will enable the charging cost reduction. Besides, the renewable energy can be applied as one of the tools to fight with the climate changes and help recover the environment. Thailand has plenty of renewable energy resources. The country has a high competency to integrate renewable energy into the EVs charging system. Using clean natural sources will be a further step in the development of the electric vehicles.

The type of renewable energy source in this dissertation has been selected by considering the geographical location and the criteria in Thailand. The study aims at designing the most suitable scale of the model that optimises the EV charging stations' renewable energy system to expose the highest achievable power and carbon saving. As illustrated in Figure 2.11 (solar energy), Thailand is situated in the tropical zone with a great number of solar sources, which can be transformed into electrical energy. As demonstrated in Figure 2.10 (wind energy), there is a problem to install the wind turbine at some specific area in many provinces. Moreover, the annual wind speed in Thailand is around 4-6 m/s per year. To install the wind turbine, the standard required is around 6-8m/s per year. Thus, wind power is not the right choice to apply for the EV charging system in Thailand.

This study, therefore, concentrated on the integration of solar power into the EVs charging station system, which is expected to be more productive than using the other types of renewable energy sources.



Wind Energy Solar Energy

Figure 2.11 : The potential of renewable energy in Thailand (Source: Department of Alternative Energy Development and Efficiency, Ministry of Energy)

According to Figure 2.11, the annual solar irradiance in the central area of Thailand is around 1850 w/m2, whereas the minimum solar insolation required to generate electricity is 100 -200 W/m2, which is sufficient to run at least one light and one fan. The solar energy technology will be detailed in Chapter 4.

Chapter 3 : National Grid Profile

3.1 Current Grid Energy Mix

Electricity Generation

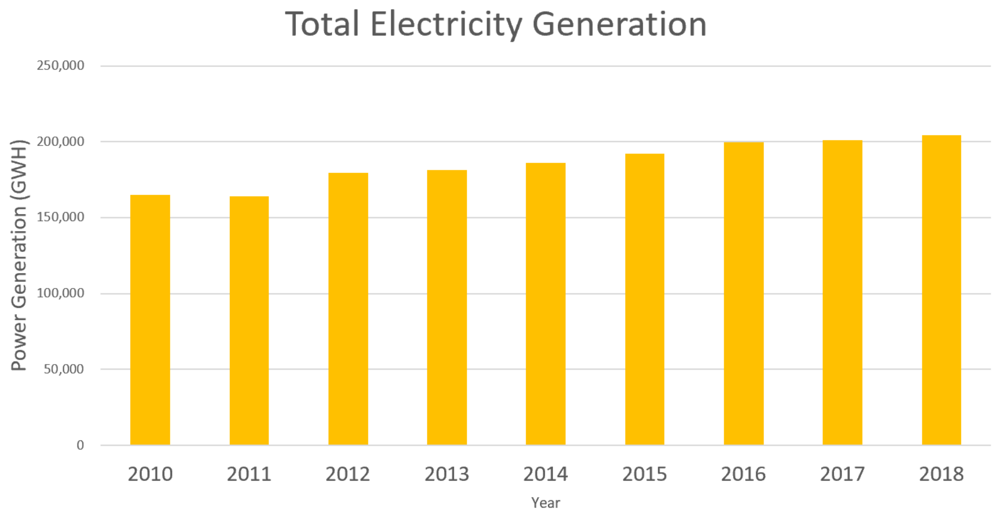


Figure 3.1 : Power generation in GWh (Source: IEA Data Services)

The data in Figure 3.1 expresses that the power generation between 2010 and 2018 rises from 160,000 GWh to 210,000 GWh constantly. The National Grid of Thailand classifies the fuels applied to produce the electric power into two major groups, namely the fossil fuels, and the renewable energy. The details are as follows:

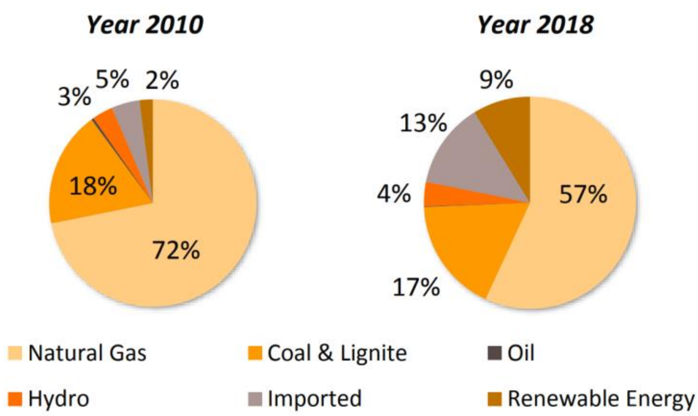


Figure 3.2 : Power generation by Fuels (Source: EPPO)

1) Fossil fuels: Coal/ lignite, natural gas, and crude oil are classified as fossil fuels. In Thailand, the fossil fuels play a primary role in the electricity generation. Approximate 57% of the electricity in the country is produced using natural gas; about 17% of the electricity is generated from coal.

2) Renewable energy: Around 9% of Thailand's electricity is generated from the renewable energy sources, such as bio-mass (from agricultural products), solar, bio-gas (from pig manure), wind, wastewater (from the processing of the agricultural products), crops, waste-to-energy (from the community or the industrial waste), solar, wind, and hydroelectric power. (KRUNGSRI RESEARCH, 2018).

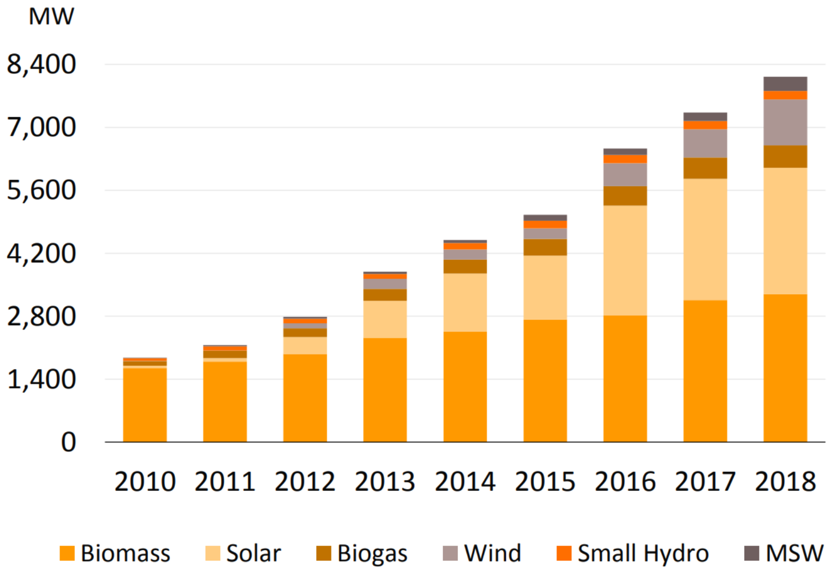


Figure 3.3 : Installed capacity of renewable energy (Source: Department of Alternative Energy Development and Efficiency, Ministry of Energy)

As illustrated in Figure 3.3, in 2018, the energy is with a total of 8,127 MW. Five types of renewable energy are sold out to the grid throughout the year. The year-end statistics of 2017 indicates that the entirety of the installed capacity of the renewable energy increases by 10.8%. The installed capacity of the waste-to-energy and the wind power rise by 66.5% and 62.1%, respectively, which opens a competitive advantage for the country to accelerate the growth of both renewables. The government considers the waste-to-energy as one of the opportunities for solid waste management and the higher capacity of the electricity generation. Most electric power could be generated, and the excess waste problems could be mitigated at the same time. As for the wind farms, the legal issues related to the land ownership have been resolved, making the setting of the wind farms easier. As a result, there is less difficiculty for SPPs to sell and provide the waste-to-energy and the wind farms power to the national grid. The National Grid has established the goal of installing 16,788 MW of renewable capacity by 2036. Presently, the national power system is only 48.5%.

Recently, the sales growth of the solar power supplied to the grid has enlarged significantly. Most of the solar power is generated from the solar farms operated by the government agencies and the agricultural cooperatives, including the rooftop installation. The cost reduction of the purchase and the installation of solar cells has boosted the continual growth in the solar segment since the second half of 2016.

Electricity Consumption

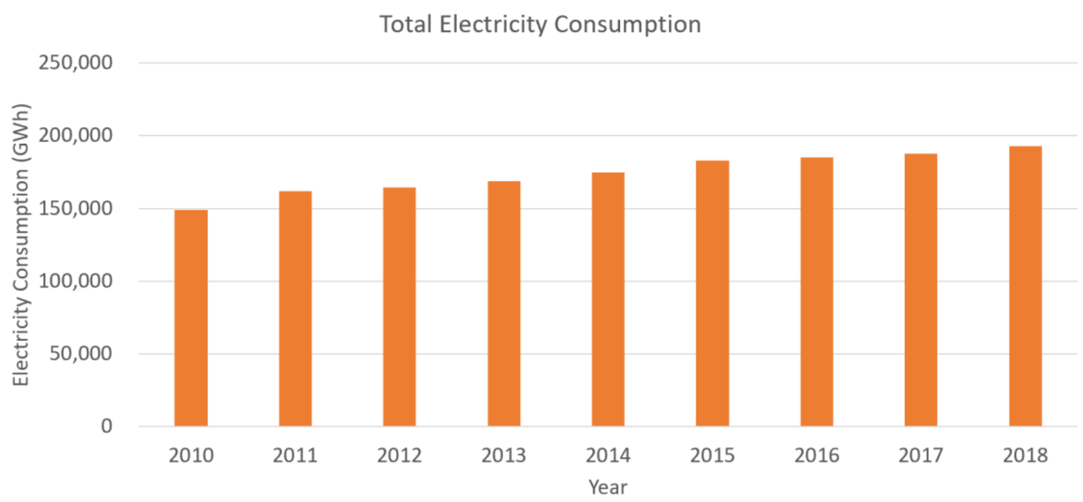


Figure 3.4 : Electricity consumption growth by sector (Source: Department of Alternative Energy Development and Efficiency, Ministry of Energy)

The research prepared by the Department of Alternative Energy Development and Efficiency revealed that the electricity demand in 2018 had increased to 187,832 GWh. The annual demand was 170,300 GWh, which is higher than the demand in 2017. The growth was boosted up by the economic recovery in Thailand. The government put all efforts to enhance energy-savings. As a result, the demand decreased to 28,338 MW in April, which was fairly lower than the highest demand of 29,619 MW in 2016.

3.2 Carbon Content Profile

The electricity generation aims at fulfilling the consumption need. Nonetheless, the process during the electricity generation becomes the main source of global carbon intensity. Figure 3.5 presents the carbon emission from non-renewable energy.

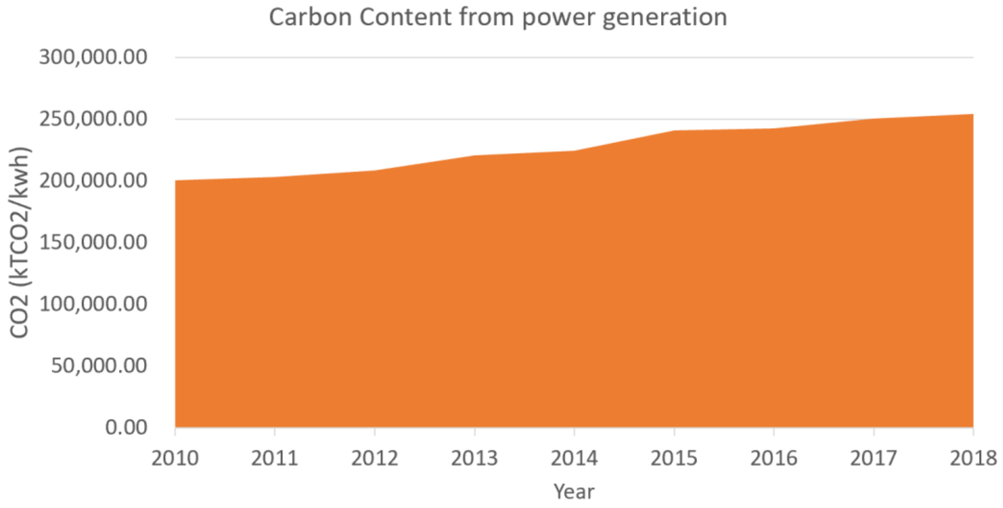


Figure 3.5 : Carbon emission from non-renewable energy (Source: Department of Alternative Energy Development and Efficiency, Ministry of Energy)

According to the Department of Alternative Energy Development and Efficiency, as illustrated in Figure 3.5, the carbon emission between 2010 and 2018 has been enlarged immensely. The carbon emission is emitted during the power generation process via non-renewable energy sources. The carbon emission damages and degrades the environment. It has a critical impact on the large-scale climate change. The smart solution should be defined; otherwise the carbon emission at the grid will be at a high level when there are loads of demand.

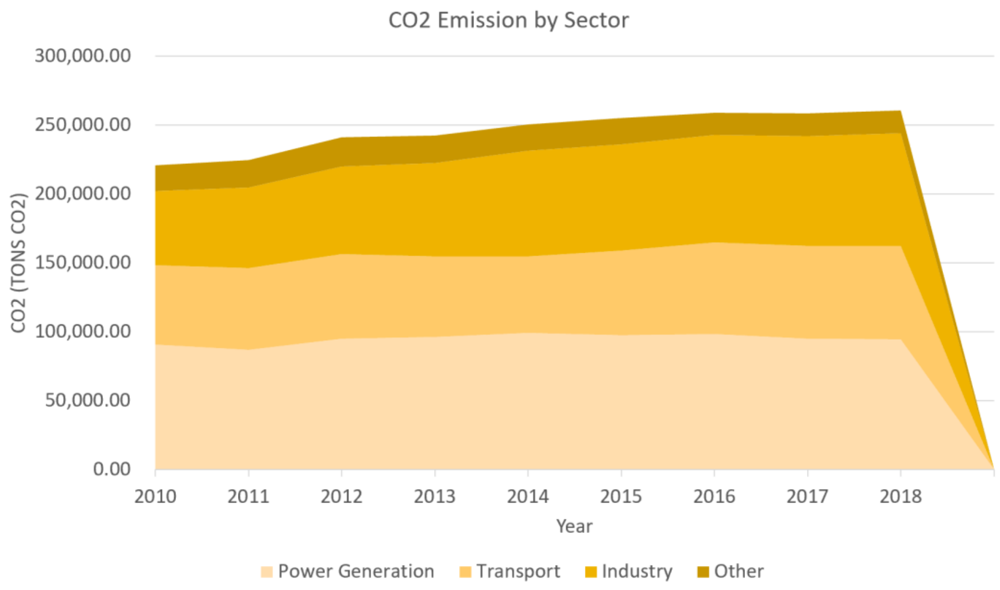


Figure 3.6 : Carbon emission by sector (Department of Alternative Energy Development and Efficiency, Ministry of Energy)

As demonstrated in Figure 3.6, the three major areas that critically release carbon emissions are the power generation, the transport, and the industrial sector,. Putting EVs to use will help diminish the carbon emission caused by the road transport sector. Nonetheless, the EVs transition causes the high electricity demand, increasing in power generation, and unavoidably a high carbon intensity level.

According to the aforementioned problems, the researcher of this study believes that the EVs charging station with off-grid system should be initiated so that the grid will not rise too high. It should be a non-grid connection so that there will be no demand damage to the grid system.

Chapter 4 : Solar Energy Technology

4.1 Solar PV Panel

Szokolay (1996) defined the photoelectric effect as a fundamental process in which the PV cells turn the light sources. The cell's surface is speckled with the overabundance of the electrons (negative), whereas the base of the cell has an electron deficiency (positive). The semi-conductor, which is utilised as an intermediate material, obstructs the movement of the electron between upper and lower layers. When photons collide with the negative electron layer, the electrons will be knocked out of the surface. Then, the electrons move through the metal portion to the lower part and create an electric current. The particles on the layers are obtained by adding the silicon with boron and phosphorous.

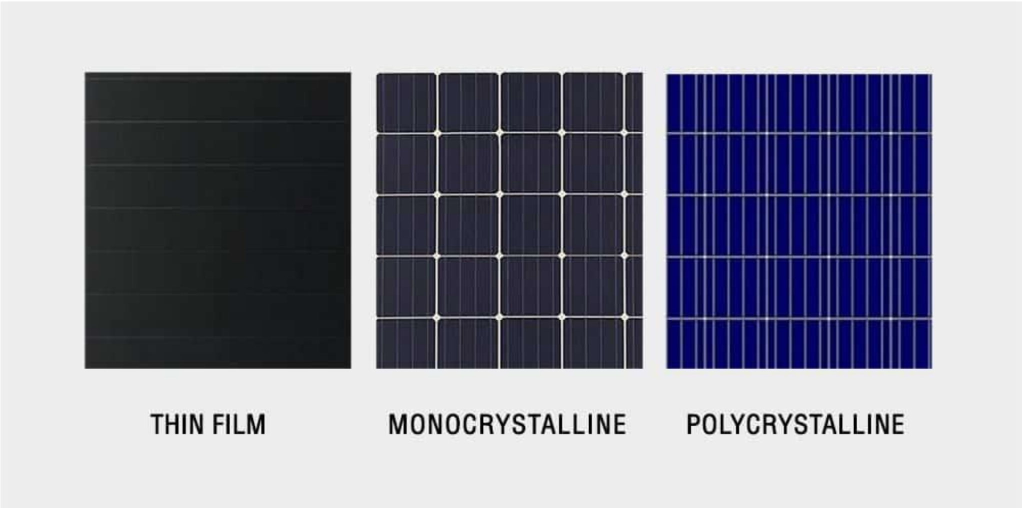


Figure 4.1 : Three main based Silicon PV (Source: Solar Matic)

The silicon-based PVs can be categorised into three major types, namely the monocrystalline, the polycrystalline, and the thin-film.

Cell material	Module efficiency	Surface area needed for 1 Kilowatt peak (kWp)
Mono-Si	14-25%	c.7 m2
Poly-Si	12-16%	c.8 m2
Thin-film	6-11%	c.10 m2

Table 4-1 : Comparison of the PV modules types (Source: The Solar Electricity Handbook, 2017)

The standard test conditions (STC) applied in measuring the module efficiencies of the crystalline silicon and the thin-film PV modules are as follows:

- Cell temperature of 25°C,

- the irradiance of 1000 W/m2

The study aimed at designing the best model that enhances the EV charging stations' renewable energy system with the highest achievable power. For this, the polycrystalline panels are needed in the process as the efficiency and performance remain at the high temperature though the efficiency is not as high as that of the monocrystalline.

The PV modules focus on a particular method to attain the highest power. The solar azimuth angle (φ) and the elevation angle at the solar noon are the two key angles applied for adjusting. A standard mathematics equation is employed to calculate each PV size for each study case, and a HOMERpro software is applied to analyse the performance of the PV design by using the formula and the factors below:

Solar Geometry

The solar geometry involves the relation between the earth and the sun, including the heat obtained, shading, and the prospect of daylight penetration.

Declination (δ)

Declination (δ) is defined as the angular distance of the sun, north (positive) or south (negative) of the equator. Declination refers to a sine function, which is zero at the equinoxes and has an annual cycle range of: $-23.5° < \delta < +23.5°$.

The distance from the March equinox until the end of the year (284 days) is included in the quantity of the days in a year (NDY), so that the yearly variation in declination can be computed, e.g. NDY=1 January the 1st. The quantity of the days in a year (365) should be in line with a full circle (360 degrees), thus the ratio 360/365 is exploited:

$$\delta = 23.45° \sin[\frac{NDY + 284}{365} x\ 360°] \quad (1)$$

Where declination (δ) is measured in degrees.

Local solar time (LST)

The solar and the local clock time (CT) do not have to be corresponded. The solar time (LST) is engaged to determine the position of the sun. A profound understanding regarding the clock's standard setting, the number of the days in a year, and the location are necessary in computing the conversion between the solar time and the clock time (Chun-Sheng, et al., 2008). The conversion between LST and CT (in 24- hour) is shown below (using this formula, the format of the time is to be translated from decimal to 24h):

$$LST = CT + E_t + \frac{L_{std} + L_{loc}}{15} - DT \quad (2)$$

Where:

LST = Local Solar Time (h)

CT = Clock Time (h)

Lstd = Standard Meridian for the local time zone (degrees)

Lloc = Longitude of actual location (degrees)

Et = Equation of Time (h)

DT = Daylight Savings Time correction (DT = 0 if not on Daylight Savings Time, or else DT equals the number of hours that the time is advanced for the Daylight Savings Time)

Each degree difference in longitude amounts to 1/15 hour (4 minutes) of time.

Equation of Time (Et)

The Equation of Time (Et) is the difference in hours between the mean time and the solar time. The calculation is as follows:

$$E_t = 0.165 \sin(2B) - 0.126 \cos(B) - 0.025 \sin(B) \quad (3)$$

Where:

$$B = \frac{360\,(NDY - 81)}{365} \quad (4)$$

If the sundial time is ahead of the clock time, it can be implied by the positive value of the equation. In case that the clock time is ahead of the sundial time, it can be explained by the negative value of the equation.

Hour angle (h)

The hour angle (h) defines the time of the day regarding the solar noon. Every hour, the hour angle will vary by 15 degrees. At the solar noon, the hour angle is zero. Before the solar noon, the hour angle is negative. The following equation is applied to compute the solar hour angle.

$$h = 15 * (LST - 12) \quad (5)$$

Derived Solar angles

Apart from the latitude, the hour angle, and the sun's declination which comprises the three based angles: the azimuth angle (φ), the sun's zenith angle (θH), and the elevation angle (β), are essential for calculating the solar radiation. The surface-solar azimuth angle (γ) and the sun's incidence angle (θ) is to be determined in order for a specific surface orientation.

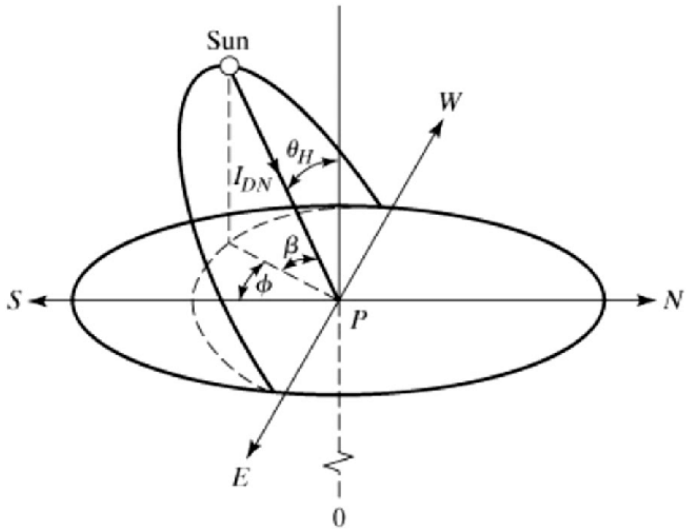


Figure 4.2 : Explanation of the Sun's zenith, the Altitude and the Azimuth angles (Source: Kuehn & Ramsey, 2009)

The following equations are used for calculation:

$$\cos\theta_H = \cos(L)\cos(h)\cos(\delta) + \sin(L)sin(\delta) \quad (6)$$

Since

$$\beta = 90 - \theta_H \quad (7)$$

$$\sin\beta = \cos\theta_H = \cos(L)\cos(h)\cos(\delta) + \sin(L)sin(\delta) \quad (8)$$

The sun's azimuth (φ) in degrees can be calculated as follows:

$$\cos\varphi = \frac{1}{\cos\beta}\left(\cos(\delta)\sin(L)\cos(h) - sin(\delta)\cos(L)\right) \quad (9)$$

To compute the non-horizontal surfaces, the position of the sun regarding the incidence angle (θ) has to be identified. The sun's angle between the solar rays and the surface normal is determined as the solar angle of incidence.

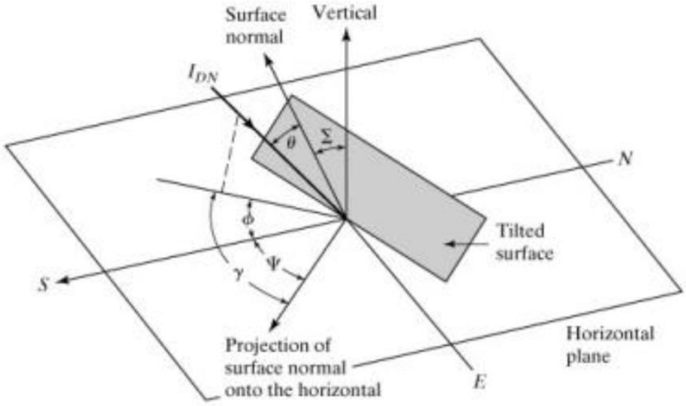


Figure 4.3 : The Relation of the Sun's Rays to a tilted Surface (Source: Kuehn & Ramsey, 2009)

To assess the angle of the incidence, the direction of the surface normal is to be determined. This is conducted with respect to the surface tilt angle (Σ) and the azimuth angle of the panel (Ψ). The surface-solar azimuth angle (γ) is the angle between the surface normal's horizontal projection and the solar rays' horizontal projection. The equation used to calculate is:

$$\gamma = \varphi - \psi \qquad (10)$$

Where:

φ = the Sun's azimuth (degrees)

ψ = azimuth angle of the panel (degrees)

The following test is performed to define whether the azimuth angle of the sun is greater or less than 90◦ away from the south. If:

$$\cos h \geq \frac{\tan \delta}{\tan L} \qquad (11)$$

Then $|\varphi| \leq 90°$; otherwise $|\varphi| > 90°$ (Masters, 2004)

As for the tilted surface, the sun incidence angle (θ) can be calculated by

$$\cos\theta = \cos\beta \cos\gamma \sin\Sigma + \sin\beta \cos\Sigma \qquad (12)$$

Where Σ = 90° if surface is vertical and Σ = 0°

Solar radiation striking an inclined surface

The three components of the total solar radiation incident on an inclined surface (Iβ) comprise direct radiation (Idβ), ground-reflected radiation (Ir), and diffuse radiation (Ibβ)

$$I_\beta = I_{d\beta} + I_{s\beta} + I_r \qquad (13)$$

Diffuse radiation (Isβ)

The isotropic model and the anisotropic model are the two models of the diffuse solar radiation which are usually applied for the inclined surfaces. The diffuse radiation, according to the isotropic model, is spread consistently over the sky dome. The anisotropy of the diffuse radiation, as specified by the anisotropic model, is the circumsolar region, caused by the forward diffusing of the solar radiation. Klucher's Anisotropic Model (Klucher, 1978) has been employed to calculate the diffuse radiation states as follows:

$$I_{s\beta} = I_{fh}\left[\frac{1}{2}\left(1+\cos\left(\frac{\Sigma}{2}\right)\right)\right]\left[1+\left(1-\left(\frac{I_{fh}}{I_{gh}}\right)^2\right)\sin^3\left(\frac{\Sigma}{2}\right)\right]\left[1 + \left(1-\left(\frac{I_{fh}}{I_{gh}}\right)^2\right)\cos^2\theta\sin^3(90-\beta)\right] \qquad (14)$$

Where:

Ifh = hourly diffuse horizontal solar radiation

Igh = hourly global horizontal solar radiation

When the sky is completely overcast, $If/Ig = 1$ and the expression reduces to the isotropic sky case.

The hourly global diffuse solar radiation is measured with a pyranometer and the hourly global horizontal solar radiation by:

$$I_{gh} = I_{dh} + I_{fh} \qquad (15)$$

Where:

Id = the direct horizontal irradiance; calculated by:

$$I_{dh} = I_{dn} \sin \beta \qquad (16)$$

Where:

Idn= the direct normal irradiance; measured by a pyrheliometer.

Direct radiation (Idβ)

The direct irradiance is determined by:

$$I_{d\beta} = I_{dn} \cos \theta \qquad (17)$$

Where:

Idn = the solar direct normal radiation

Ground-reflected radiation (Ir)

Ground-reflected radiation refers to the solar radiation which is reflected from the surface of the earth, including other intercepting objects. The equation below is used for calculating the reflected solar flux striking a surface (Ir), in the event that the ground is horizontal and the reflection is diffuse.

Where:

ρg = the ground reflectivity

4.2 Battery Storage for PV

Battery refers to an appliance comprising one or more electrochemical cells. The battery transforms the chemical energy contained within its energetic materials into electrical energy, through an electrochemical procedure. Nowadays, there are three kinds of photovoltaic batteries: lead-acid batteries, gel batteries, and absorbed glass mat (AGM).

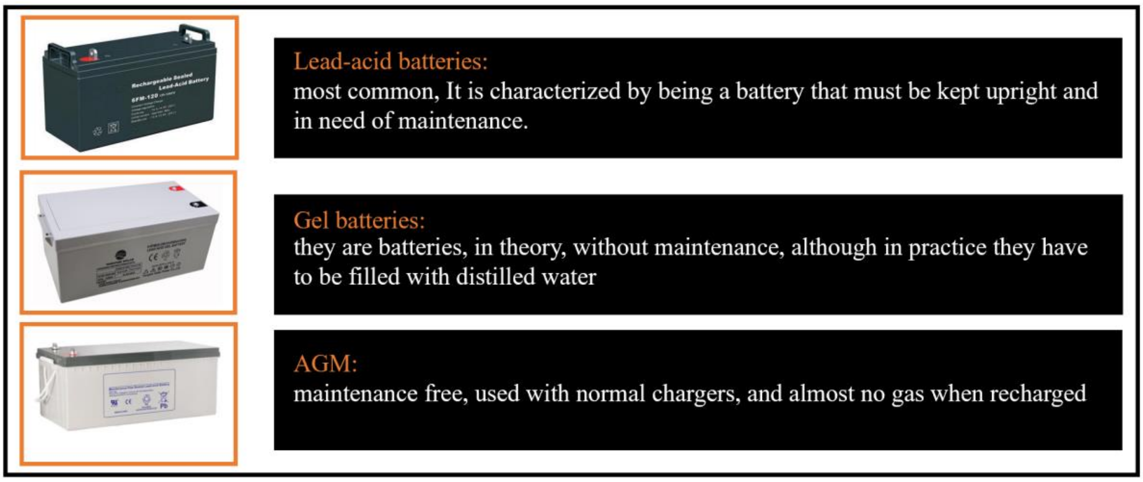


Figure 4.4 : Solar Battery (Source: Energysage.com)

The following features are considered in characterising the battery:

1. The volume of the energy that a battery can maintain (Wh).

2. The highest current that a battery can supply (discharge).

3. The depth of discharge (DOD) that a battery can perform (%).

In addition, the other features, e.g. capacity, life cycles, and self-discharge should be considered. It is important to select the right battery. The comparison of the three types of the batteries is demonstrated in Table 2-2, as shown below.

	Lead-acid	Gel	AGM
Depth of discharge (%)	55-60	80-90	80-90
Energy density (Wh/kg)	50-60	40-60	40
Self-discharge (%/month)	3	< 2	< 2
Life Cycles	1500-2000	1500-3000	1500-2000
Life (years)	3 - 8	5 - 15	7 - 12

Table 4-2 : Comparison of the three types of batteries (Source: Viana, 2015)

Considering the range of life cycles, it is clear that the gel battery is the right option.

To compute a number of the batteries needed for installation, the total nominal capacity, Cn (A) required by the batteries is calculated using the following formula.

$$C_n = \frac{E_r * N}{DOD + V_{bat}} \tag{19}$$

Where:

Er = the energy consumed by the installation (kWh)

N = the number of autonomy of installation (days)

DOD = depth of discharge (%)

$Vbat$ = voltage of the selected battery (V)

Once the total nominal capacity is functioned, the number of batteries required can be calculated as follows:

$$N_{bat} = \frac{C_n}{C_{bat}} \tag{20}$$

Though the lead acid, the Gel, and the AGM batteries are usually used for the installing of the battery storage system of the solar farm, nowadays a Li-on battery that is cheaper with higher efficiency is more well-known. According to the California Public Utilities Commission (2016) the renewable energy technology that Tesla applies in the battery storage system has played a significant role in the electric vehicle batteries. The commission presented a study concerning the potential comparison between a number of small batteries and one battery container, which is called Tesla's New Battery Storage Farm in California. The outcome has shown that one power pack battery container contains energy capacity circa 232 kWh, 430V 3phase. The study has revealed that the efficiency of the Tesla's power pack's energy storage is 92%, which is considerably higher than the lead-acid batteries around 85%.

As a result, the most suitable battery storage for the solar farm is the power pack battery container. Its efficiency is higher. The battery container provides more power than the packs of several small batteries. Therefore, the researcher considered and applied the Li-on inside the Tesla power pack battery in this study.

4.3 Solar Energy System

The Clean Energy Company (2020) categorises three main types of the installation of the solar power systems as follows:

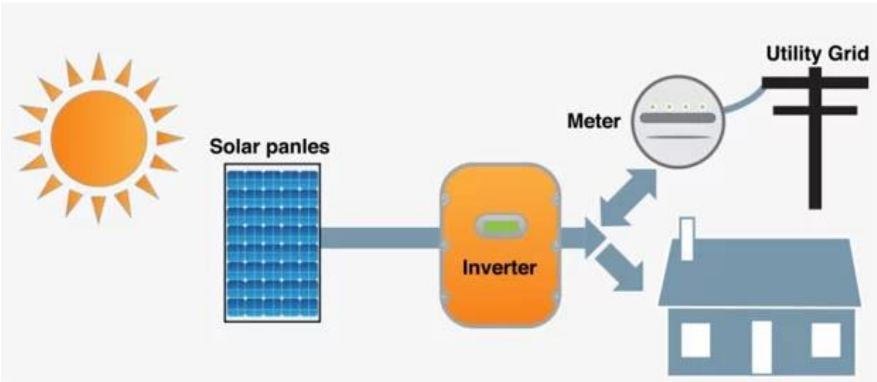


Figure 4.5 : Solar On-Grid System (Source: Silicon Solar.com)

On-Grid System

The on-grid system is extensively consumed by the governmental sector, the private business, and the residences. The common solar inverters are connected to the public electricity grid. It can operate without batteries. For safety reasons, the system will stop supplying electricity automatically when there is a power outage, otherwise; it will be dangerous for the staff working in the network, as the outage often occurs when the electricity grid is damaged.

Electricity delivered to the grid from the customer's solar system can be consumed by the on-grid system's clients. When the solar-farm system is over consumed and stops operating, users can import and consume electricity from the grid.

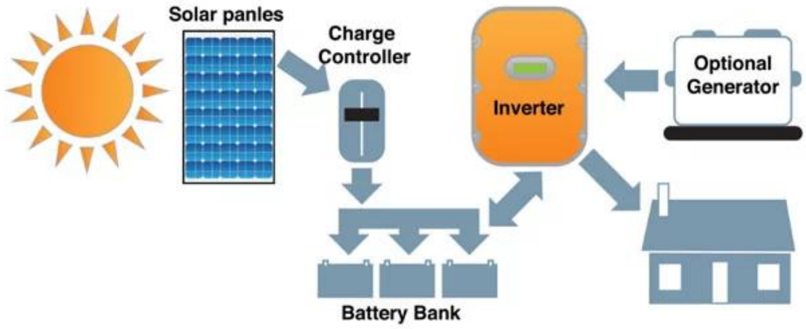


Figure 4.6 : Solar Off-Grid System (Source: Silicon Solar.com)

Off-Grid System

The off-grid system is referred to as a stand-alone power system (SAPS). It requires battery storage as it is not attached to the electricity grid. To ensure that the battery capacity meets the household electricity demand, the off-grid solar systems has to be designed correctly, particularly during the coldest part of winter when there is the least amount of sunlight. In the past, the cost of the batteries and the off-grid inverters was much higher than those of the on-grid system. Therefore, the off-grid was previously installed only in the remote areas where there was no electricity supplied by the grid system. Nowadays, battery price is much cheaper. The market growth of the off-grid solar battery systems has been growing and extending into the cities.

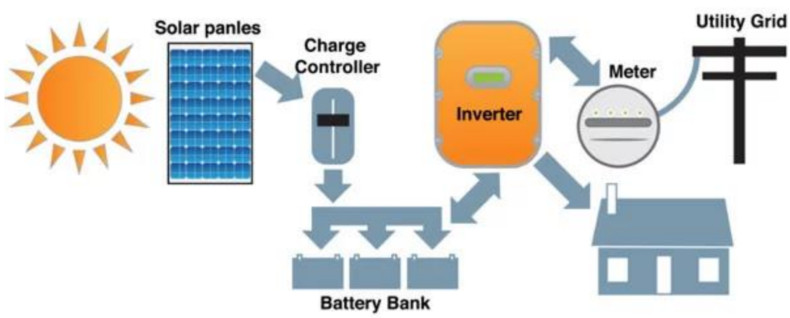


Figure 4.7 : Solar Hybrid System (Source: Silicon Solar.com)

Hybrid System (On/Off Grid)

The modern hybrid systems combine solar energy and battery storage with the grid connection. Currently, the systems offer various features and configurations. In addition, the systems that have already been attached to the electricity grid can be operated using the battery storage. The solar energy will be stored in daytime, so that clients can use it in the nighttime. In the hybrid system, if the saved energy is used up, consumers can charge batteries using the low-cost electricity, usually from midnight till six o'clock in the morning.

4.4 Solar Irradiation in Thailand

As described earlier in Chapter 2, Thailand has a good chance to make the most of the renewable energy, especially the solar energy. According to the World Bank Group's solar factor map, the daily solar-radiation in Thailand is 18-20 MJ/m2 on average (equivalent to circa 5.278-5.556 kWh/m2/day). Most of the high solar-irradiation is available in the northeastern region and along the seaside of the southern part.

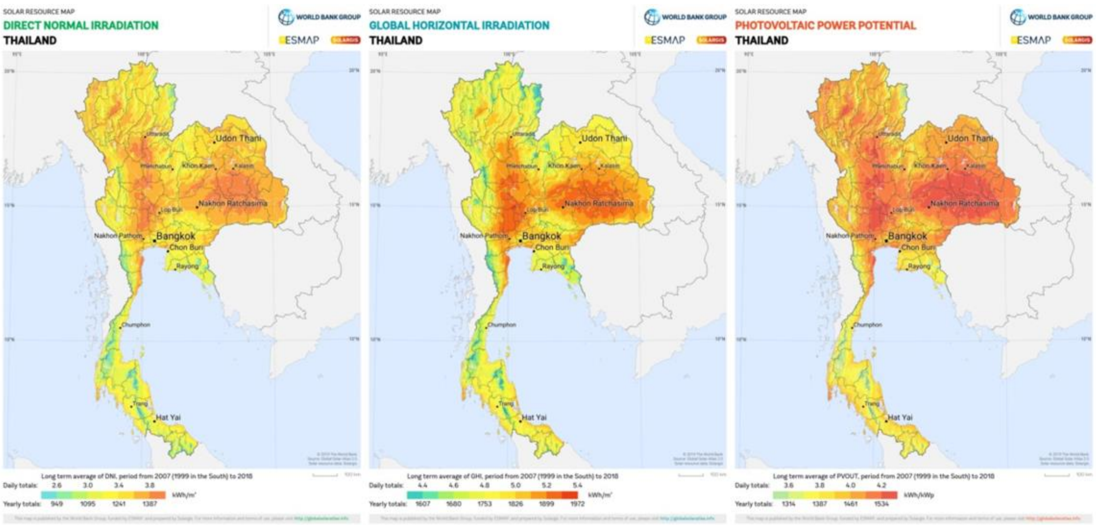


Figure 4.8 : Solar Factor Map of Thailand (Source: World Bank Group)

Though the highest level of the solar irradiation level (kW/m2), as shown in Figure 4.8, is mostly found in the North East of Thailand, the researcher has selected the Megabangna Shopping Centre as the geographical location of the case study because it is one of the biggest shopping centres in Southeast Asia. It is situated in Samut Prakan province, which is the most important industrial city in the central part. Samut Prakan province is on the outskirts of Bangkok, the capital of Thailand. Almost the entire EVs assembly factory is in this zone. Additionally, the number of the EVs used in Samut Prakan province is higher than in other provinces. Regularly, the high level of solar radiation is obtainable. The average solar radiation lasts approximately 5 hours per day, as show in Figure 4.9.

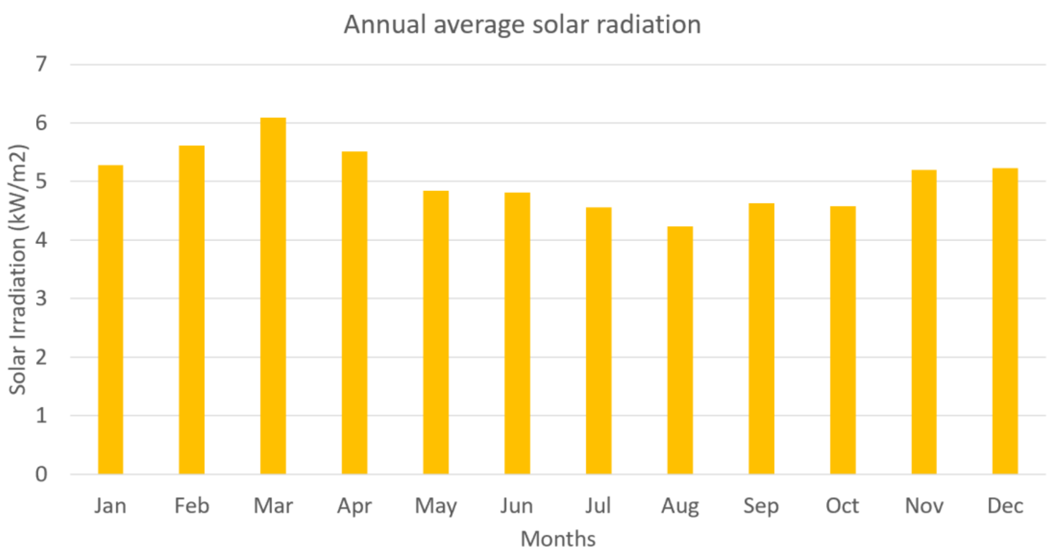


Figure 4.9 : An average of the yearly Solar Radiation per hour per day in Bangkok, Samut Prakan, and in the Suburbs (Source: National Renewable Energy Laboratory, 2015)

As depicted in Figure 4.9, the irradiation in winter is 5.3 kW/m2. It increases higher than 6 kW/m2 in summer. In the rainy season, the irradiation is 4.5 kW/m2.

4.5 Software Review

There is a variety of software that can be applied to perform simulations concerning the electricity generation using renewable energy, i.e. ESP-r, Merit, Energy-PLAN, RETScreen, and HOMER. The performance of the software has been reviewed to define the most suitable one for this study.

ESP-r simulation program has been developed in 1974 by the University of Strathclyde, UK. The simulation program works in both realistic and actual physical manners focusing on the integrated modelling of the entire building energy and environmental performance. It can perform a range of simulation activities (Morton, Grant, and Kim, 2014).

MERIT software has been developed by the University of Strathclyde, UK. It is a software program used for renewable energy systems. The program is applied to determine the relations of all data related to and affected by the climate data, e.g. the battery storage, the wind-speed, the renewable-supply, and the direct-solar. It's outstanding feature is a dynamic demand and supply matching-design of the electricity and the thermal.

Energy-PLAN is a software program designed by the Sustainable Energy Planning Research Group at Aalborg University, Denmark. It is developed to simulate the overall performance of the national energy systems, which include electricity, heating, cooling, industry, and transport. The simulation is on an hourly basis. The program is advantageous for the strategic decision-making on a national level (Ostergaard, 2015).

RETScreen is a free, comprehensive software platform, supported by the government of Canada. It is known as clean energy management software assisting in analysing the feasibility and performance of the potential energy and renewable energy efficiency (RETScreen, 2015).

HOMER software application has been initiated by the National Renewable Energy Laboratory in the USA. This application helps simplify the designing. It facilitates in assessing the alternatives for the off-grid and on-grid power systems for optimizing the technical and financial aspects of the distributed generation (DG) application. HOMER's optimisation and sensitivity enable the users to evaluate the feasibility of numerous technology alternatives to prepare for the variations in technology costs, energy resource availability, and other factors.

Simulation: One of the major outstanding points of HOMER is its simulation model. It will keep simulating the practical systems for the assortments of the equipment that the researchers intend to perform. HOMER may simulate enormous systems subjecting to the method and criteria of the problems that the researchers determined.

Optimisation: Optimisation algorithm of HOMER is exclusively designed. It is the next step after all simulations. To finalise the best possible solution, every viable grouping of the system types will be analysed, sorted, and filtered based on the defined criteria. Basically, HOMER is an economic optimisation model, but it can also be applied in minimising the use of fuels.

Analysis of the Sensitivity: The sensitivity analysis is not obligatory. It enables the users to spot the impact of the uncontrolled factors, e.g. the wind-speed and the fuel-ate. It guides the users to comprehend the finer changes by these factors.

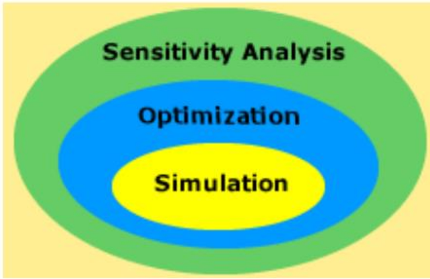


Figure 4.10 : The HOMER Software

To work with the HOMER software, it is necessary to have an insightful understanding about its three core competencies: the simulation, the optimization, and the sensitivity analysis. It is also important to comprehend how the three core competencies interact (Homer Energy, 2015).

Figure 4.11 : The feature of HOMER Software

As a result, HOMER is considered the most suitable simulation software that meets the project objective. The software facilitates designing a simulation model for the combination of the renewable energy demand and supply required for the EV's battery charge. Figure 4.12 illustrated the software process.

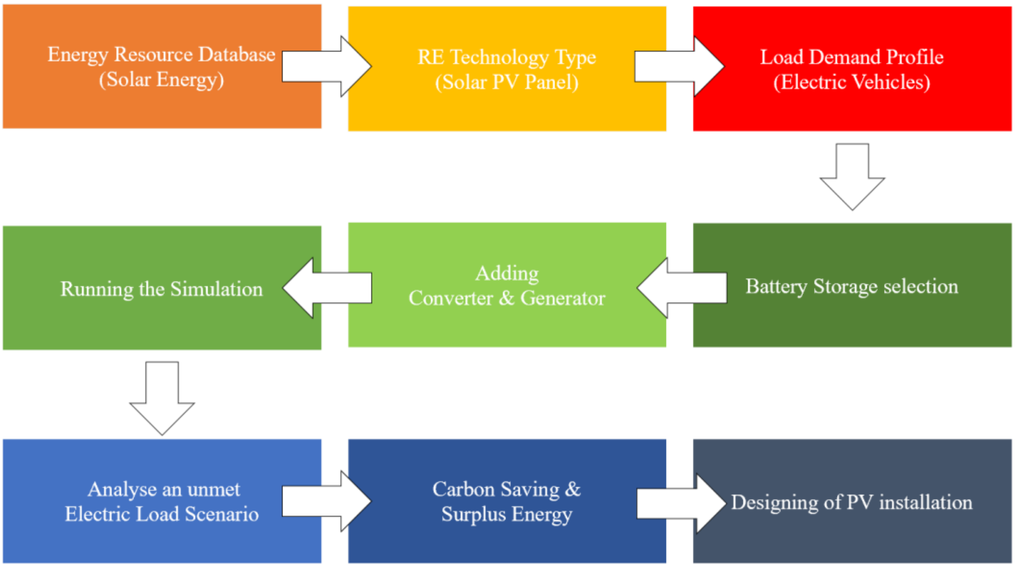


Figure 4.12 : The process of HOMER Software

As demonstrated in Figure 4.12, the process starts with the analysis of the energy resources database, which includes the intensity of sunlight, the temperatures, the climate, and the seasonal thermal energy supply. The analysis targets to place the system at the most appropriate location and design the productive solar system model. In this study, the Megabangna Shopping Centre has been chosen as a site location. After that, input data will be defined, analysed, and processed through the simulation program. The data comprise EVs demand profiles of each case (S, M, L, XL, and mixed), a PV panel, a converter, a grid represented by the generator (for comparing the system), and battery storage. The simulation results will display the surplus electricity or the unmet load, which is the major aim of the simulation in this study. The values obtained from the simulation and the processing process (solar Off-Grid system) will be analysed and compared with the values attained from the national grid connecting system (non-renewable). The carbon saving and the grid system are the two main subjects for consideration and comparison. The comparison aims at analysing the difference among the consumed amount of the electricity, the amount of the emitted carbon, and the surplus energy. Whether or not the excess energy can be supplied to and made use of by the shopping centre should be considered. Finally, the best productive design of the PV installation is determined. The in-depth technical analysis has been described in Chapter 6.

Chapter 5 : Site Location

5.1 Site Location of the Parking

This chapter comprises two main sections: the site location and the statistics of the EV charging behaviour. The site location depicts the details about the area, the electricity profile, and the customer behaviour. The statistics of the EV charging-behaviour express the potential of solar radiation in the area and technical analysis.

The Megabangna Shopping Centre has been deployed as a site location in this project because of its large parking area. In Thailand, most shopping centres are established with the one-stop concept where the clients spend their time shopping and performing all kinds of activities, i.e. eating, watching movies, exercising in the fitness, visiting the beauty salon, and attending the tutorial schools, etc. Customers will enjoy themselves rather than just shop and buy products. The shopping centres nowadays become the centres for meeting and social communities.

Figure 5.1 : View of the Megabangna Shopping Centre (Source: Matichon News)

The Electric Energy Consumption

Figure 5.2 demonstrates statistics of the electric energy consumption of the Megabangna Shopping Centre. The high demand for electricity-energy is found in summer (April to May).

The electricity peak demand reaches 8 MW in May. In the rainy season (June-September), the radiation slightly decreases to 6.8 MW. In winter (October-Decembr), the graph goes down with a lower consumption of 5.9 MW. The total annual electricity consumption is 87.8 MW, or equivalent to 24,853.546 kg CO2. The amount of annual electricity consumption can be compared to the consumption that 29,641 EVs consume. This suggests that the majority of the maximum 10MWp PV generation will be absorbed by the shopping centre if there are no vehicles charging and a smaller proportion would be exported. The calculation formula is as follows:

Energy Consumption Tesla Model 3 23.7kW/160miles 6.7km per 1kWh	If 1-year drive 20,000km	→	Consume 2,962 kWh
	Mega Bangna 87.8 MWh	=	No. of EV 87.8M / 2,962 = 29,641 cars

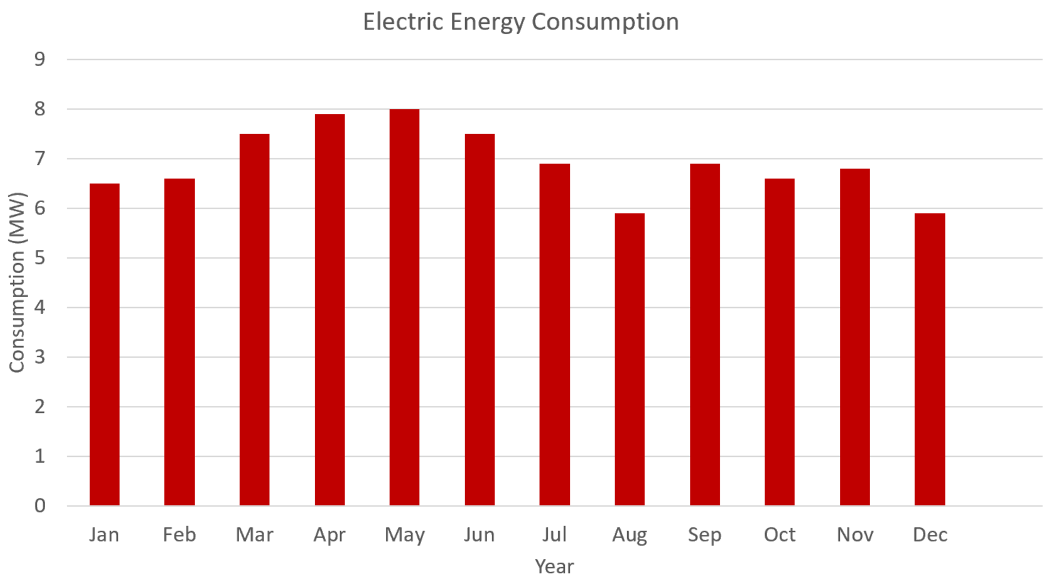


Figure 5.2 : Electric Energy Consumption (Source: The Megabangna Shopping Centre)

The Parking Space's Profile

The Megabangna Shopping Centre has been employed as a location to perform a case study. It located in Samut Prakan province, which is the most important industrial province in the central part. It is legally a separate entity to Bangkok; the capital of Thailand, but for Thai people, it is considered a suburb of Bangkok. Almost all of the EV assembly factories are in this zone. Additionally, the number of the EVs in Samut Prakan province is relatively higher than in other provinces. The shopping centre is very close to Suvarnabhumi International Airport located in the same province. It is one of the greatest shopping complexes in Southeast Asia, covering a total area of 400,000 square metres, with a car park capacity for 12,000 cars. Figure 5.3 depicts the number of the cars/week. Figure 5.4 presents the arrival and the departure time of customers.

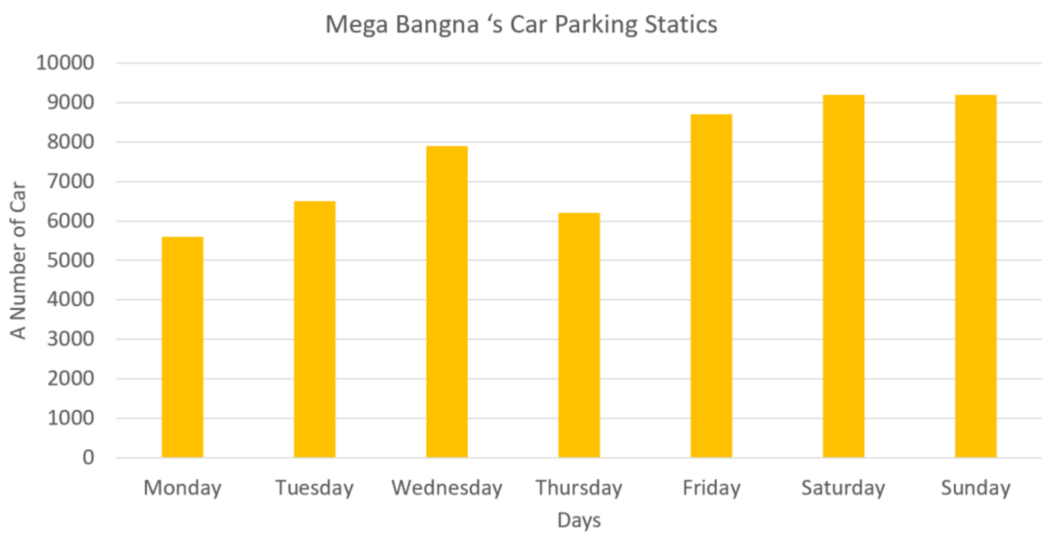


Figure 5.3 : A car parking statics of customer (Source: Megabangna Shopping Centre)

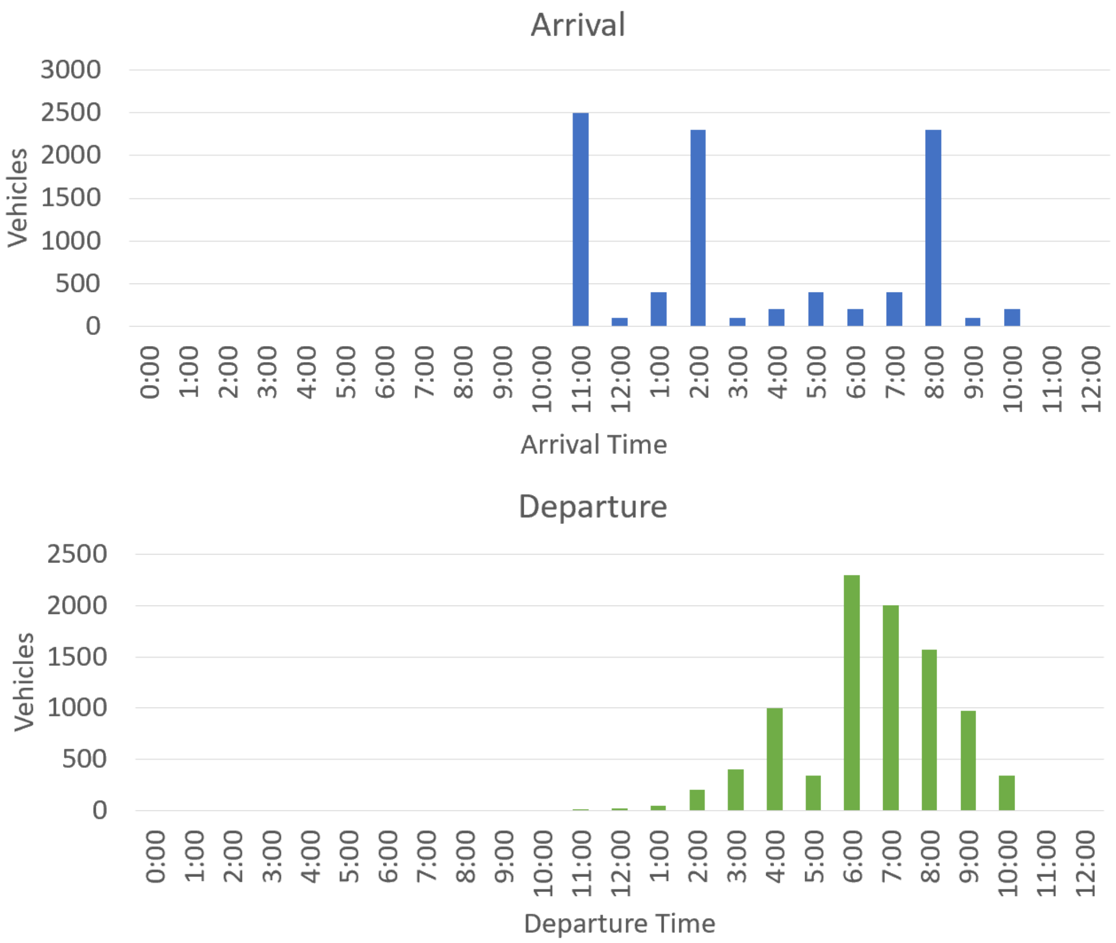


Figure 5.4 : A Car Park's Arrival and Departure Time (Source: Megabangna Shopping Centre)

Figure 5.3 and 5.4 point out that most of the customers visit the shopping centre at 11.00 a.m., which is one hour after the opening time. Many of them come at 2.00 p.m. Some clients come at 8.00 p.m. Most of the clients leave between 6.00 p.m.- 8.00 p.m.

Charging Station Service

As earlier mentioned in Chapter 1, the statistics from the Electric Vehicles Association of Thailand exposes that there is a total of 520 public EV charging locations and 793 outlets in Thailand, e.g. EA, PEA, EGAT, PTT, EA Anywhere, Charge Now, EQ, CP, Delta, etc. The charging price depends on the charging level and the charging power, as shown in Table 5-1 (based on the exchange rate as of 2019 from the National Bank of Thailand; approximately 40 THB. (Thai Bath) = 1 GBP (British pound sterling)

	AC (43kW)	DC (43kW)	DC (50kW)	DC (150kW)
Price Per Unit	0.0175 £	0.0225 £	0.02375 £	0.06575 £

Table 5-1 : Charging Price

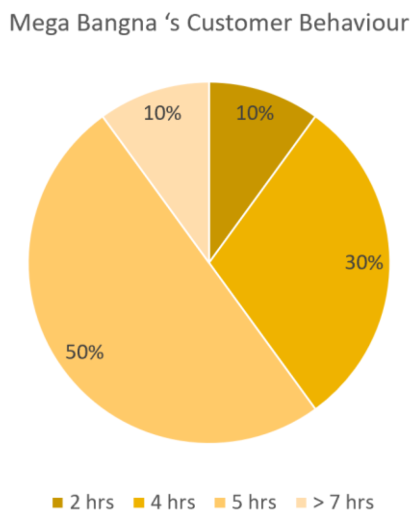


Figure 5.5 : Customer Behaviour in Department Store (Source: The Megabangna Department Store)

According to the customer behaviour-statistical data conducted by the Megabangna Shopping Centre, as shown in Figure 5.5, the average hours per day that customers spend at the shopping centre are as follows:

- 50% of the customers spend 5 hours in the shopping centre,
- 30% spend 4 hours,
- 10% spend 2 hours,
- the rest 10% are in the shopping centre for more than 7 hours.

If there are the EV solar charging stations in the shopping centre’ parking space, clients can use time wisely and enjoy a variety of pleasant activities.

According to the statistical data in figure 5.6 conducted by the Megabangna Shopping Centre with regards to the customer behaviour and the charging time, the data depict as follows:

- 61.30% of the clients charge their batteries 60-100%,
- 17% of them charge 40-60%,
- 16% of them charge 20-40%,
- the rest 6% charge their batteries only 0-20%.

Pertaining to the behaviour in charging speed and charging power, the statistics as shown in Figure 5.6 are as follows:

- 55% of the clients charge their batteries with rapid charging 100kW (0.3-0.6 hrs.).
- 34% prefer fast charging 75kW (1-2 hrs.)
- only 11% charge with the slow charging 25kW (6-12 hrs.)

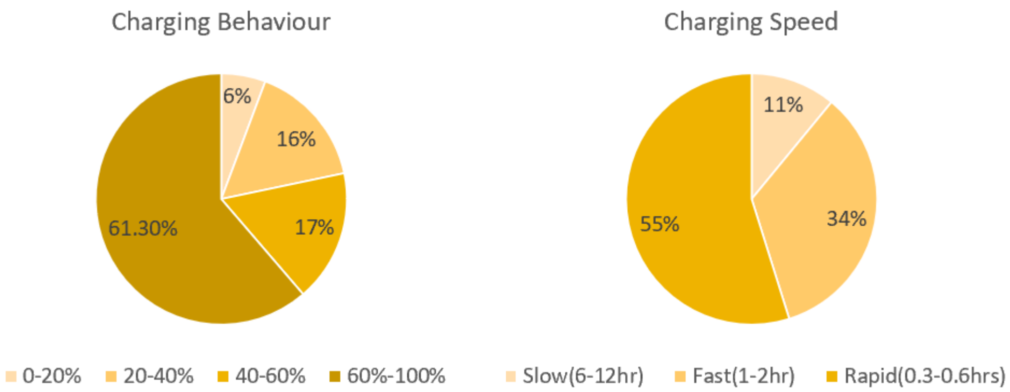


Figure 5.6 : The Charging Behaviour & Charging Time (Source: The Megabangna Shopping Centre)

The size of the EVs is associated with the battery size. A result of the research performed by the Electric Vehicle Association of Thailand (EVAT), as shown in Figure 5.7, reveals that 38% of the EVs are size S, 34% are size M, 24% are size L, and only 4% are size XL. Parking space is one of the principal factors that influences the user’s decision-making in choosing the size of electric cars.

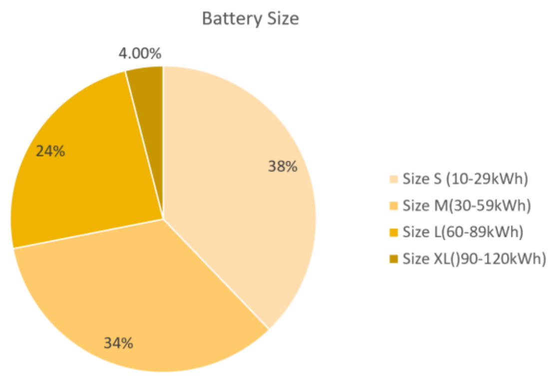


Figure 5.7 : The EVs' Battery-Size (Source: EVAT)

Chapter 6 : Technical Analysis

For environmental sustainability, the government and the private sectors in Thailand put every attempt available to replace the fossil fuels by making the most of the enormous renewable resources in the country. One of the smartest solutions is the EVs charging stations using renewable energy resources. The working steps can be outlined as follows:

- Clients park and charge EVs in the parking of the shopping centre.
- The charging process takes at least 0.3-2 hours until the cars are fully charged. The range of the charging time is subject to the EV model and the charging mode.
- While having an electric car charged, clients can enjoy a variety of pleasant activities in the shopping centre: eating, watching movies, exercising in the fitness, visiting the beauty salon, attending the tutorial schools, etc.
- An automatic intelligence device is equipped with the customers' smart phones or the department stores' system. The device will notify the cars' owners when their EVs are fully charged.
- If the car owners are not convenient to move their cars, valet parking service is available.

Technical analysis was undertaken to ensure adequate power supply for the charging stations in the parking space. The technical analysis in this study dealt with the simulation analysis concerning the different cases of the demand data classified according to different battery-sizes and the scenario of the solar PV technology.

Figure 6.1 : Solar Car Park Medel (Source: www.infiniteenergy.com)

In this study, an EV battery pack was equipped to the charging station. The battery was charged throughout the day via solar energy (renewable resources). The demand prediction was analysed. The optimised solar farm parking space has been designed to define the suitable amount and efficiency of the PV panels needed for installation in the limited area, which can achieve the maximum power saving and the carbon reduction.

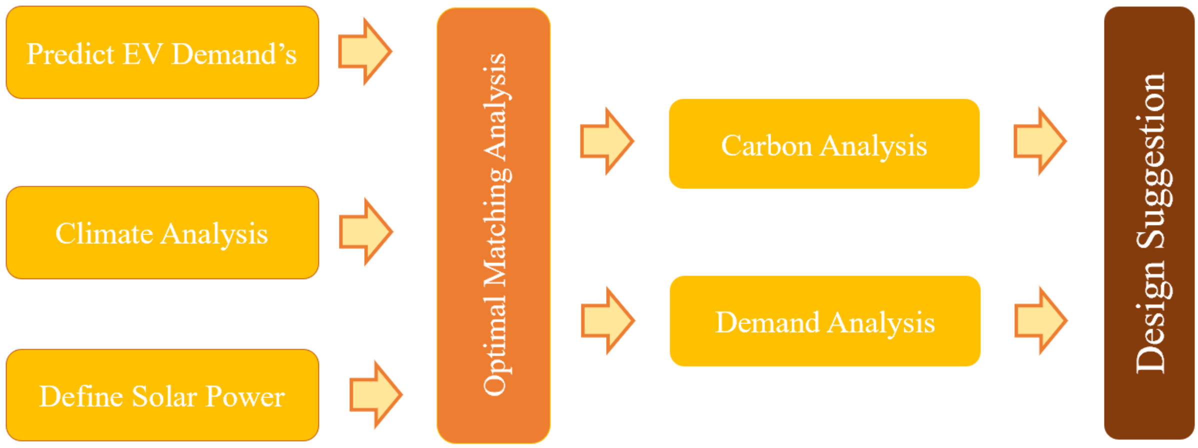


Figure 6.2 : Procedure of designing the optimised Solar Farm Parking

6.1 Input data

The simulation process's input data comprised two main factors: the EVs demand profile and the PV profile.

6.1.1 EV Demand Profile

Thailand registrations of EV model specifications, together with the battery's capacity are demonstrated in Figure 6.3 (The Land Transport Department). The battery sizes classify the model.

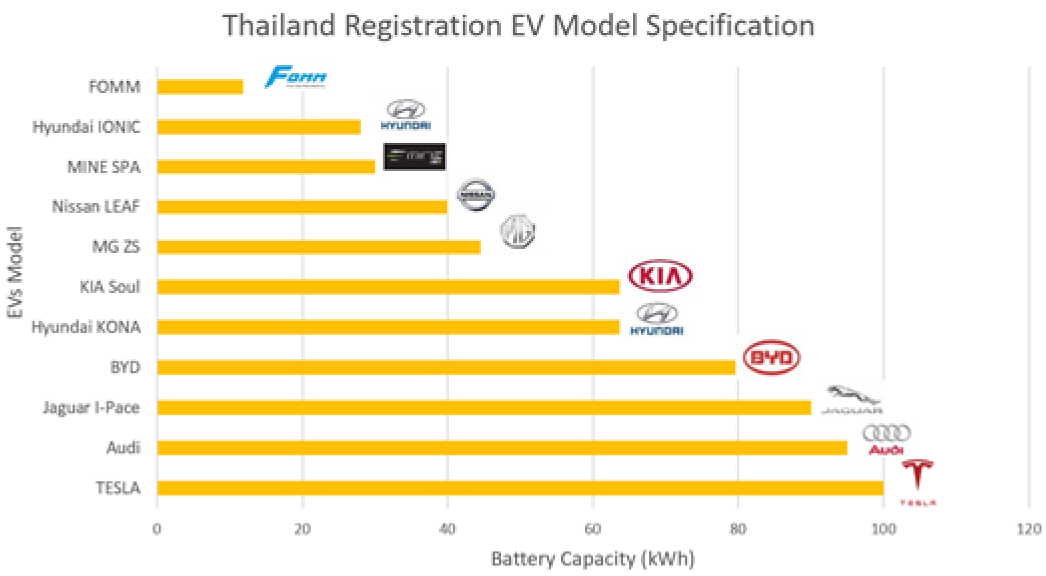
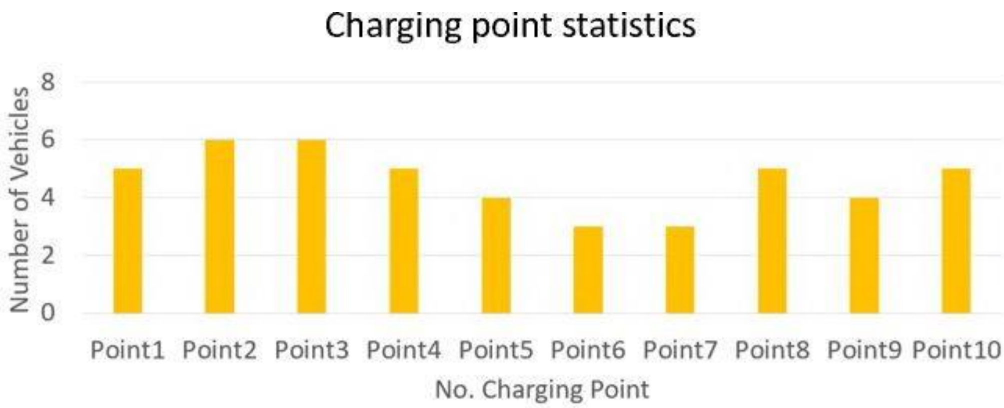
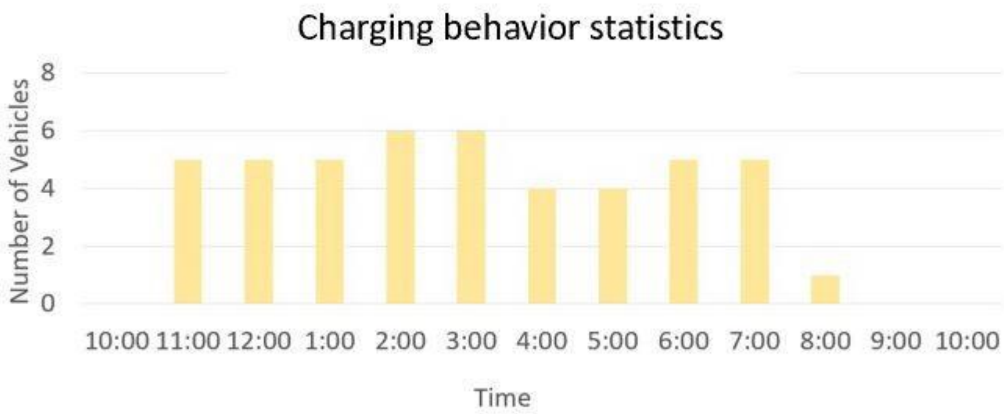


Figure 6.3 : Thailand Registration of EV Model Specification (Source: Land Transport Department)

Figure 6.3 indicates that the battery of the FOMM ONE contains the lowest capacity, whereas the Tesla's battery has the highest capacity.





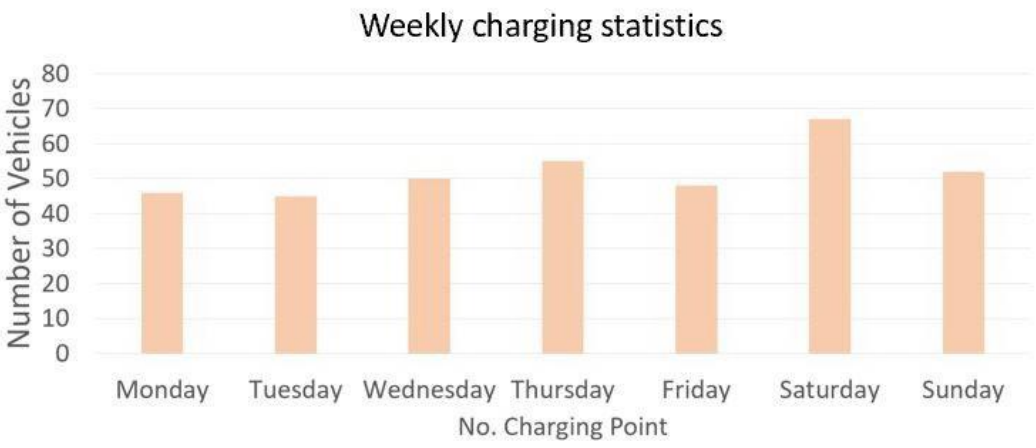


Figure 6.4 : Charging Point Statistics (Source: The Megabangna Shopping Centre)

Figure 6.4 presents ten charging points at the Megabangna Shopping Centre. According to above charging point statistics, each charging point can supply energy for 3-6 cars/day (from 10.00 am.-10.00 pm.). The EVs can be charged around 46 cars/day, or 1,380 cars/month. The data were recorded at the end of March 2020 before Thailand was locked down due to the Coronavirus Disease (COVID-19).

As depicted in the below formula, the monthly power demand is calculated using the EV data specification, which includes the maximum capacity, charging hours/day, the number of days per month (30 days), and full hours for charging.

$$\text{Power Demand per month} = \frac{\text{Maximum Capacity}}{\text{Full hours for charging}} \times \text{Charging hour per day} \times \text{Day of month}$$

Four models are employed for simulation, namely FOMM ONE, Nissan leaf, KIA-E-SOUL, and Tesla model S. Each model represents each battery-size. As presented in Table 6-1, FOMM ONE represents size S (10-29 kWh), Nissan Leaf represents size M (30-49 kWh), KIA E-SOUL represents size L (50-79 kWh), and TESLA model S. represents size XL (more than 80 kWh).

Size	Model	Battery Capacity (kWh)	Time for full charging (hrs)		Range in full charging (km)	Power Demand per month (kWh)
			AC	DC		
Small	FOMM ONE	11.8	4.45	0.21	90	238
Medium	Nissan Leaf	40	11.45	0.40	220	314
Large	KIA E-SOUL	64	10.30	0.44	335	559
X large	Tesla Model S	100	7.00	0.38	525	1285

Table 6-1 : EV specification by Model (Source: EV Specification Blog, 2020)

The EVs' specifications as presented in Table 6-1 include the battery capacity (kWh), the time for full charging via AC current (AC) and DC current (DC), the range in full charging (km), and the power demand per month (kWh). The power demand was calculated based on an average temperature in Thailand, which is normally higher than 25 Celsius.

Estimating the EV demand involves the EV battery's state of charge (SOC) and the arrival time at the charging station. SOC is the measurement for measuring the remaining capacity level in an electric battery in a use's current state, at a specific point. It is counted in the percentage (0% = empty; 100% = full). The other measurement employed for the same measure is the depth of discharge (DOD). DOD is the reverse of the SOC (100% = empty; 0% = full). It is deployed to determine the depth of the battery's capacity amount that has been discharged from the fully charged battery. SOC and DOD apply in a different situation. DOD also concerns the lifetime of a battery after several uses (Battery University, 2016). The SOC charge curve is illustrated in Figure 6.5.

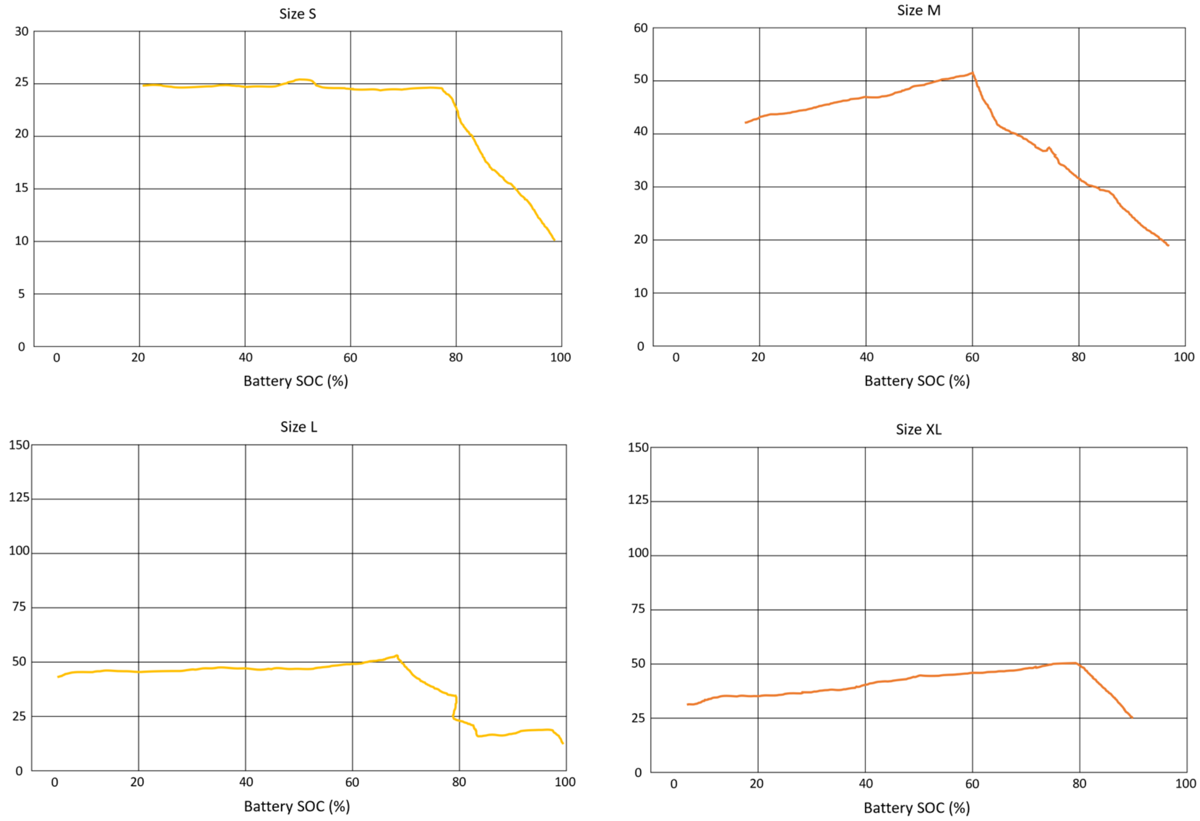


Figure 6.5 : SOC Charge curve (Source: EV-data-base.org)

The project assumption of the state of charge of the vehicles at the arrival time, and the assumption of the power chargers is detailed on the assumption part.

As earlier mentioned, four models are employed for the simulation: FOMM ONE, Nissan Leaf, KIA E-SOUL, and Tesla model S. Each model represents each battery-size: S, M, L, and XL. Five cases have been defined to determine the list of the EV demand profiles, as demonstrated in Table 6-2.

Case 1: All 1,380 cars are in size S,

Case 2: All 1,380 cars are in size M,

Case 3: All 1,380 cars are in size L,

Case 4: All 1,380 cars are in size XL,

Case 5: The cars are mixed with size S, M, L, and XL.

The simple formula is used in calculating the total power demand as shown in Table 6-2.

Total Power Demand per month (Each case)	= Power Demand per month x Number of EVs per month

As depicted in Table 6-2, case 1-4 have a specific size in each case. Case 5 is mixed with the ratio of the actual data: size S (38%), size M (34%), size L (24%), and size XL (4%).

Case	Size	Model	Battery Capacity (kWh)	Power Demand per month (kWh)	Number of EVs per months	Total Power Demand per month (kWh)
1	Small	FOMM ONE	11.8	238	1380	328,440
2	Medium	Nissan Leaf	40	314	1380	433,320
3	Large	KIA E-SOUL	64	559	1380	771,420
4	X large	Tesla Model S	100	1,285	1380	1,773,300
5	Mixed	Combined	Combined	S = 238 M = 314 L = 559 XL = 1,285	S = 525 M =469 L = 331 XL = 55	457,776

Table 6-2 : Total Power Demand per Month (kWh)

The simulation was conductd based on the actual number of vehicles in the shopping centre, which are around 1,380 per month. The total power demand/month is shown in Table 6-2. Consequently, the power supply in proportion to the consumption demand was defined.

6.1.2 PV Profile: Designing the PV Panel Installation

The PV panel has been designed to suit the area, the power demand, and the solar factors by considering the climate, temperature, seasons, and sunlight. The Megabangna Shopping Centre has been selected as the location to conduct a case study because of its huge area. High level of solar-radiation is obtainable almost the whole day. The daily solar-radiation lasts about five hours on average.

There are three official seasons in Thailand: winter season (Nov.-Feb.), summer season (Mar.-June), and the rainy season (July-Oct.), as shown in the table below.

Season	Month	Solar Irradiation (kWh/m2/day)	Solar generation time (hr/day)
Winter	Nov-Feb	5.07	4.5
Summer	Mar-June	6.23	5
Rainy	July-Oct	4.93	3.5

Table 6-3 : The Season in Thailand

Solar Irradiation

Solar irradiation is a significant factor in the PV panel installation. The solar-radiation for the PV panel installation should be greater than 1 kW/m2 per day to generate efficient solar power. As illustrated in Figure 6.6, there is enough space in the parking area for installing the PV panels. The solar irradiation in the site location is presented in Figure 6.6.

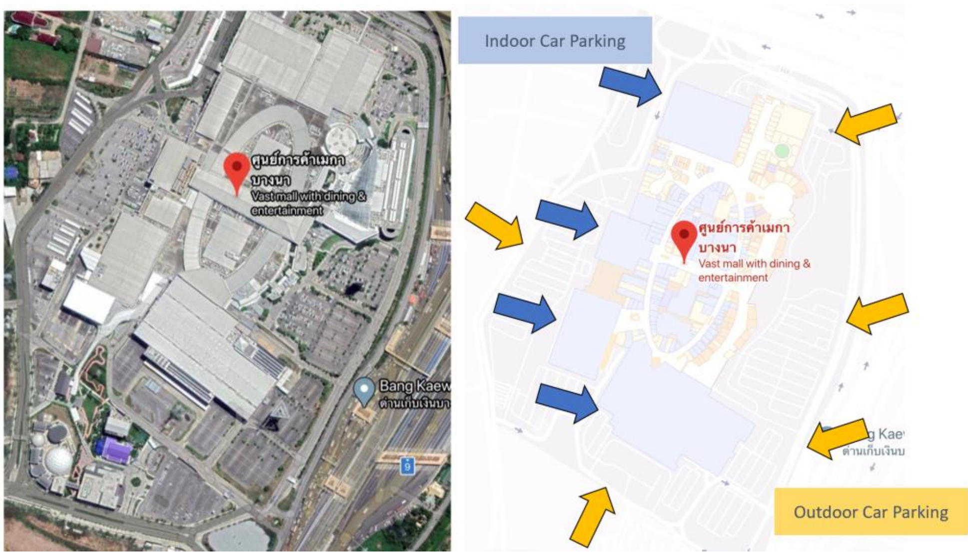


Figure 6.6 : Site Location (Source: The Megabangna Shopping Centre)

The advantage of the Megabangna Shopping Centre is that the solar panel can be installed on the rooftop of the indoor parking's building and on the aluminium roof of the outdoor parking, as indicated in Figure 6.6.

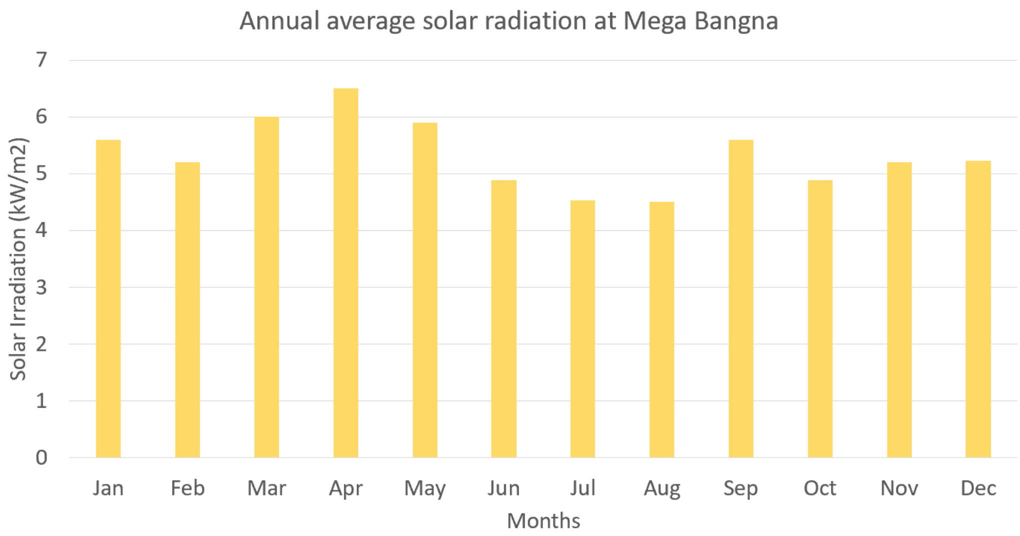


Figure 6.7 : Solar Irradiation at the site location (Source: NASA Laboratory, 2005)

As shown in Figure 6.7, the average solar-radiation in this area is 5.14 kWh/m2/day.

Solar PV Panel

Thailand locates in a tropical climate. Average temperature is higher than 25 degrees Celsius (kg solar, 2019). Monocrystalline panels have slightly high efficiency, but the efficiency decreases at the warmer temperature as the dark cells absorb the heat very well. The polycrystalline panels' efficiency is not as high as that of the monocrystalline, but the efficiency and performance remain at the high temperature because the blue cells absorb less heat. Besides, the price is lower. Thus, the polycrystalline solar panels are selected for a case study at the Megabangna Shopping Centre, as shown in Table 6-4 below.

Technology	Module	Efficiency (%)	Temperature ©
Poly c-Si	DTP275-24/VD	14.2	42
Mono	Q-Cell SL1 SN2	11.3	42

Table 6-4 : Solar PV Panel types

Solar factor

To meet the load, the factors for computing solar energy are the solar tilt angle (degree from horizontal), the orientation (nearest compass heading), and the time of solar irradiation).

The proper inclination angle is 15° south direction, the solar azimuth in Bangkok is shown in Figure 6.8.

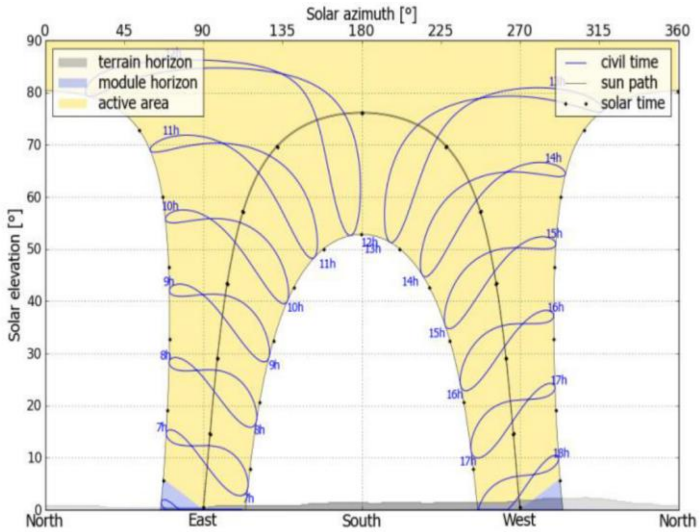


Figure 6.8 : Solar Azimuth in Bangkok (Source: Solar GIS dataset)

As stated by EGAT (2019), it takes at least five hours/day till the solar panels produce power effectively.

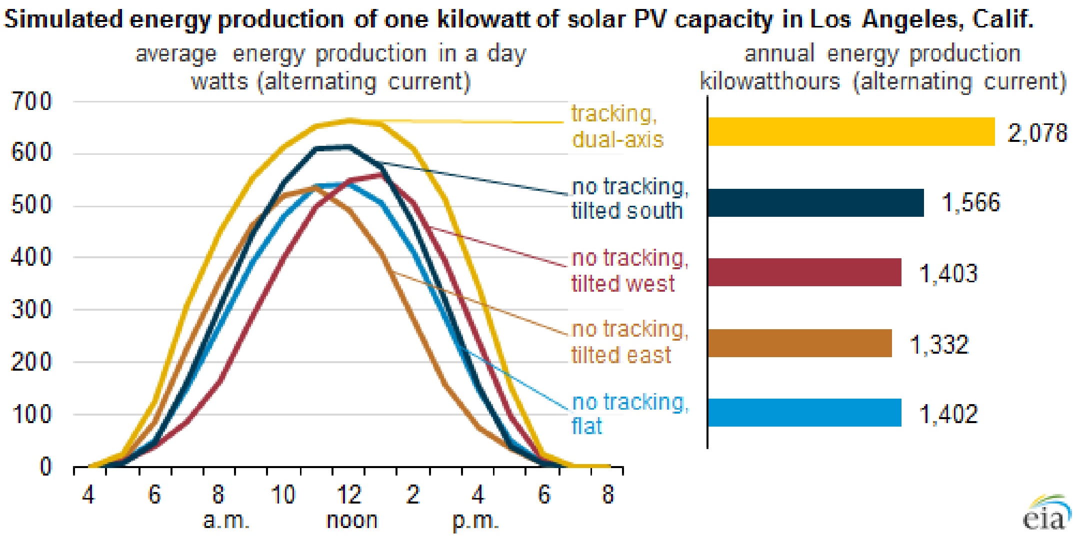


Figure 6.9 : Solar Energy Production in one day (Source: EIA)

Solar Panel	
Characteristics	315W
Vmp (V)	33.67
Imp (A)	6.61
Isc (A)	8.72
Voc (V)	44.81
Area (m2)	1.938

Table 6-5 : PV Panel Characteristics

Table 6-5 describes the solar panel characteristics of each module, Vmp refers to a maximum voltage, the Imp is a maximum current, Voc signifies an open circuit voltage, and the Isc represents a short circuit current. To achieve the power at the maximum level, it is necessary to combine the current and the voltage at Imp and the Vmp, which is employed for the best working of the highest power point (Pmp), as "Pm = Vmp x Imp"

The relation between the four parameters (Maximum Voltage, Maximum Current, Open Circuit Voltage, and Short Circuit Current) is depicted in Figure 6.10.

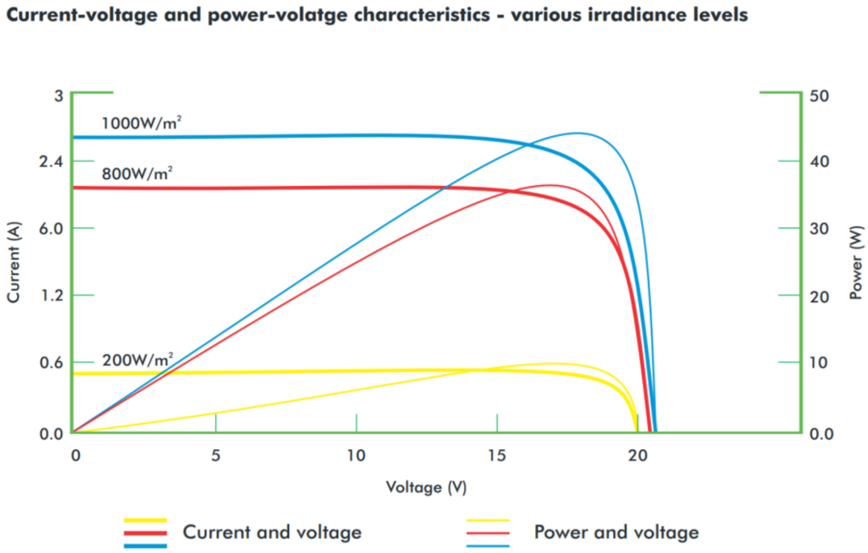


Figure 6.10 : V-I Characteristics for the Solar Panels from Modelling Tool

The below formula was employed to compute the solar panel size.

$$\text{Solar PV Panel System Size} = \frac{\text{Load Power Consumption per month (kWh)}}{\text{Solar hours per day (hr) x 30 days}}$$

Equation 1 : Solar Panel sizing (Source: www.solarpowerauthority.com)

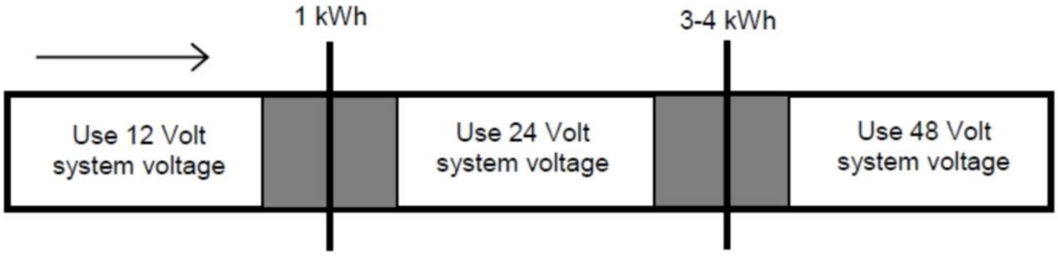
The below formula was employed to compute the number of PV panels.

$$\text{Number of PV Panel} = \frac{\text{Solar PV Panel System Size (kW)}}{\text{Solar PV Panel Module}}$$

Equation 2 : Number of PV Panel (Source: www.solarpowerautority.com)

The following steps were conducted to examine the optimal battery for solar energy.

1. The voltage was defined to examine the optimal battery's voltage. The condition of the battery selection was applied as follows:



The electrical load in this scenario was more than 4kWh: using 48V-system voltage.

2. The load unit was converted from Watt-Hour (Wh) to Amp-Hour (Ah). To compute the proper battery, the converted load was divided based on the depth of discharge (DOD), which was around 80% or 0.8. All SOC in the battery was 40%-100%.

Battery Storage

$$\text{Current (Ah)} = \frac{\text{Power load (Wh)}}{\text{Voltage system (V) x DOD}}$$

Equation 3 : Battery Storage Capacity Calculation (Source: www.solarpowerauthority.com)

Use a standard mathematics equation to calculate each PV size for each case, and use HOMERpro software to analyse the performance of the PV design.

Carbon Content: According to the Greenhouse Gas report conducted By the Department for Business, Energy and Industrial Strategy, the conversion factors used for converting kWh to kgCO2 are 0.28307 kgCO2.

Assumption of a model Simulation

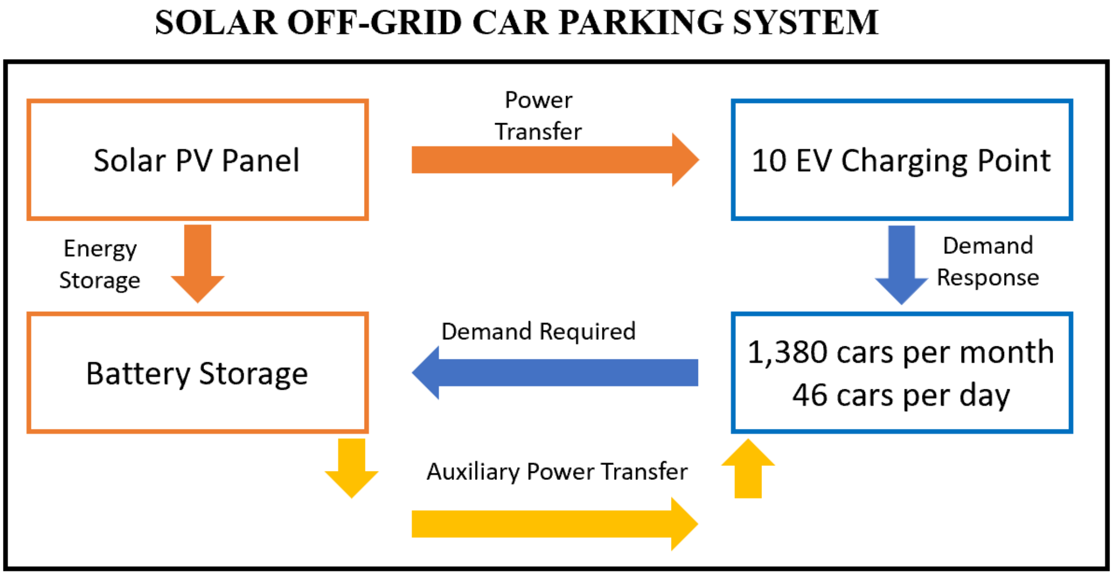


Figure 6.11 : The Schematics of the solar off-grid parking system

The simulation in this study performed using the existing ten EV charging points, 1,380 cars/month. Four models are employed for the simulation: FOMM ONE, Nissan Leaf, KIA E-SOUL, and Tesla model S. Each model represents each battery-size: S, M, L, and XL. Five cases have been defined: S, M, L, XL, and mixed-size. To determine the list of the EV demand, each of the five cases has been simulated under two conditions: on the bright day and the cloudy day.

6.2 Assumptions

The simulations in this study are performed under the defined assumptions below.

1. Seasons influence on solar power generation. The solar generation depends on Thailand's official seasons. In summer, the solar generation takes 5 hrs, in the rainy season 4.5 hrs, and winter 3.5 hrs. The annual energy consumption at the Megabangna is 87.8 MW (around 7.31 MW/month). The applied climate data are based on Bangkok's and its suburbs (NASA laboratory).

2. The simulation performed based on the assumption that Nissan Leaf is charged 0.40 hours per day. The power charger at the charging point is 3 kW/7 kW/50 kW/ 175kW/350 kW. All cars are charged via DC power charging station output: All DC fast charge at 50 kW/175 kW/350 kW.

3. The electrical component in the solar off-grid system includes the inverter and the battery. Set up of the electric vehicle-average daily load (kWh/day) depends on each case. Renewable energy component set up is generic flat-plate PV battery storage: a Li-on battery. HOMER's system converter is applied.

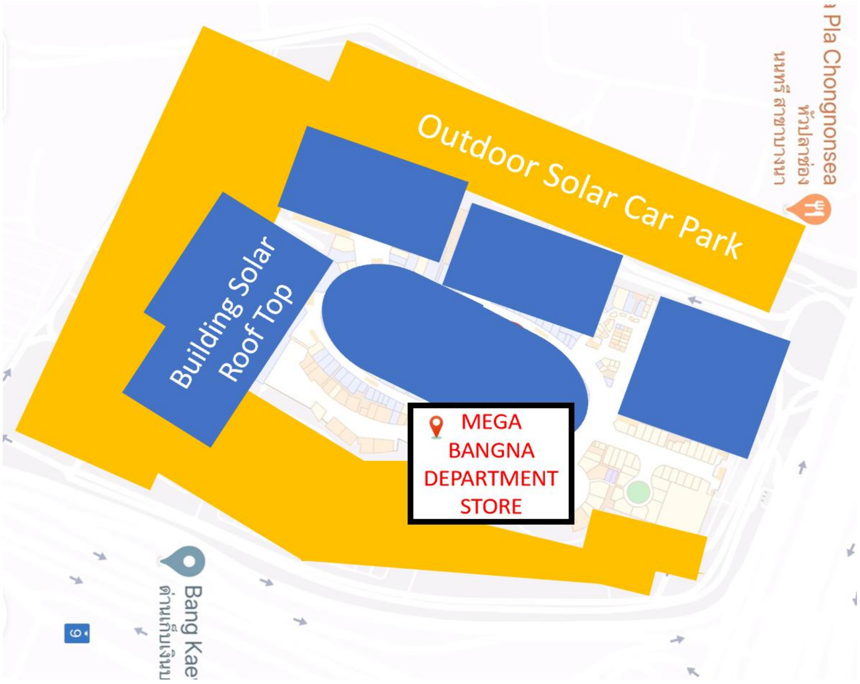


Figure 6.12 : Area for Designing the Solar Farm

4. The total area for PV panel installation is 400,000 m^2. PV panels were installed on rooftops of the building (blue box) and on aluminium roofs of the outdoor parking (yellow box).

6.3 Simulation Analysis

The approach taken in the analysis is, first of all, to establish the monthly demand. Then, use each of the different 20 demand cases to do a simple PV sizing by taking into account a mathematic equation as shown in Section 6.1.2. Then, use the HOMERpro to analyse the performance.

The simulations (analisation) performed using the HOMERpro software and Thai modelling under the aforementioned defined assumptions. The scenarios have been simulated to tackle the problems concerning the EVs fleet demand, e.g. electricity fluctuation, high-level carbon content from non-renewable energy production. Such problems impact the national grid electricity. The solar off-grid system is the solution that can disconnect the grid and the EVs load.

The system architecture consists of PV panel, battery storage, and an inverter. The project scenario focused on designing the optimal solar farm in the parking space, which can generate adequate solar power to meet the EV's demand. The unmet electric vehicle load analysis, the scenario has been conducted. Four models are employed for the simulation: FOMM ONE, Nissan Leaf, KIA E-SOUL, and Tesla model S. Each model represents each battery-size: S, M, L, and XL. Five cases have been defined: S, M, L, XL, and mixed-size. To determine the list of the EV demand, each of the five cases has been simulated under two conditions: on the bright day and the cloudy day. The methodology for analysis; firstly, the simple calculation is applied to design the system. Secondly, HOMERpro is applied to analyse the system's performance. The simulation in each case concerns the power of the solar off-grid system, the power of stand-alone grid System, the capacity shortage and the unmet electrical load of the solar off-grid system, the state of charge (SOC) of a solar off-grid system, and the fuel consumption of a stand-alone grid system. The carbon and the particulate matters have been analysed in all five cases. The off-grid system and the on-grid system are compared to evaluate and determine the difference between the carbon savings and the surplus energy in each case. The simulation results are applied in designing the most efficient and effective EV charging station system at the shopping centres in Thailand.

DEMAND CASE		SCENARIO			
		1	2	3	4
1		20%	40%	60%	80%
2		20%	40%	60%	80%
3		20%	40%	60%	80%
4		20%	40%	60%	80%
5	MIXED	20%	40%	60%	80%

Table 6-6 : Scenario Simulation

Table 6-6 demonstrates the simulation plan using a solar-panel icon, solar-battery icon, and EV car icon (S, M, L, XL, and mixed-size). The SOC in the percentage of EVs battery in each case was assessed with a ratio of 20% SOC, 40% SOC, 60% SOC, and 80% SOC.

Size	Battery Capacity (kWh)	Demand per month (kWh/day) 0%SOC	Demand per month (kWh/day) 20%SOC	Demand per month (kWh/day) 40%SOC	Demand per month (kWh/day) 60%SOC	Demand per month (kWh/day) 80%SOC
Small	11.8	1,095	876	657	438	219
Medium	40	1,444	1,156	867	578	289
Large	64	2,571	2,057	1,543	1,029	514
X large	100	59,110	47,288	35,466	23,644	11,822
Mixed	Combined	1,526	1,221	916	610	305

Table 6-7 : The Demand by %SOC of the second Scenario Simulation

Table 6-7 shows the input data of the EV's demand per month and the SOC's percentage of each model (battery-size). Different PV panel installation styles have been designed to suit the five EV demand profiles (S, M, L, XL, and mixed- size).

Schematic System Description

HOMERpro software has been employed to simulate Thai modelling, to analyse the power response of the entirety of the electrical load served, the entire output of solar power output, the battery input power, and the grid power output. The results showed the defined unmet electric load and the capacity shortage. Then, the SOC of EV's battery and the grid generated by diesel power were analysed. After that, the system computed and compared the carbon saving amount between the solar-parking system and the stand-alone grid system.

Case 1: All 1,380 cars are in size S

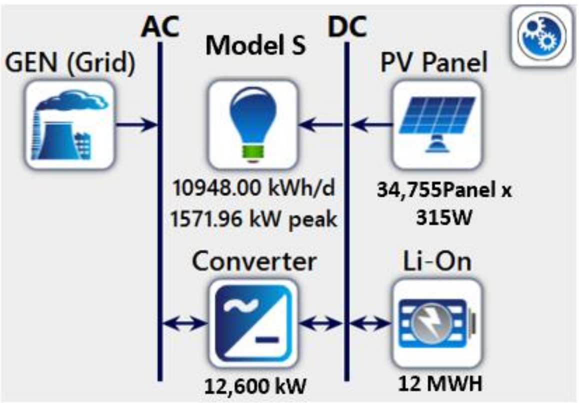


Figure 6.13 : The Schematics of the System for Case 1

As shown in Figure 6.13, the simulation shows the representative of EV's demand from a small-size battery based on a battery capacity 11.8 kWh of the FOMM ONE. The number of vehicles is 1,380 cars/month. According to Table 6-2, the total monthly demand is 328,440 kWh. The EVs demand is 10,948 kWh/day with a peak of 1,571.96 kW. The assumption of SOC is in a range of 20%-100% of the battery. The peak time of the charging period is from 10.00 am.-10.00 pm. During the nighttime, the demand is not set to zero value as there are some EVs of the officers working in the shopping centre.

The simulation system comprises a solar-car parking system and a stand-alone grid system. The stand-alone grid system has been replaced by a diesel generator.

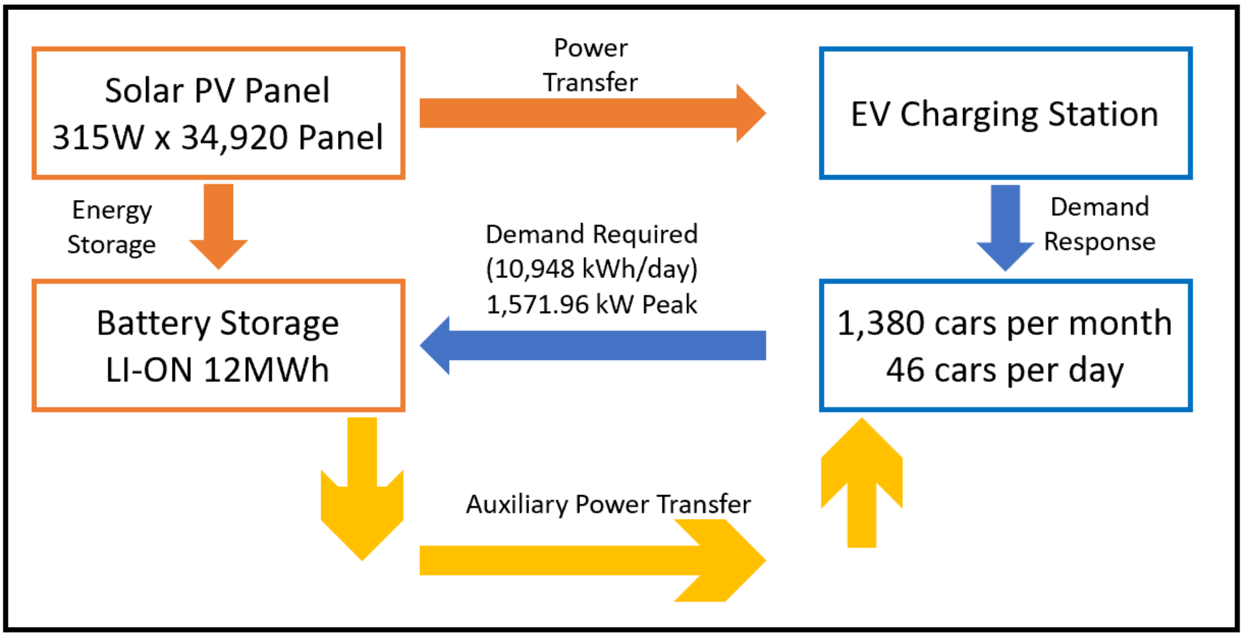


Figure 6.14 : The diagram of solar car parking system for Case 1

In Thailand, the standard PV panel used for commercial installation is a 315W PV panel. To calculate a quantity of solar panels, the electrical demand is to be divided by the standard of PV panel. In case 1 the quantity of PV panels is as follows:

$$11{,}000 \text{ kW} / 315\text{W} = 34{,}920 \text{ panels} = 11\text{MWp}$$

As for the battery capacity, normally it can be calculated by battery (Ah) = total demand (kW) / (Battery Voltage x0.6% x 0.85eff). However, this study selected to use a battery container size of Li-ON 12MWh which contains sufficient capacity for battery storage.

The solar-parking system component includes 315W x 34,920 PV panels, 12 MWh of Li-on battery, and 1,380 cars per month with a 10,948 kWh/day of electrical load. The total area for installing solar panel is 67,395 m2 which is 16% of shopping center.

The component of the stand-alone grid system consists of a diesel generator, a 12,600 kW converter, and 10,948 kWh/day of electric demand.

Case 1 - On a bright day

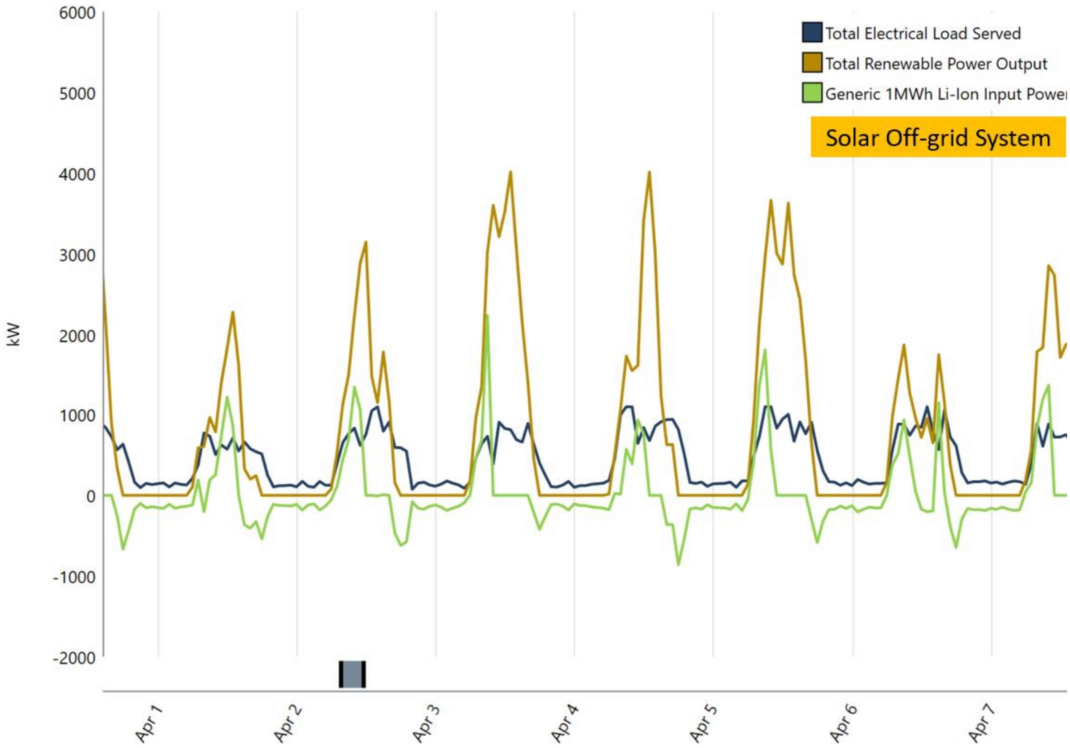


Figure 6.15 : The power of solar off-grid system (Case 1 - on a bright day)

Figure 6.15 expresses that the energy demand is with a total of 10,948 kWh. The average EVs' demand is 1,094.8 kWh/day, and the peak demand is 1571.96 kW. The upper plot indicates that the PV farm, which is equipped with 40 pieces of 315W PV panels, has an average output power of 1,260 kWh/day. The surplus energy is around 165.2 kWh. The peak demand 1571.96 kW exceeds the output power. This results in an unmet electrical load. The system has battery storage with a size of 12 MWh (1 MWh x 12 pack of Li-On), which can support the solar system when there is no power output of the solar generation.

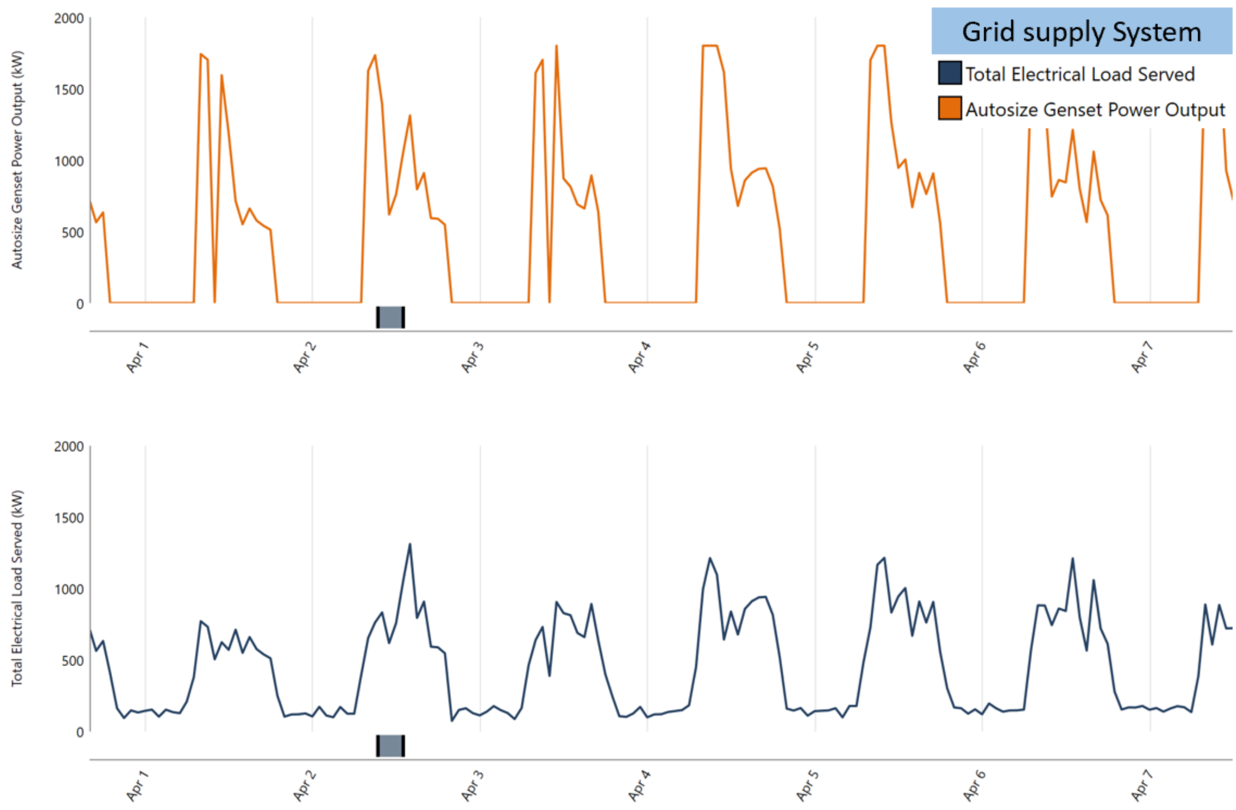


Figure 6.16 : Power from stand-alone grid system (Case 1 - on a bright day)

Figure 6.16 demonstrates the car parking system using a stand-alone grid connecting. To supply the fleet demand, the system consumes power from the grid generation, which generates power from non-renewable resources. As a result, it causes a high level of carbon intensity. In this simulation, the national grid has been represented by GEN (a Generator). The grid can supply the total electric load 1,094.8 kWh/day. The demand and supply graphs have the same value because the national grid operation supplies power equal to the load demand. There is no storage system to support power during peak demand or when there is a blackout.

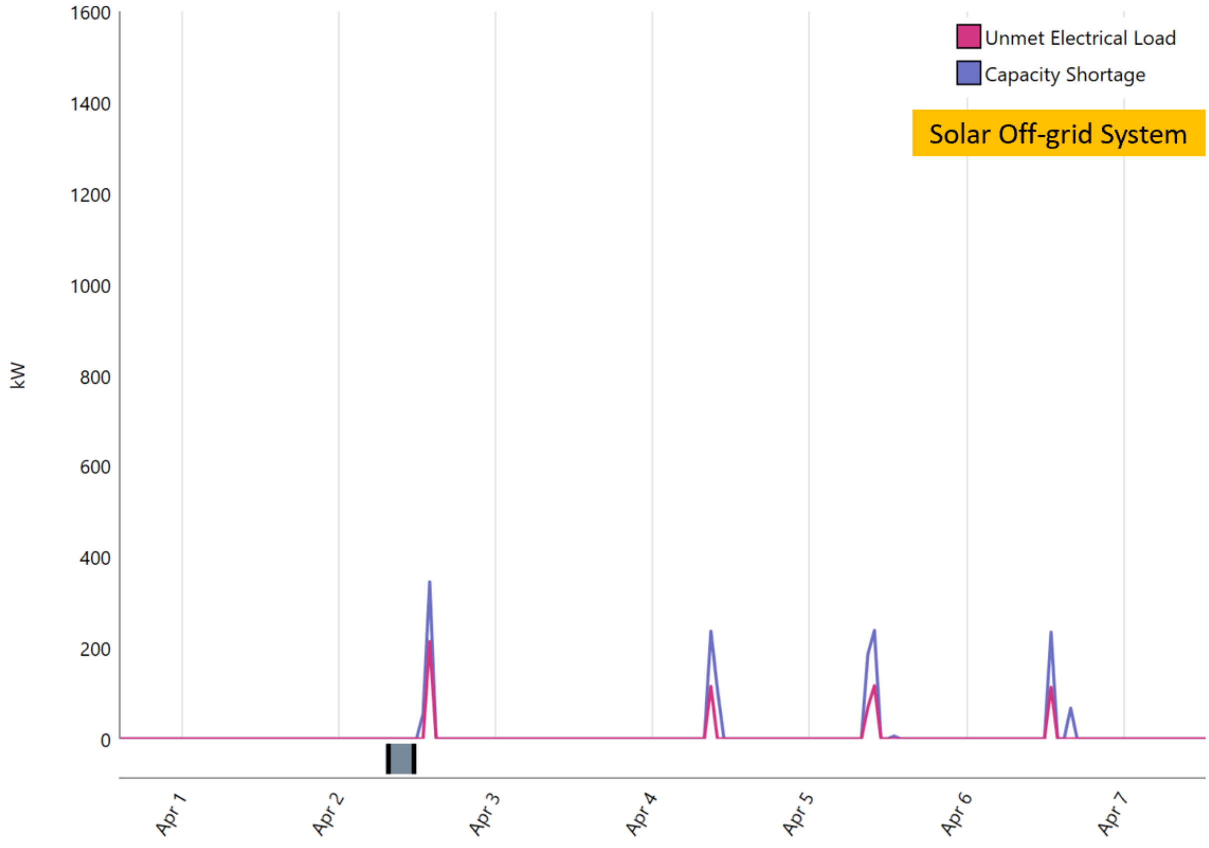


Figure 6.17 : The capacity shortage and the unmet electrical load of solar off-grid system (Case 1 - on a bright day)

Figure 6.17 indicates the deficiency of the expected minimum operating capacity and the actual capacity that the system can operates. The capacity shortage in the above plot is 300 kW. This means that if the load is 1,094 kW, the required operating reserve is 0 kW, and the actual operating capacity is 1,094 kW, the capacity shortage will be 300 kW (the unmet load is also 0 kW). In this case, the unmet load is not zero because the demand slightly exceeds the supply.

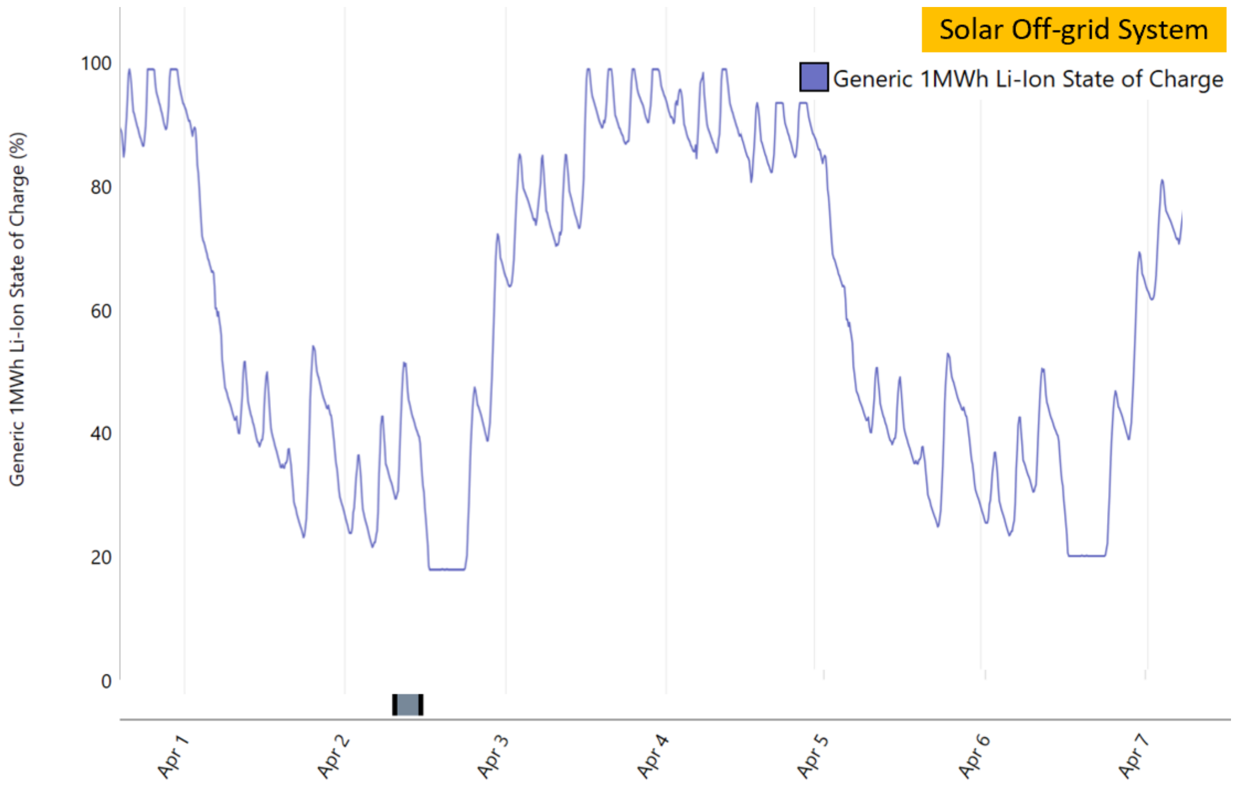


Figure 6.18 : The state of charge (SOC) of a solar off-grid system (Case 1 - on a bright day)

Figure 6.18 illustrates the SOC's percentage which refers to the remaining capacity level in an electric battery at a specific point. The unit of SOC is counted in the percentage (0% = empty; 100% = full). In this case, the %SOC of a battery normally works from 20% to 100%. When solar power is insufficient to supply the load, the battery will provide power from the SOC at 100%full to a minimum of 20%. When there is a surplus solar power, the surplus amount will be stored in the battery, which maintains the SOC from 20% to 100%.

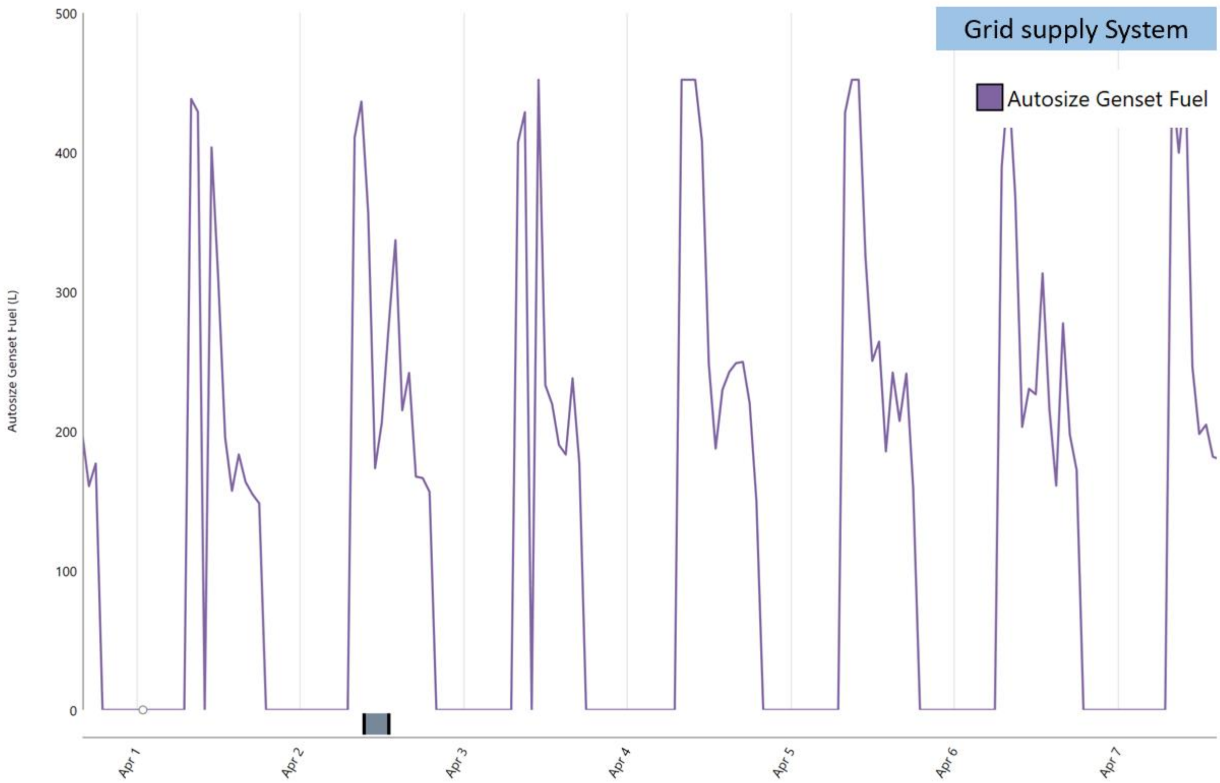


Figure 6.19 : Fuel consumption of a stand-alone grid system (Case 1 - on a bright day)

Figure 6.19 presents the fuel consumption of the national grid generation which is represented by the generator. The fuel consumes from the operating setpoint 0 litre of diesel into more than 280 litres which is 750 kg CO_2 /hr. since the generator operation works as the real national grid.

Case 1 - On a cloudy day

The simulation on a cloudy day displays the worst case when the solar generation time and the solar irradiation are lower than those of the bright day.

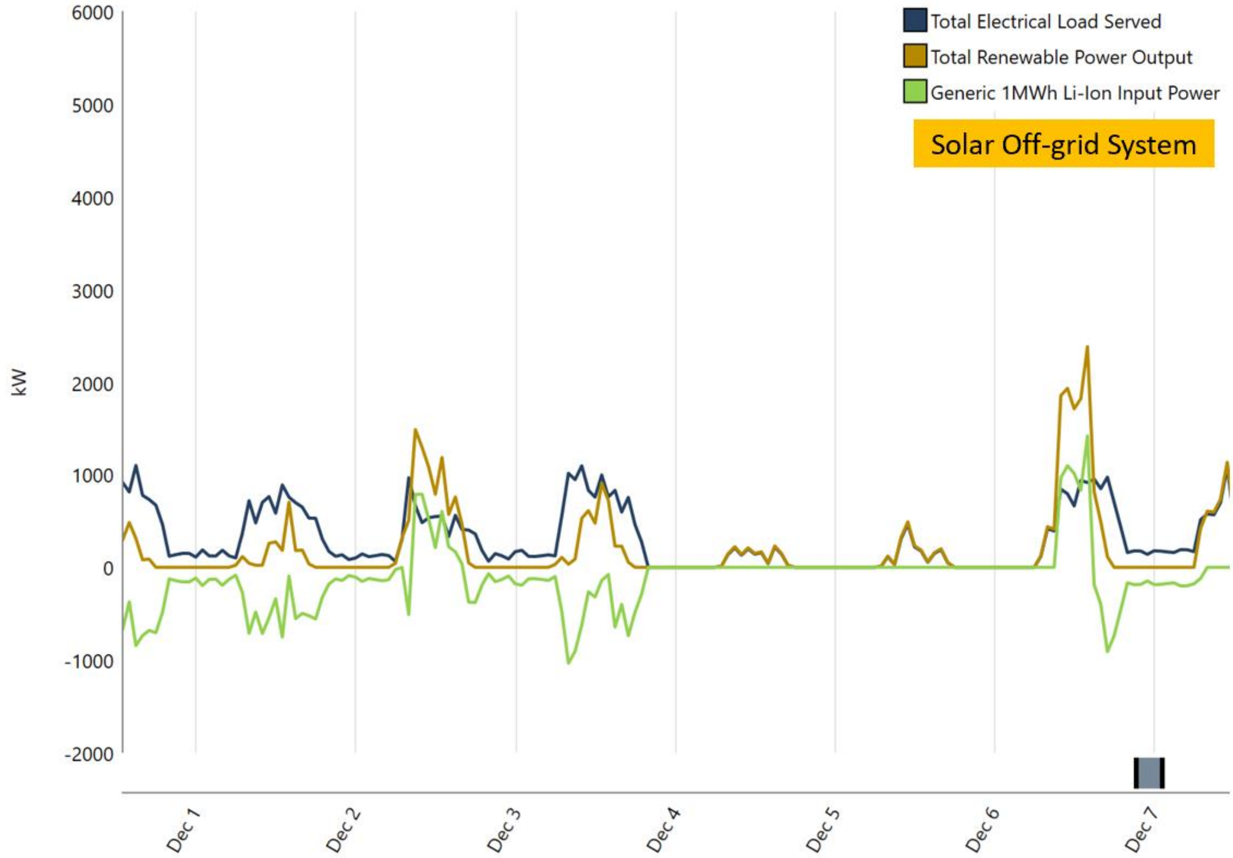


Figure 6.20 : The power of solar off-grid system (Case 1 - on a cloudy day)

Figure 6.20 illustrates the entirety of the electrical load served, the renewable system's output, and the battery's input power. The solar system can generate the power to respond to the load.

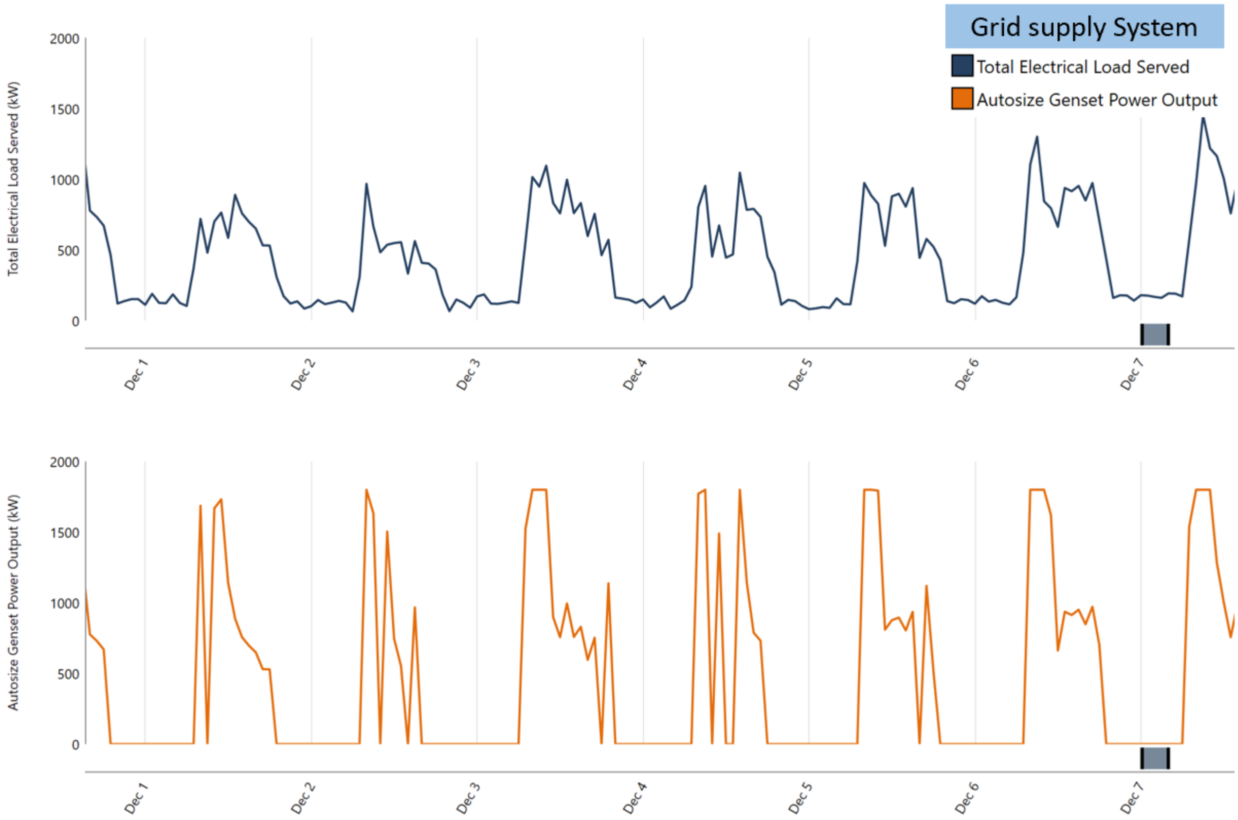


Figure 6.21 : Power of a stand-alone grid system (Case 1 - on a cloudy day)

Figure 6.21 showed that the grid can supply the total electric load 1,094.8 kWh/day. The demand and supply graphs have the same value because the national grid operation supplies power equal to the demand of the load, as on a bright day.

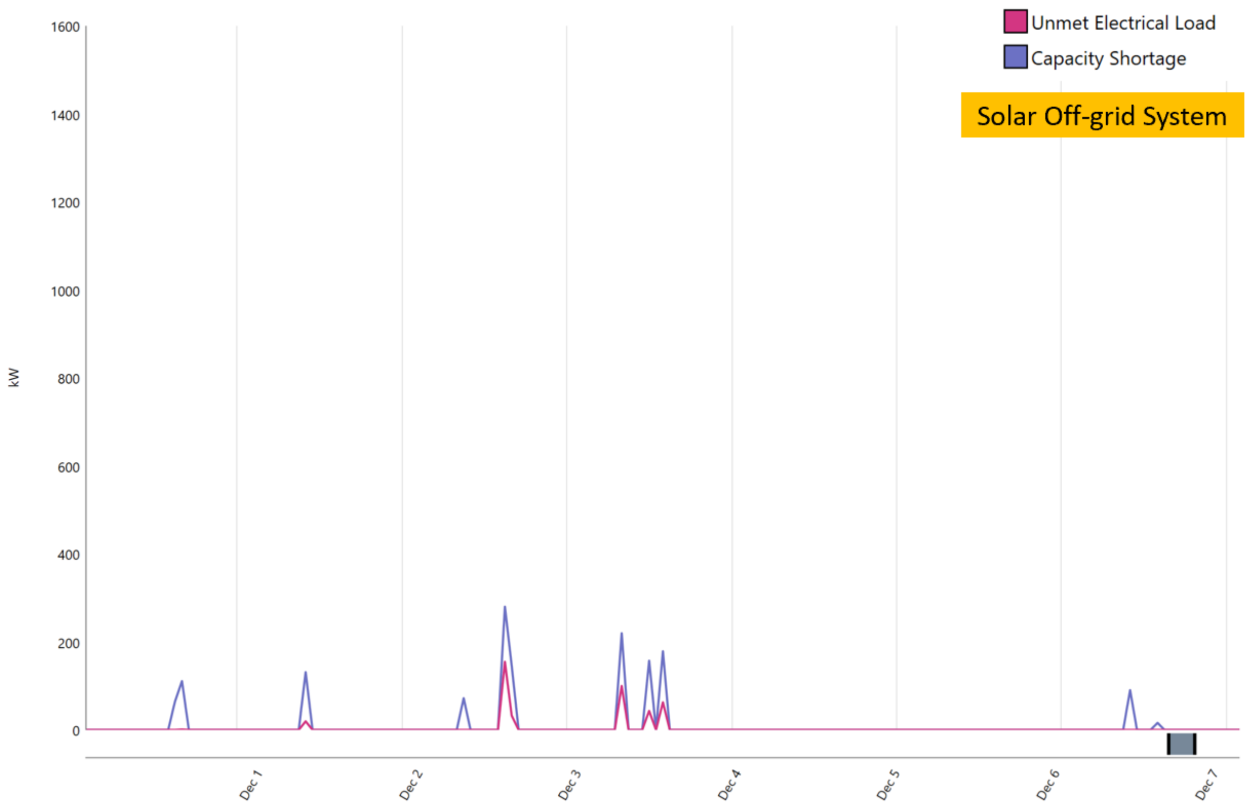


Figure 6.22 : The capacity shortage and the unmet electrical load of solar off-grid system (Case 1 - on a cloudy day)

Figure 6.22 indicates that there are a few unmet electric load and capacity shortage on cloudy days. The peak capacity shortage and the peak unmet load are 210 kW and 180 kW respectively.

Figure 6.23 : The state of charge (SOC) of a solar off-grid system (Case 1 - on a cloudy day)

Figure 6.23 illustrates SOC's percentage, which refers to the remaining capacity level in an electric battery at a specific point. The unit of SOC is counted in the percentage (0% = empty; 100% = full). In this case, the %SOC of a battery normally works from 20% to 100%. When solar power is insufficient to supply the load, the battery will provide power from the SOC at 100%full to a minimum of 20%. When there is a surplus solar power, the surplus amount will be stored in the battery, which maintains the SOC from 20% to 100%.

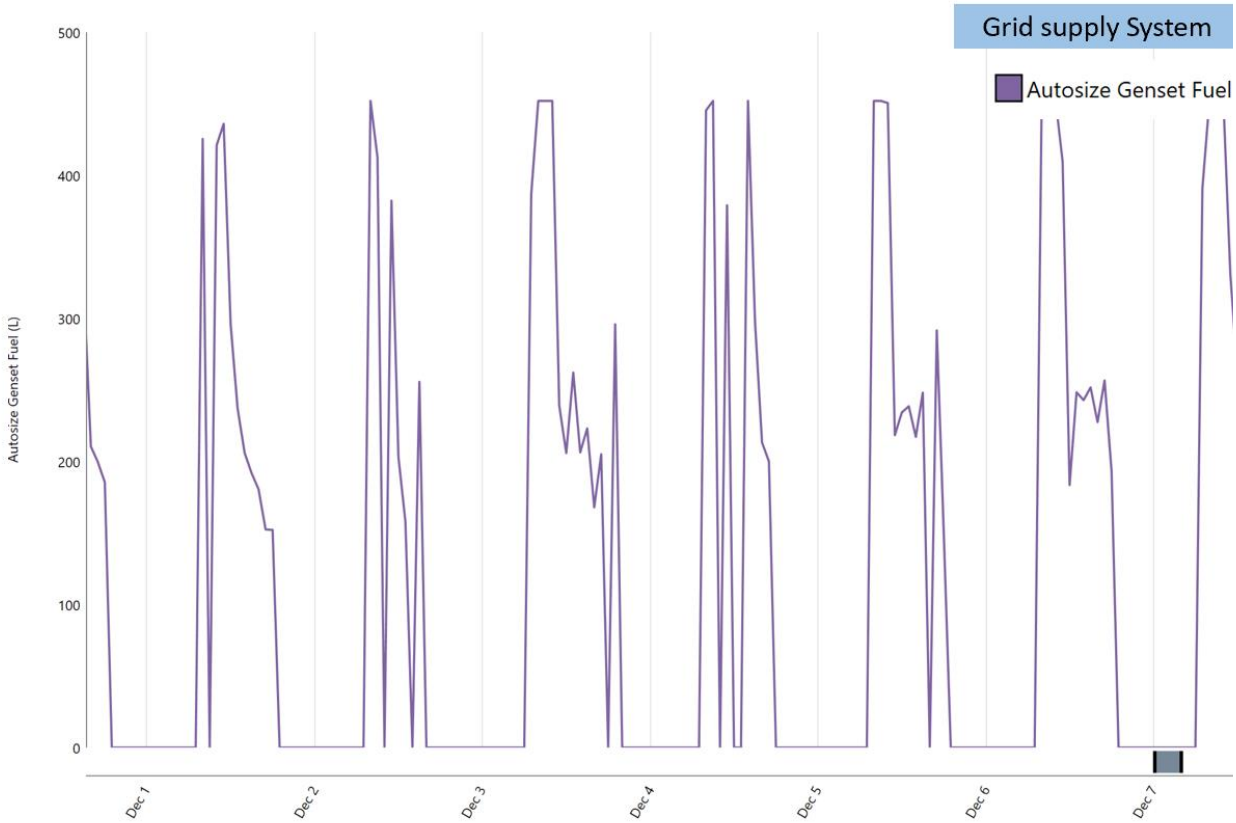


Figure 6.24 : Fuel consumption of a stand-alone grid system (Case 1 - on a cloudy day)

Figure 6.24 illustrates fuel consumption of the national grid generation, which is represented by the generator. The fuel consumes from the operating setpoint 0 litre of diesel into more than 300 litres, and the peak is 500 litres.

Quantity	Value	Units
Carbon Dioxide	0	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	0	kg/yr

Solar Off-grid System

Quantity	Value	Units
Carbon Dioxide	4,062,449	kg/yr
Carbon Monoxide	25,607	kg/yr
Unburned Hydrocarbons	1,117	kg/yr
Particulate Matter	155	kg/yr
Sulfur Dioxide	9,948	kg/yr
Nitrogen Oxides	24,055	kg/yr

Grid supply System

Figure 6.25 : The Emission

As demonstrated in Figure 6.25, the solar off-grid system is in comparison with the grid supply system. It is clear that the solar off-grid system can reduce carbon intensity by more than 4,000,000 kg CO2/year. Moreover, the annual carbon monoxide (CO), unburned hydrocarbons, particulate matter (PM), Sulfur dioxide (SO2), and nitrogen oxides (NO2) are decreased around 25,607 kg, 1,117 kg, 155 kg, 9,948 kg, and 24,055 kg respectively.

Case 2: All 1,380 cars are in size M

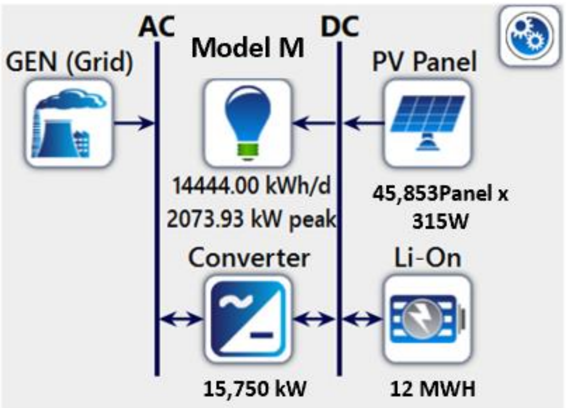


Figure 6.26 : The Schematics of the system for Case 2

As displayed in Figure 6.26, the simulation shows the representative of EV's demand from a small-size battery based on a battery capacity 40 kWh of the NISSAN LEAF. The number of vehicles is 1,380 cars/month. According to Table 6.2, the total monthly total demand is 433,320 kWh. The EVs demand is 14,444 kWh/day with a peak of 2,073.93 kW. The assumption of SOC is in a range of 20%-100% of the battery. The peak time of the charging period is from 10.00 am.-10.00 pm. During the nighttime, the demand is not set to zero value since there are some of the EVs of the officers working in the shopping centre.

The simulation systems consist of a solar-car parking system and a stand-alone grid system which has been replaced by a diesel generator.

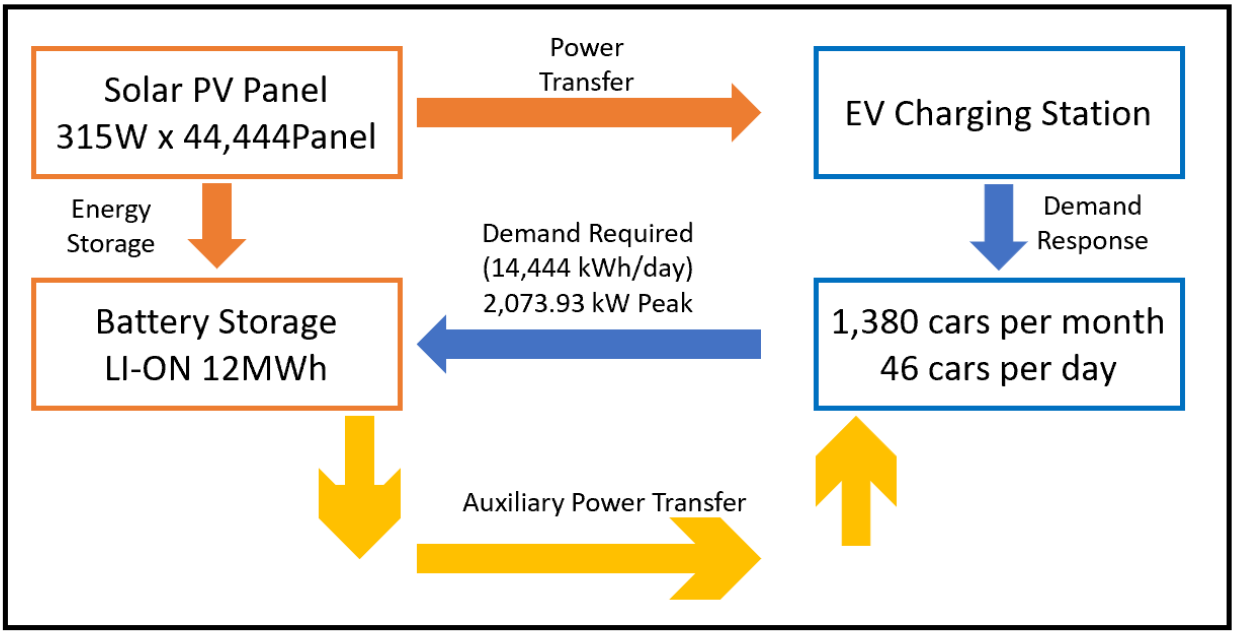


Figure 6.27 : The diagram of solar car parking system for Case 2

In Thailand, the standard PV panel used for commercial installation is a 315W PV panel. To calculate a quantity of solar panels, the electrical demand is to be divided by the standard of PV panel. In case 2 the quantity of PV panels is as follows:

14,012 kW/ 315W = 44,444 panels = 14 MWp

As for the battery capacity, normally it can be calculated by battery (Ah) = total demand (kW) / (Battery Voltage x0.6% x 0.85eff). However, this study selected to use a battery container size of Li-ON 12MWh which contains sufficient capacity for battery storage.

The component of a solar-car parking system comprises 315W x 44,444 PV panels, 12 MWh of Li-on battery, and an electrical load of model case. The total area for installing solar panel is 85,776 m2 which is 21% of shopping center.

The component of the stand-alone grid system consists of a diesel generator, a 15,750 kW converter, and 14,444 kWh electric demands.

<u>Case 2 - On a bright day</u>

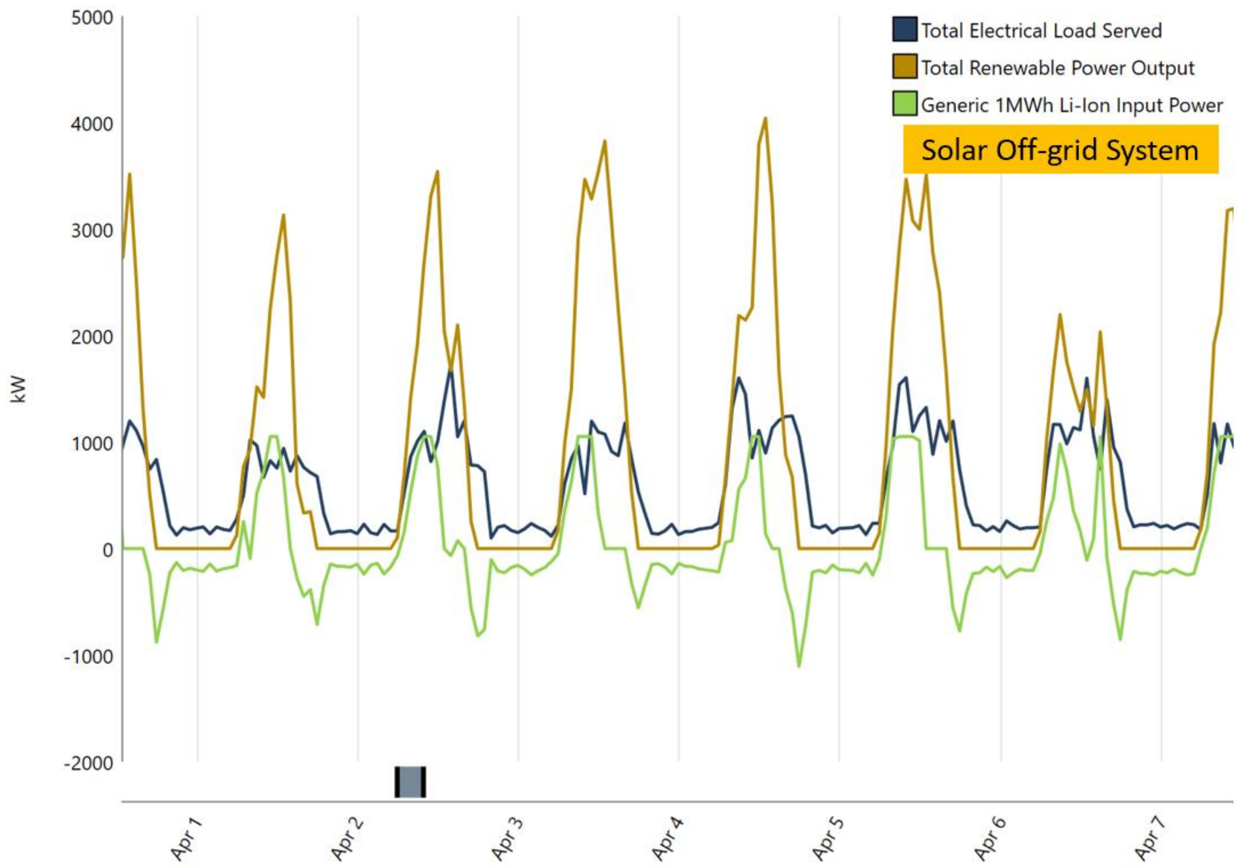


Figure 6.28 : Power of solar off-grid system (Case 2 - on a bright day)

As depicted in Figure 6.28, the total energy demand is 14,444 kWh, the average EVs demand is 1,444 kWh/day, and the peak demand is 2,073.93 kW. The upper plot indicates that the PV farm equipped with 50 pieces of 315 W PV panels has an average output power of 15,750 kWh/day. The surplus energy is around 131.2 kWh. The peak demand, which is 2,073.93 kW, exceeds the output power. This results in an unmet electrical load. The system has battery storage with a size of 12 MWh (1 MWh x 12 pack of li-on), which can support the solar system when there is no power output from solar generation.

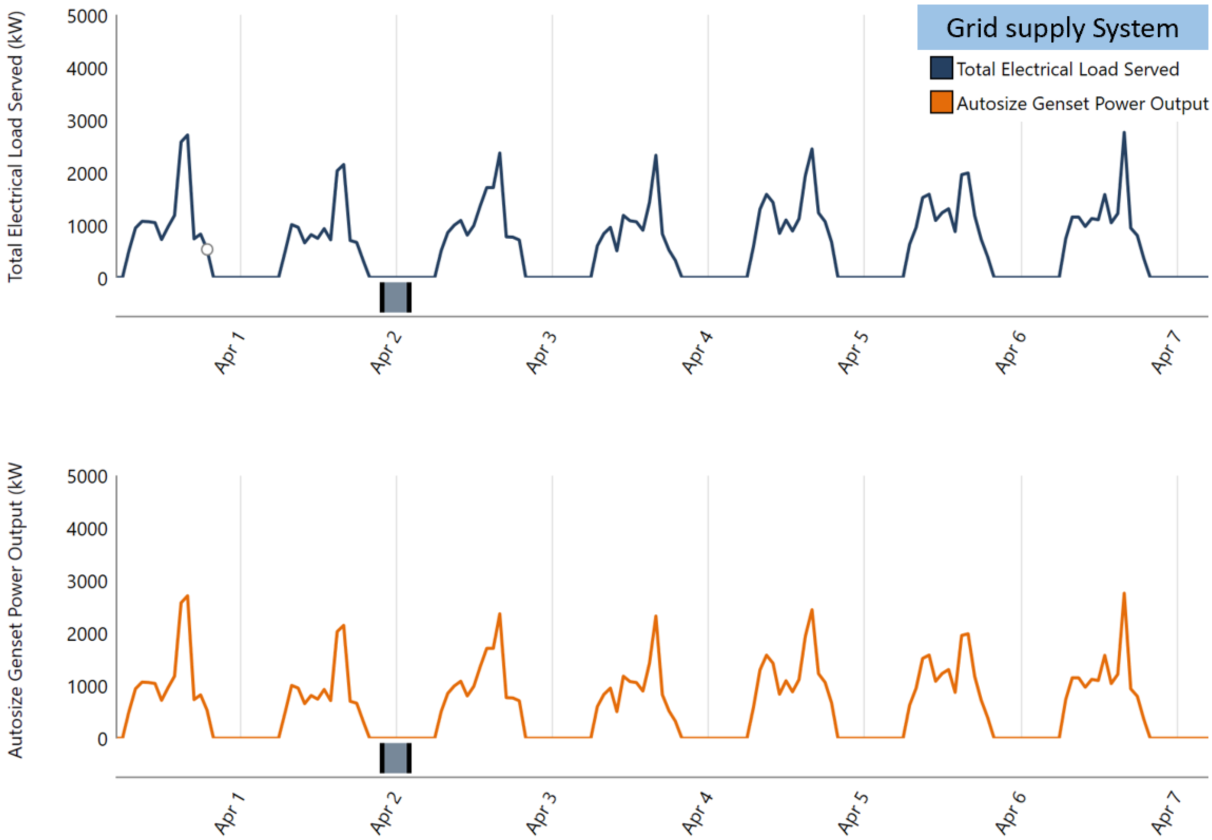


Figure 6.29 : Power of a stand-alone grid system (Case 2 - on a bright day)

Figure 6.29 demonstrates the car parking system when there is no power support from the solar farm. To supply the fleet demand, the system consumes power from the grid generation, which generates power from non-renewable resources. This causes a high level of carbon intensity. In this simulation, the national grid is represented by GEN (a Generator). The grid can supply the total electric load 2,000 kWh/day. There is no storage system to support power during peak demand or when there is a blackout.

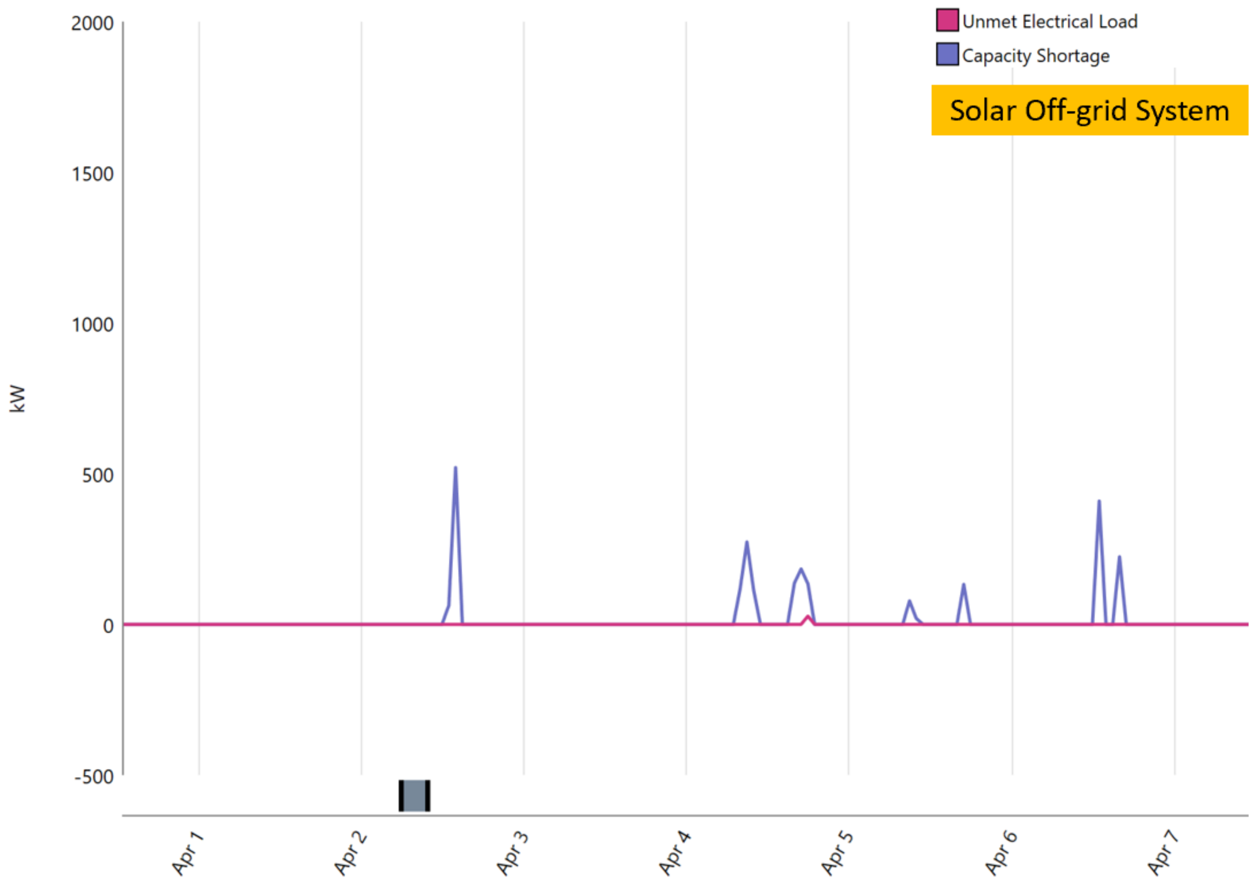


Figure 6.30 : The capacity shortage and the unmet electrical load of solar off-grid system (Case 2 - on a bright day)

Figure 6.30 indicates the deficiency of the expected minimum operating capacity and the real capacity that the system can operates. The capacity shortage in the upper plot reaches peak of 500 kW. In this case, the unmet load is zero because the demand does not exceed the supply.

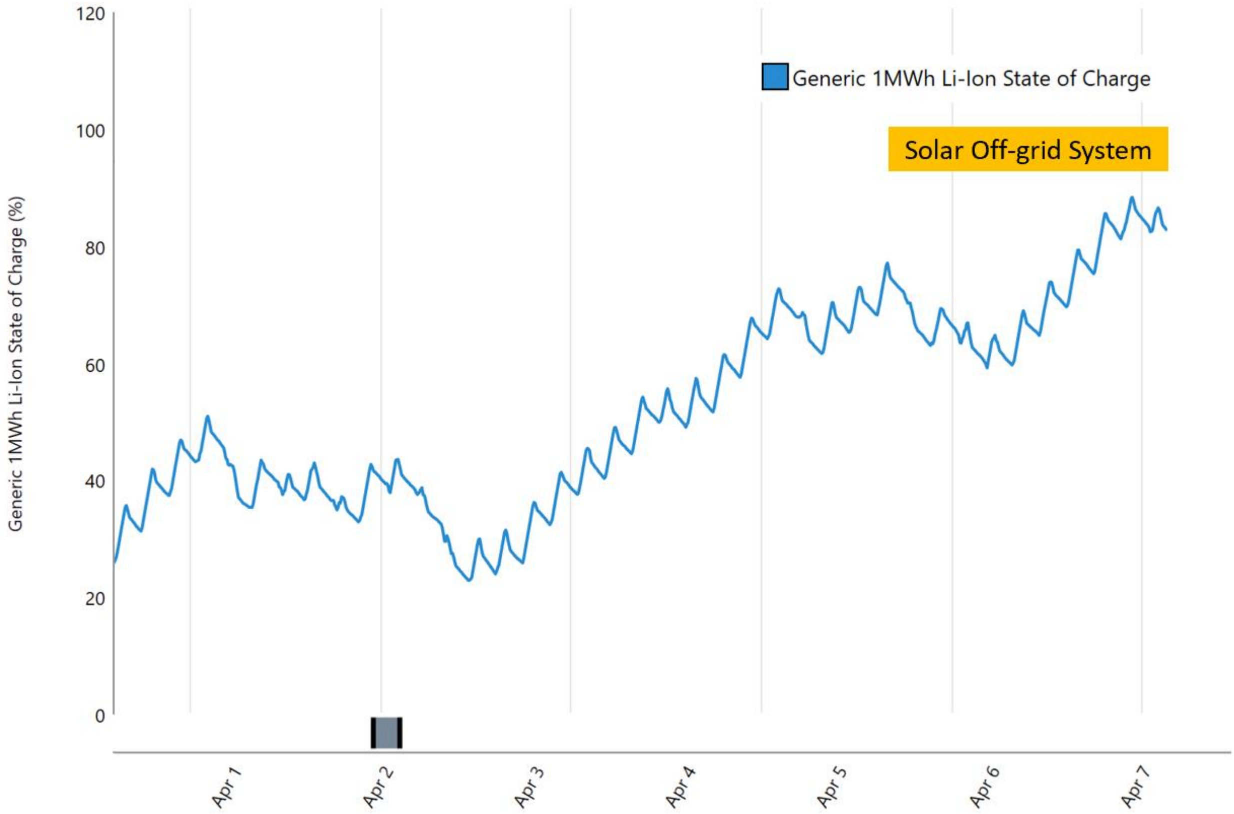


Figure 6.31 : The state of charge (SOC) of a solar off-grid system (Case 2 - on a bright day)

Figure 6.31 illustrates SOC's percentage, which refers to the remaining capacity level in an electric battery at a specific point. The unit of SOC is counted in the percentage (0% = empty; 100% = full). In this case, the %SOC of a battery normally works from 20% to 100%. When solar power is insufficient to supply the load, the battery will provide power from the SOC at 100%full to a minimum of 20%. When there is a surplus solar power, the surplus amount will be stored in the battery, which maintains the SOC from 20% to 100%.

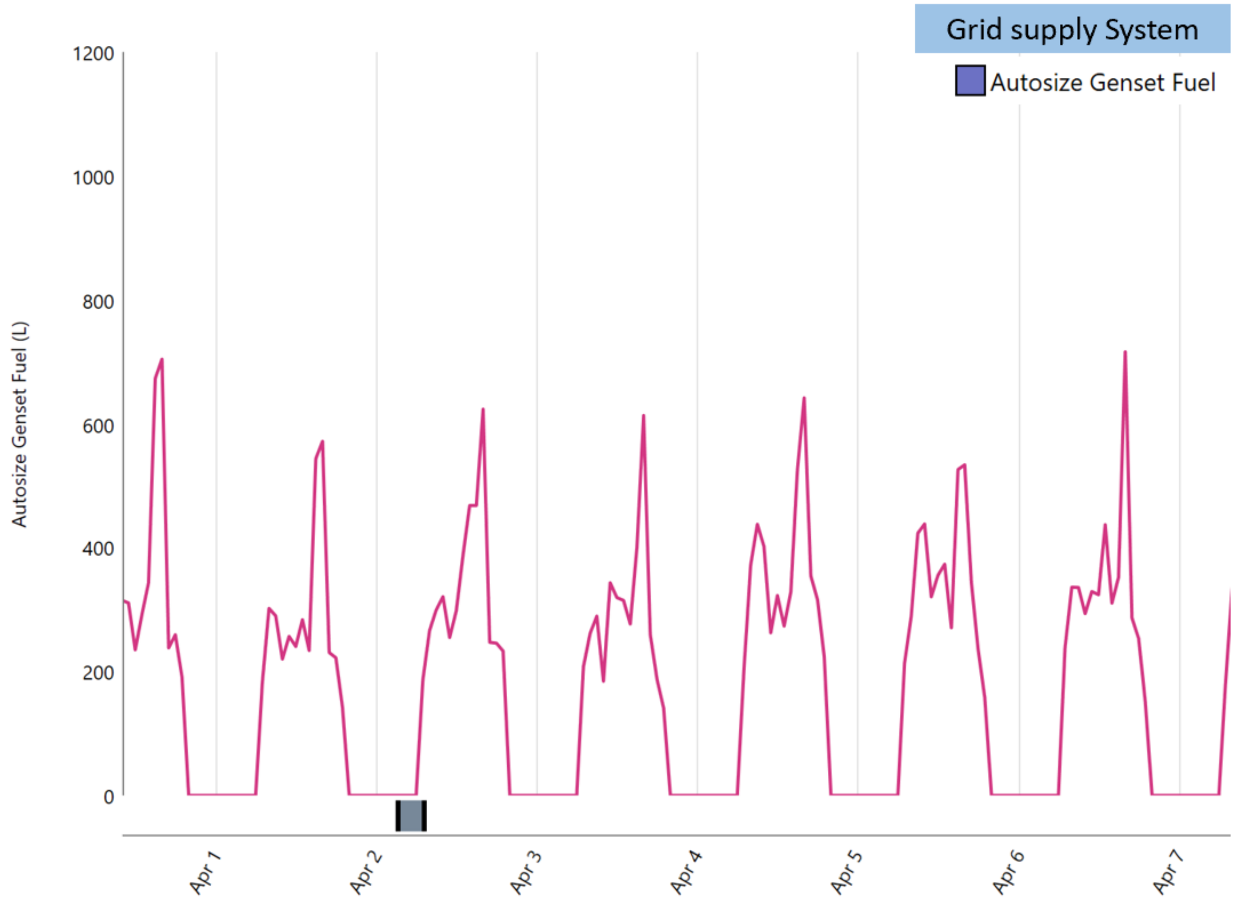


Figure 6.32 : Fuel consumption of a stand-alone grid system (Case 2 - on a bright day)

Figure 6.32 illustrates the national grid generation, which is represented by the generator. The fuel consumes from the operating setpoint 180 litres of diesel into more than 500 litres which are 1,340 kg CO2 / hr.

Case 2 - On a cloudy day

The simulation on a cloudy day shows the worst case when the solar generation time and the solar irradiation are lower than those of the bright day.

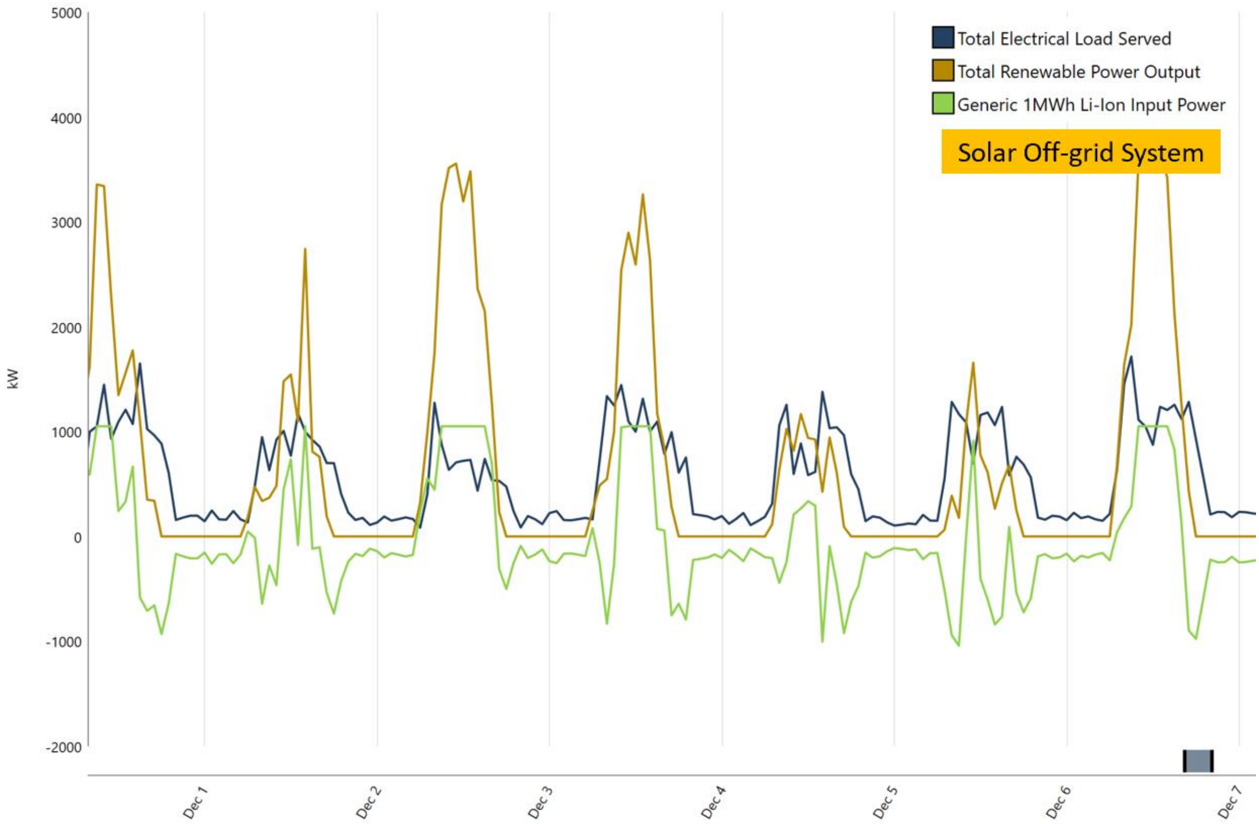


Figure 6.33 : Power of solar off-grid system (Case 2 - on a cloudy day)

Figure 6.33 illustrates the entirety of the electrical load served, the renewable system's output, and the battery's input power. The solar system can provide the power to respond to the load.

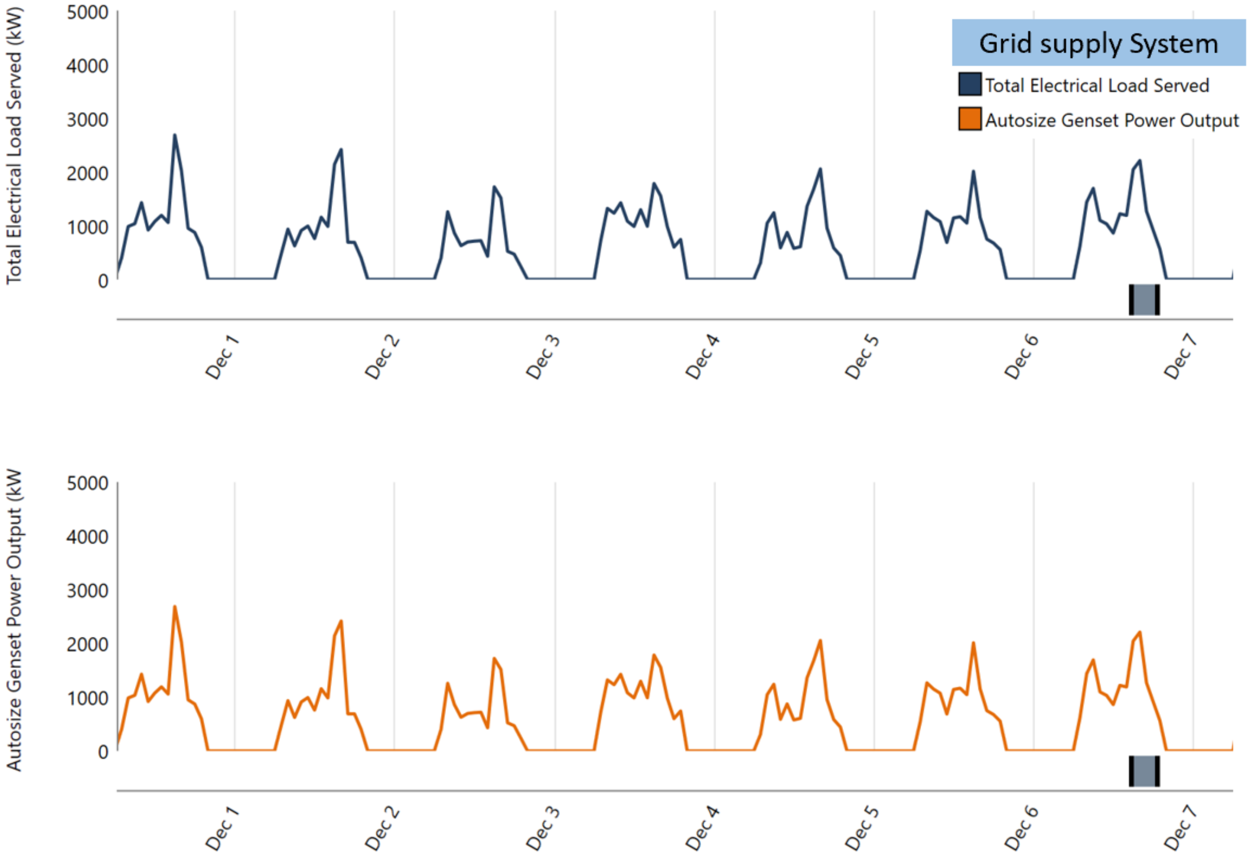


Figure 6.34 : Power of a stand-alone grid system (Case 2 - on a cloudy day)

The graph in Figure 6.34 indicates that the grid can supply the total electric load 1,444 kWh/day. The demand and supply graphs have the same value because the national grid operation supplies power equal to the demand of the load, as on a bright day.

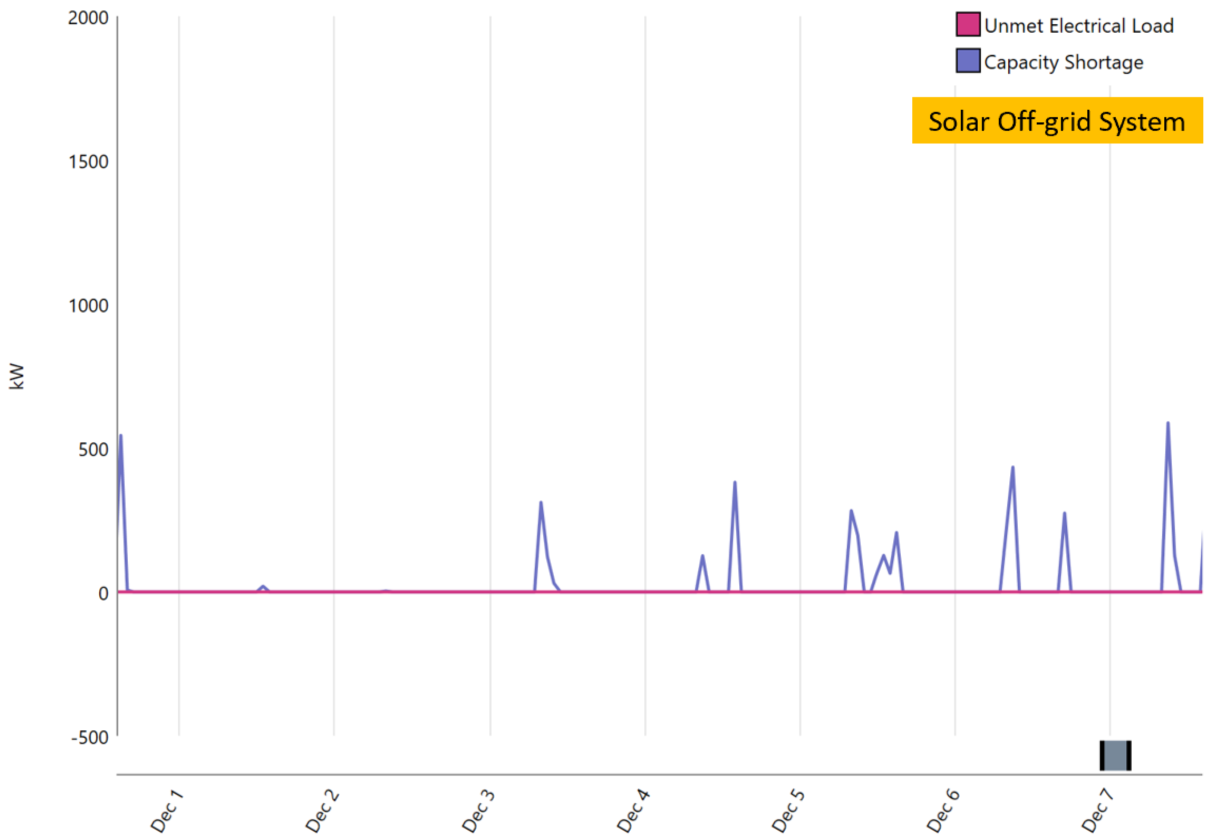


Figure 6.35 : The capacity shortage and the unmet electrical load of solar off-grid system (Case 2 - on a cloudy day)

Figure 6.35 indicates that there are a few unmet electric load and capacity shortage on cloudy days. The peak capacity shortage and the peak unmet load are 560 kW and 490 kW respectively.

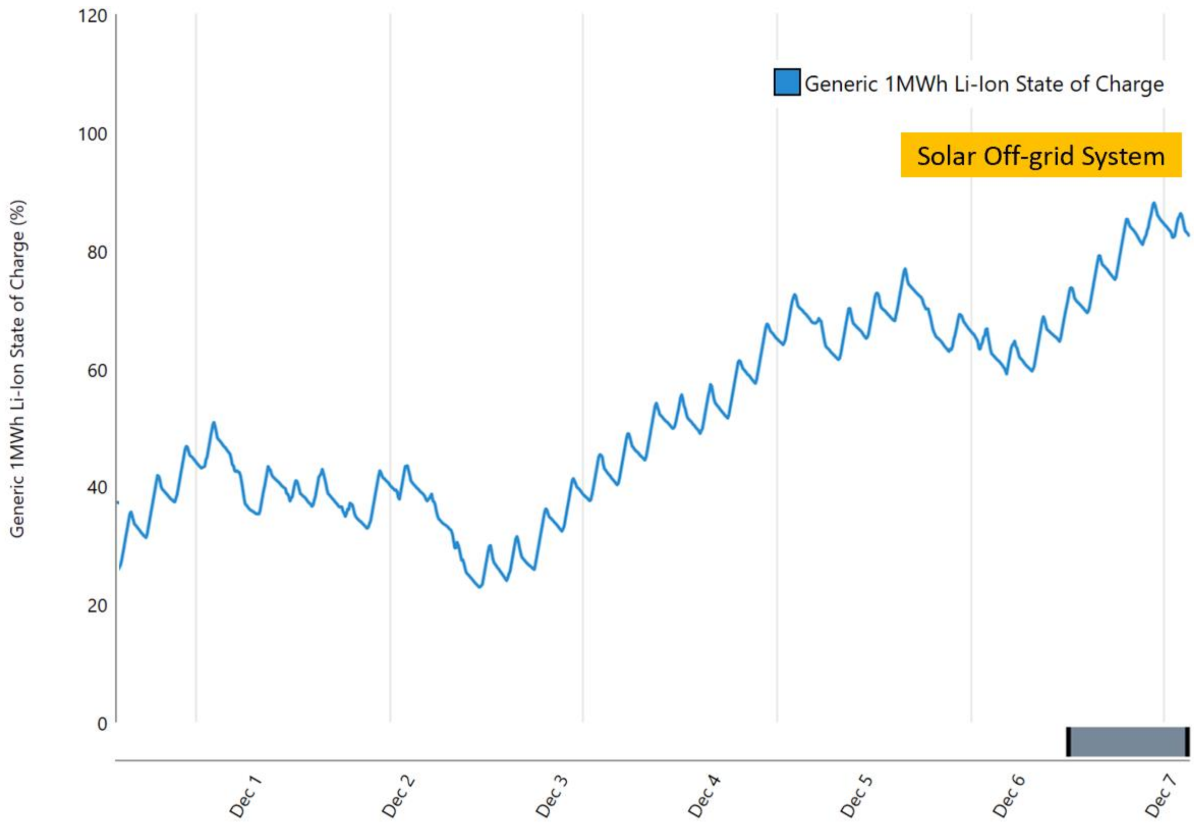


Figure 6.36 : The state of charge (SOC) of a solar off-grid system (Case 2 - on a cloudy day)

Figure 6.36 illustrates SOC's percentage, which refers to the remaining capacity level in an electric battery at a specific point. The unit of SOC is counted in the percentage (0% = empty; 100% = full). In this case, the %SOC of a battery normally works from 20% to 100%. When solar power is insufficient to supply the load, the battery will provide power from the SOC at 100%full to a minimum of 20%. When there is a surplus solar power, the surplus amount will be stored in the battery, which maintains the SOC from 20% to 100%.

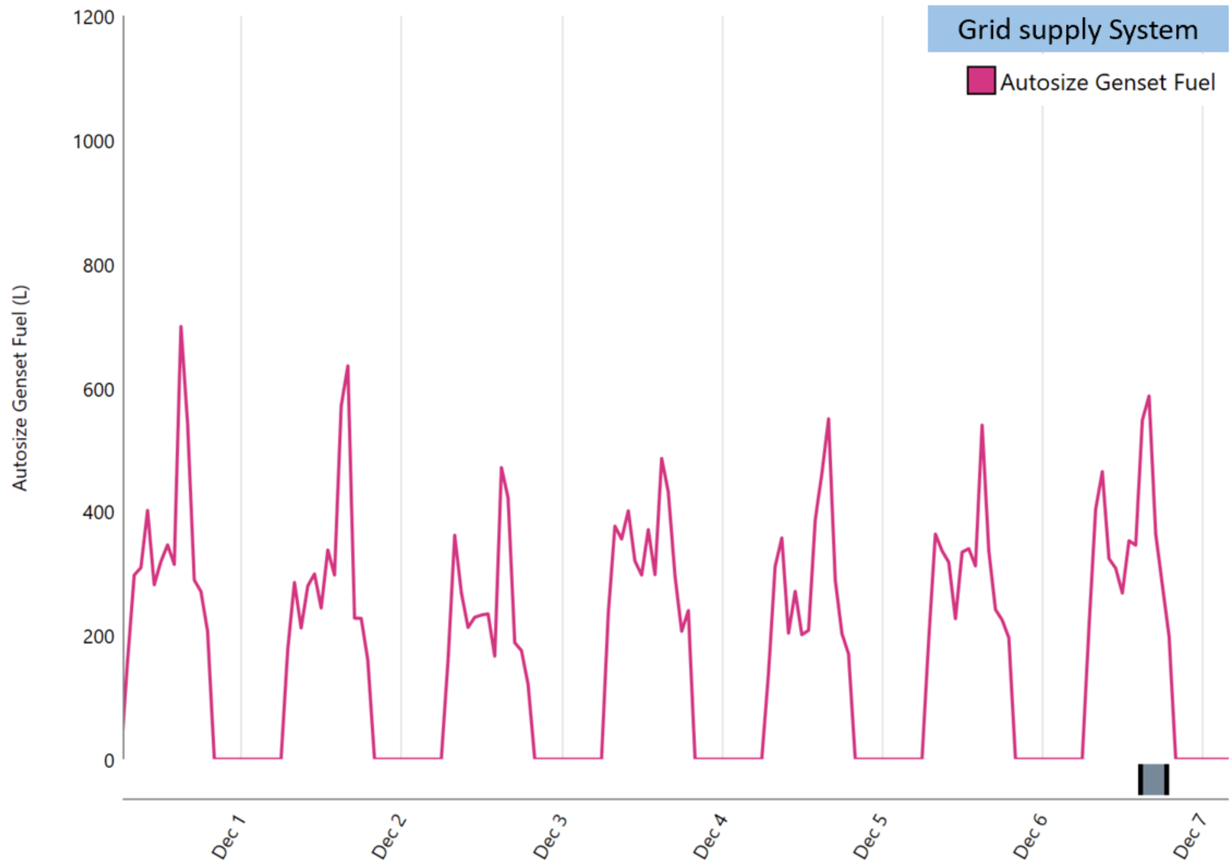


Figure 6.37 : Fuel consumption of a stand-alone grid system (Case 2 - on a cloudy day)

Figure 6.37 illustrates fuel consumption of the national grid generation, which is represented by the generator. The fuel consumes from the operating setpoint 0 litre of diesel into more than 400 litres and the peak is 800 litres.

Quantity	Value	Units
Carbon Dioxide	0	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	0	kg/yr

Solar Off-grid System

Quantity	Value	Units
Carbon Dioxide	3,761,926	kg/yr
Carbon Monoxide	23,713	kg/yr
Unburned Hydrocarbons	1,035	kg/yr
Particulate Matter	144	kg/yr
Sulfur Dioxide	9,212	kg/yr
Nitrogen Oxides	22,276	kg/yr

Grid supply System

Figure 6.38 : The Emission

As depicted in Figure 6.38, the solar off-grid system is in comparison with the grid supply system. It is clear that the solar off-grid system can reduce carbon intensity more than

3,761,926 kg CO2/year. Moreover, the annual carbon monoxide (CO), unburned hydrocarbons, particulate matter (PM), Sulfur Dioxide (SO2), and Nitrogen Oxides (NO2) are decreased around 23,713 kg, 1,035 kg, 144 kg, 9,212 kg, and 22,276 kg respectively.

Case 3: All 1,380 cars are in size L

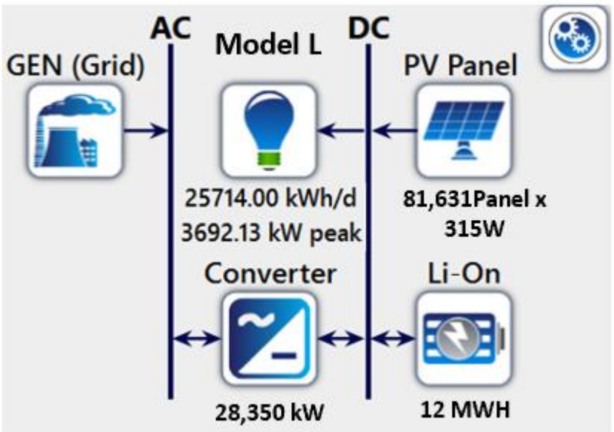


Figure 6.39 : The schematics of the system for Case 3

As demonstrated in Figure 6.39, the simulation shows the representative of EV's demand for a small-size battery based on a battery capacity 64 kWh of the KIA E-SOUL. The number of vehicles is 1,380 cars/month. The EVs demand is 25,714 kWh/day with a peak of 3,692.13 kW. According to Table 6.2, the total monthly demand is 771,420 kWh. The assumption of SOC is in a range of 20%-100% of battery. The peak time of the charging period is from 10.00 am.-10.00 pm. During the nighttime, the demand is not set to zero value as some of the EVs of the officer works in the shopping centre.

The simulation consists of a solar-car parking system and a stand-alone grid system replaced by a diesel generator.

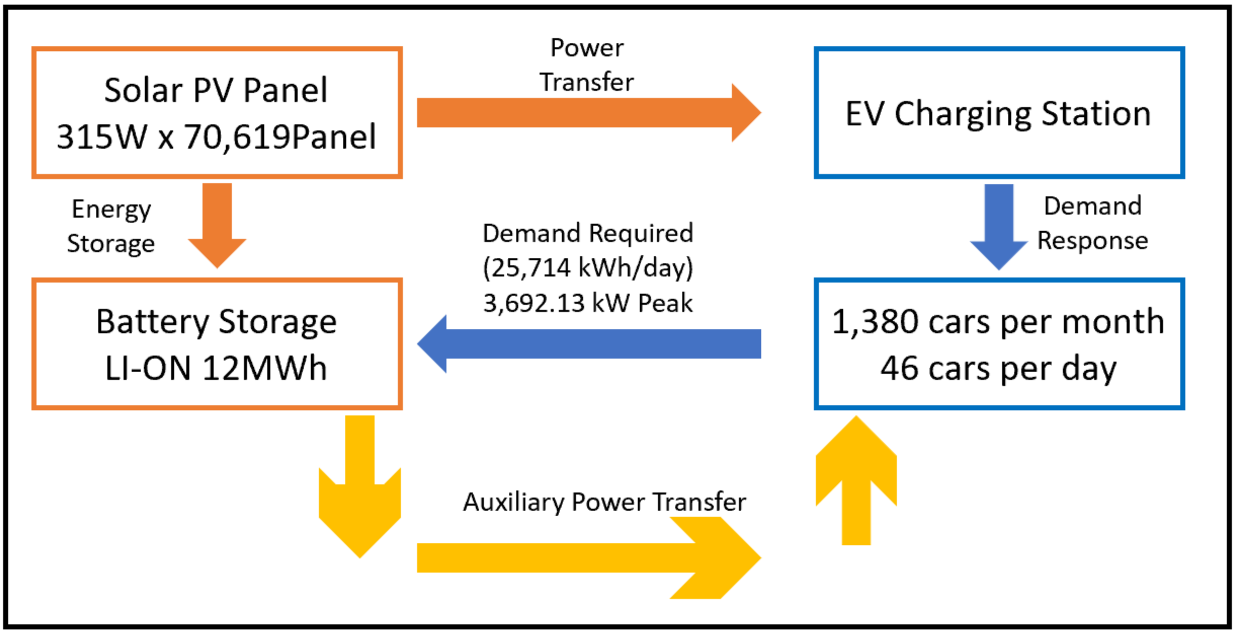


Figure 6.40 : The diagram of solar car parking system for Case 3

In Thailand, the standard PV panel used for commercial installation is a 315W PV panel. To calculate a quantity of solar panels, the electrical demand is to be divided by the standard of PV panel. In case 3 the quantity of PV panels is as follows:

22,245 kW/ 315W = 70,619 panels = 22 MWp

As for the battery capacity, normally it can be calculated by battery (Ah) = total demand (kW) / (Battery Voltage x0.6% x 0.85eff). However, this study selected to use a battery container size of Li-ON 12MWh which contains sufficient capacity for battery storage.

The component of a solar-car parking system comprises 315W x 70,619 PV panels, 12 MWh of Li-on battery, and an electrical load of model case. The total area for installing solar panel is 115,108 m2 which is 28% of shopping center.

The stand-alone grid system component consists of a diesel generator, a 25,714 kW converter, and 28,350 kW-electric demands.

<u>Case 3 - On a bright day</u>

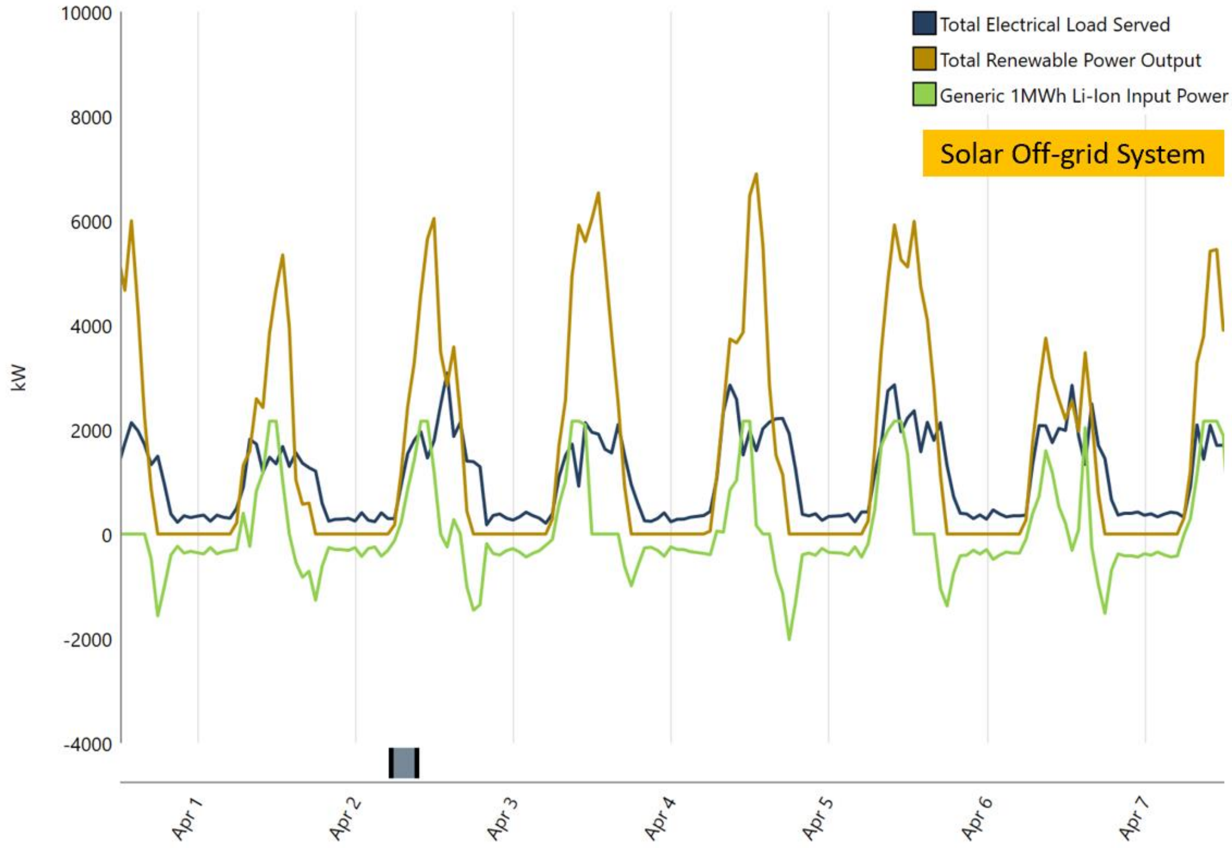


Figure 6.41 : Power of solar off-grid system (Case 3 - on a bright day)

Figure 6.41 indicates that the total energy demand is 25,714 kWh, the average of EVs demand is 2,571 kWh/day, and the peak demand is 3692.13 kWh. The upper plot expresses that the PV farm, equipped with 90 pieces of 315W PV panels, has an average output power 28,350 kWh/day. The surplus energy is around 1,121.13 kWh. The peak demand 3692.13 kWh exceeds the output power. This results in an unmet electrical load. The system has battery storage with a size of 12 MWh (1 MWh x 12 pack of Li-On) which can support the solar system when there is no power output from the solar generation.

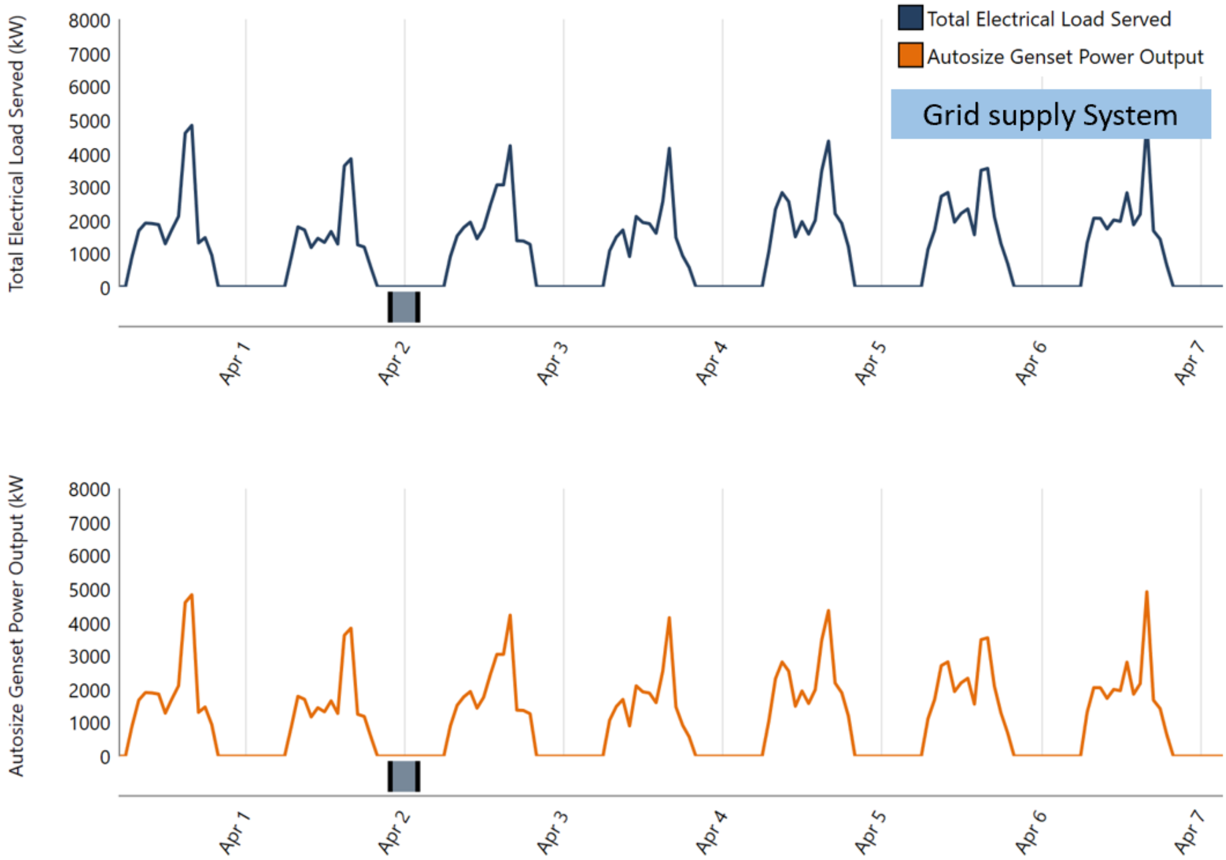


Figure 6.42 : Power of a stand-alone grid system (Case 3 - on a bright day)

Figure 6.42 depicts the car parking system when there is no power support from the solar farm. To supply the fleet demand, the system consumes power from the grid generation which generates power from non-renewable resources. This causes a high level of carbon intensity. In this simulation, the national grid is represented by GEN (a Generator). The grid can supply the total electric load 3,000 kWh/day. There is no storage system to support power during peak demand or when there is a blackout.

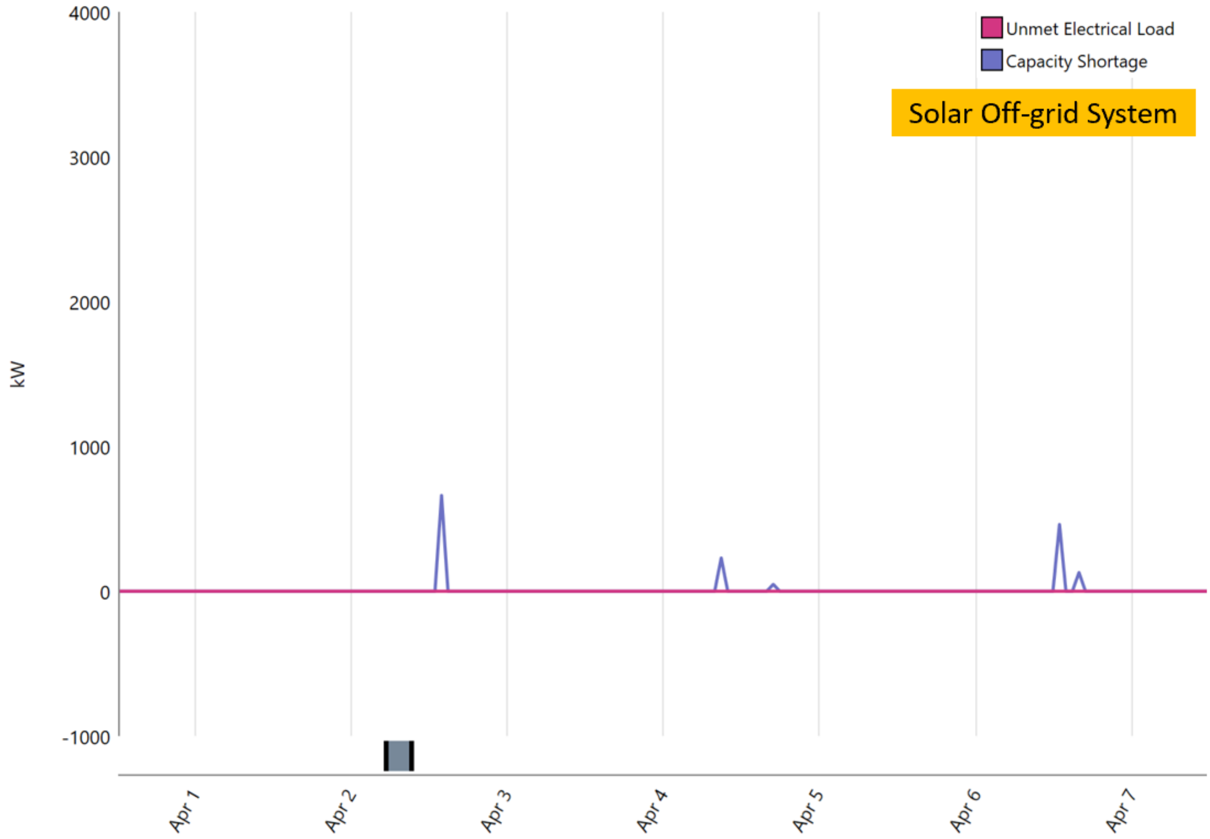


Figure 6.43 : The capacity shortage and the unmet electrical load of solar off-grid system (Case 3 - on a bright day)

Figure 6.43 indicates the deficiency of the expected minimum operating capacity and the real capacity that the system can operates. The capacity shortage reaches a peak at 700 kW. The unmet load is zero, as there is no excessive demand.

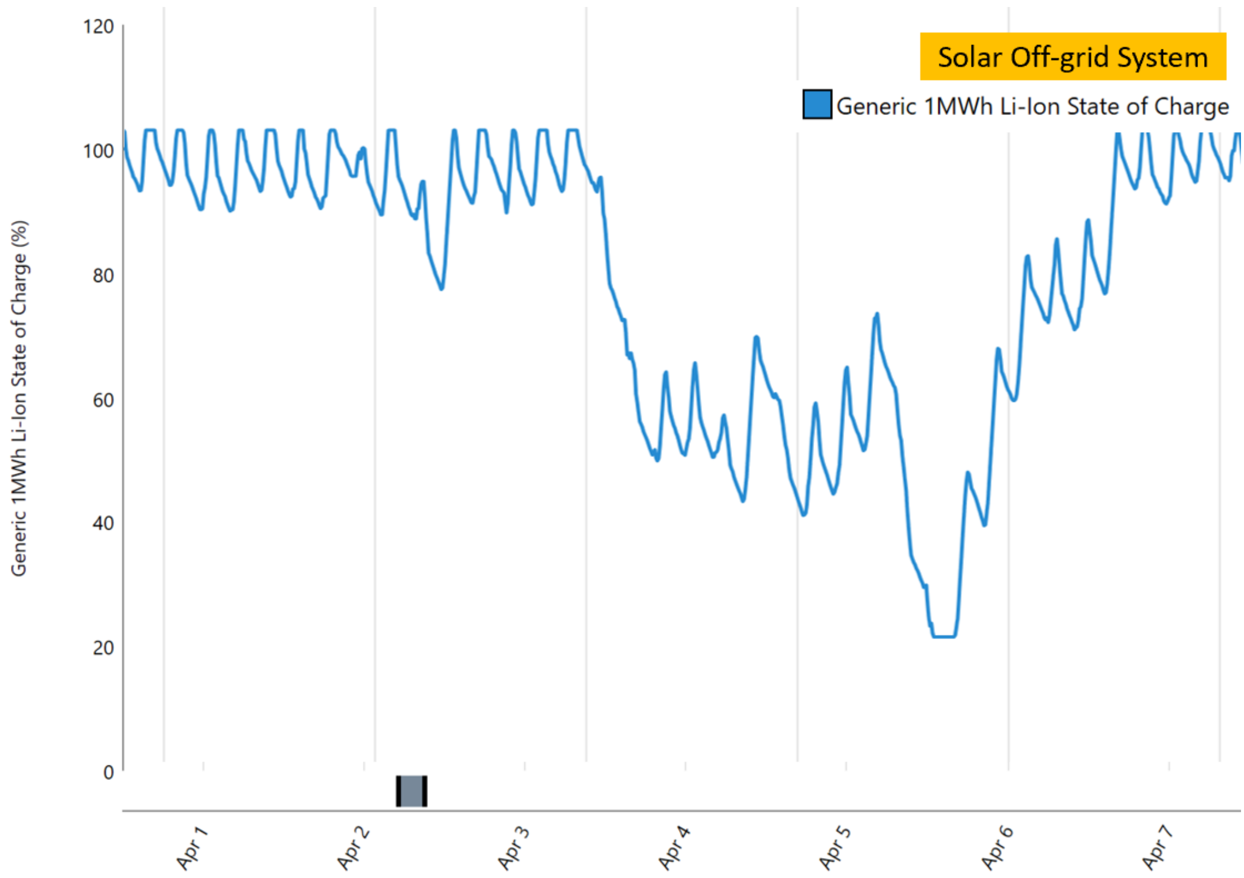


Figure 6.44 : The state of charge (SOC) of a solar off-grid system (Case 3 - on a bright day)

Figure 6.44 illustrates SOC's percentage which indicates the remaining capacity level in an electric battery at a specific point. The SOC is counted in the percentage (0% = empty; 100% = full). In this case, the %SOC of battery works normally from 20% to 100%.

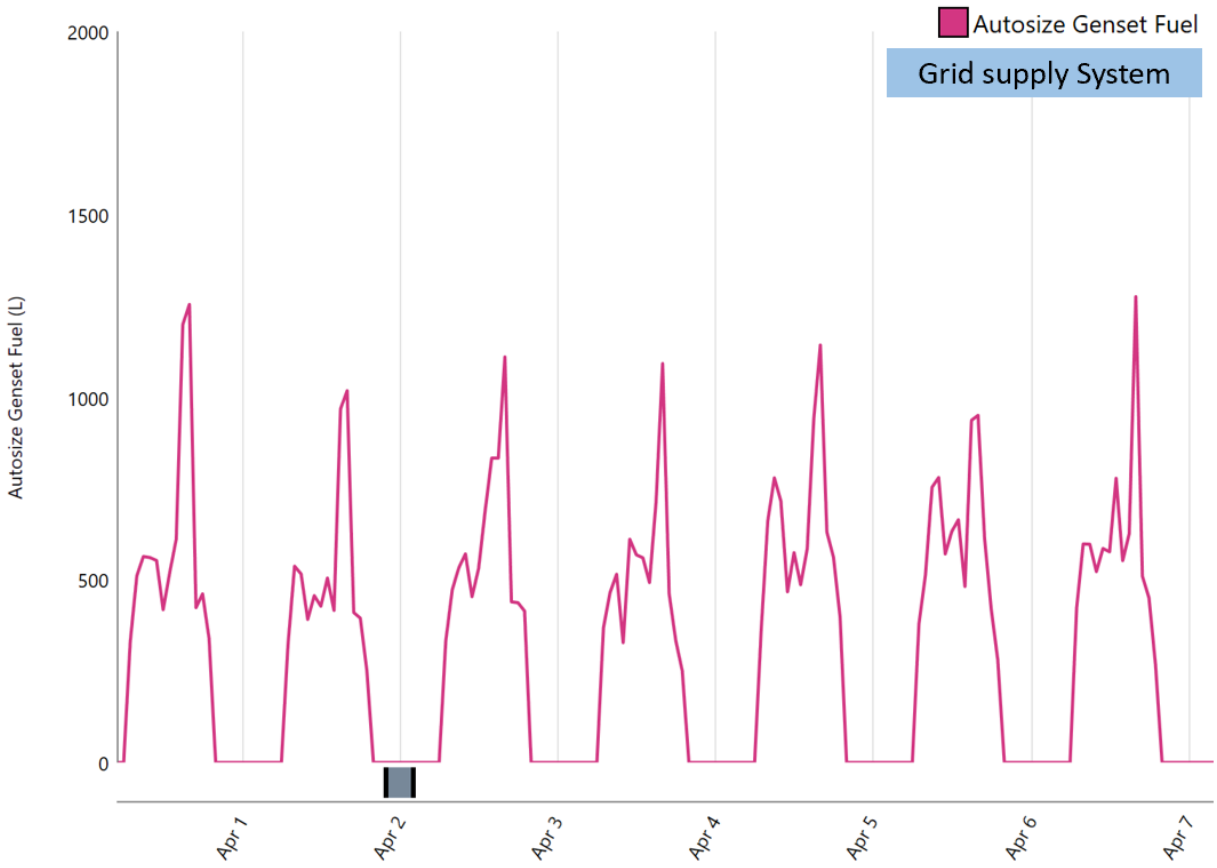


Figure 6.45 : Fuel consumption of a stand-alone grid system (Case 3 - on a bright day)

Figure 6.45 presents fuel consumption of the national grid generation, which is represented by the generator. The fuel consumes from the operating setpoint 300 litres of diesel into more than 750 litres which is 2,010 kg CO2 / hr.

Case 3 - On a cloudy day

The simulation on a cloudy day shows the worst case when the solar generation time and solar irradiation are lower than the bright day.

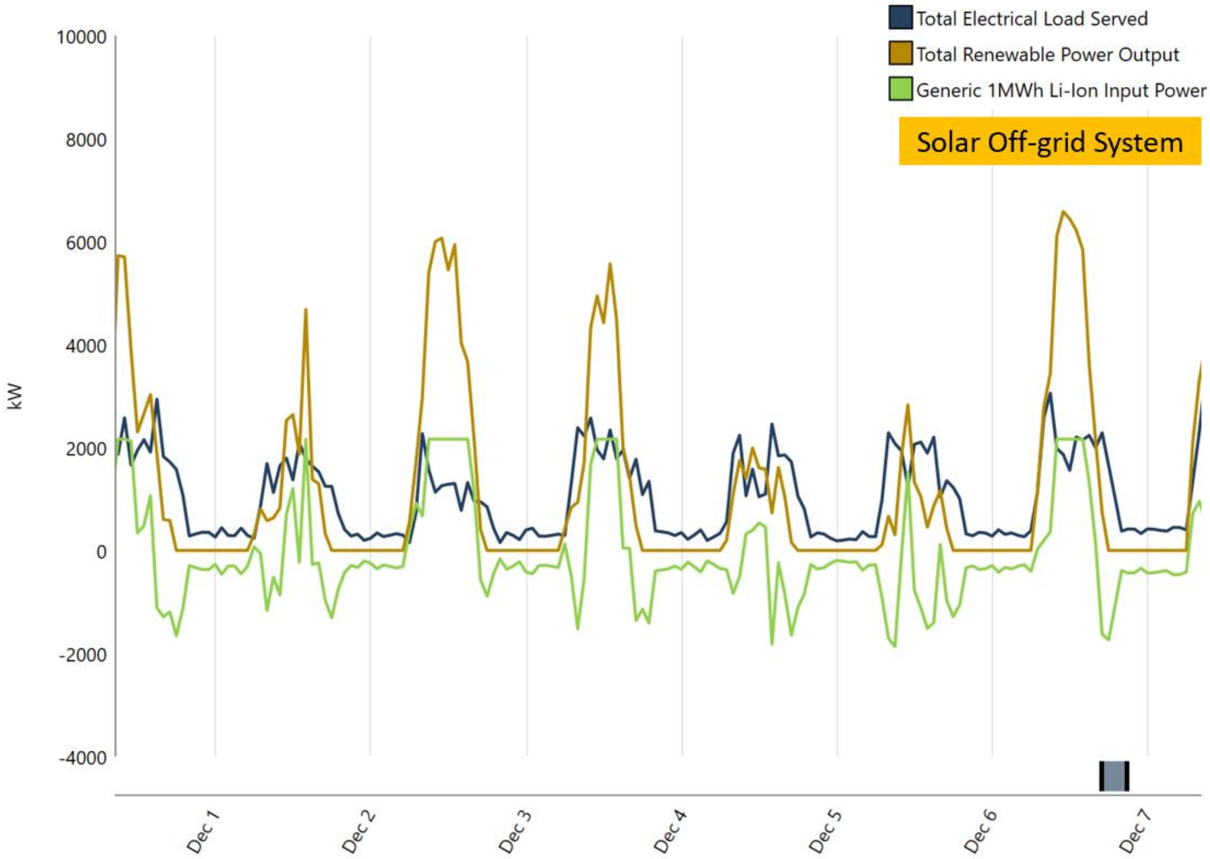


Figure 6.46 : The power of solar off-grid system (Case 3 - on a cloudy day)

Figure 6.46 illustrates the entirety of the electrical load served, the renewable system's output, and the battery's input power. The solar system can provide the power to respond to the load.

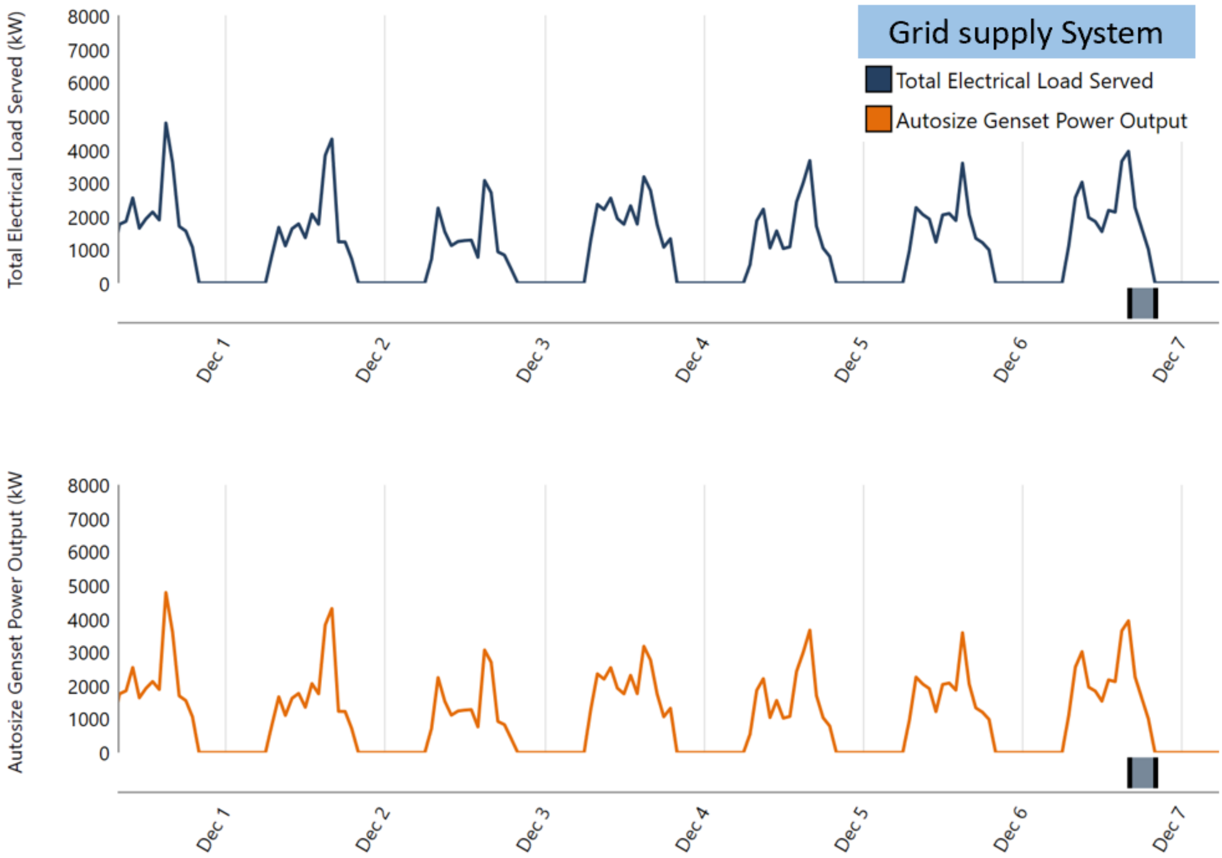


Figure 6.47 : The power from stand-alone grid system graph in (Case 3 - on a cloudy day)

As depicted in Figure 6.47, the grid can supply the total electric load with a 2,571.4 kWh/day. The demand and supply graphs have the same value because the national grid operation supplies power equal to the demand of the load, as on the bright day.

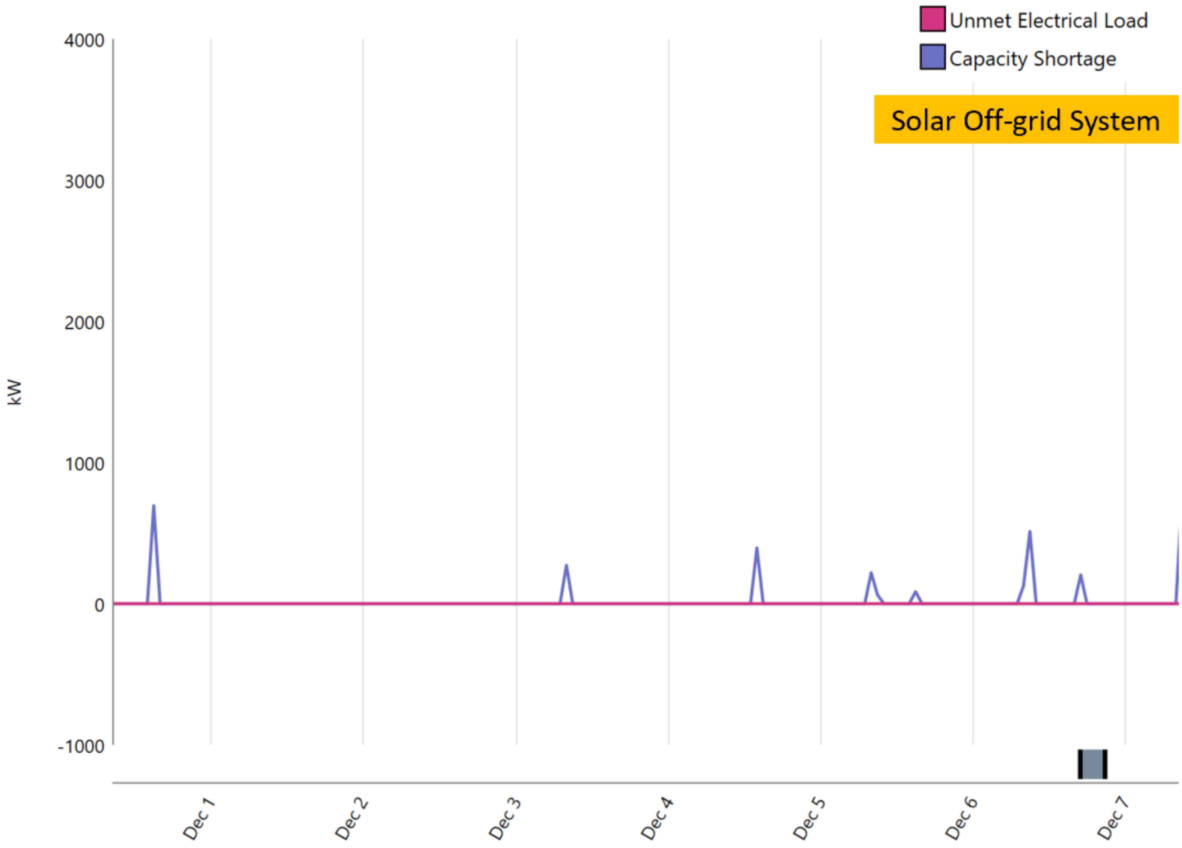


Figure 6.48 : The capacity shortage and the unmet electrical load of solar off-grid system (Case 3 - on a cloudy day)

Figure 6.48 indicates that there are a few unmet electric load and capacity shortage on cloudy days. The peak capacity shortage and the peak unmet load are 850 kW and 560 Kw respectively.

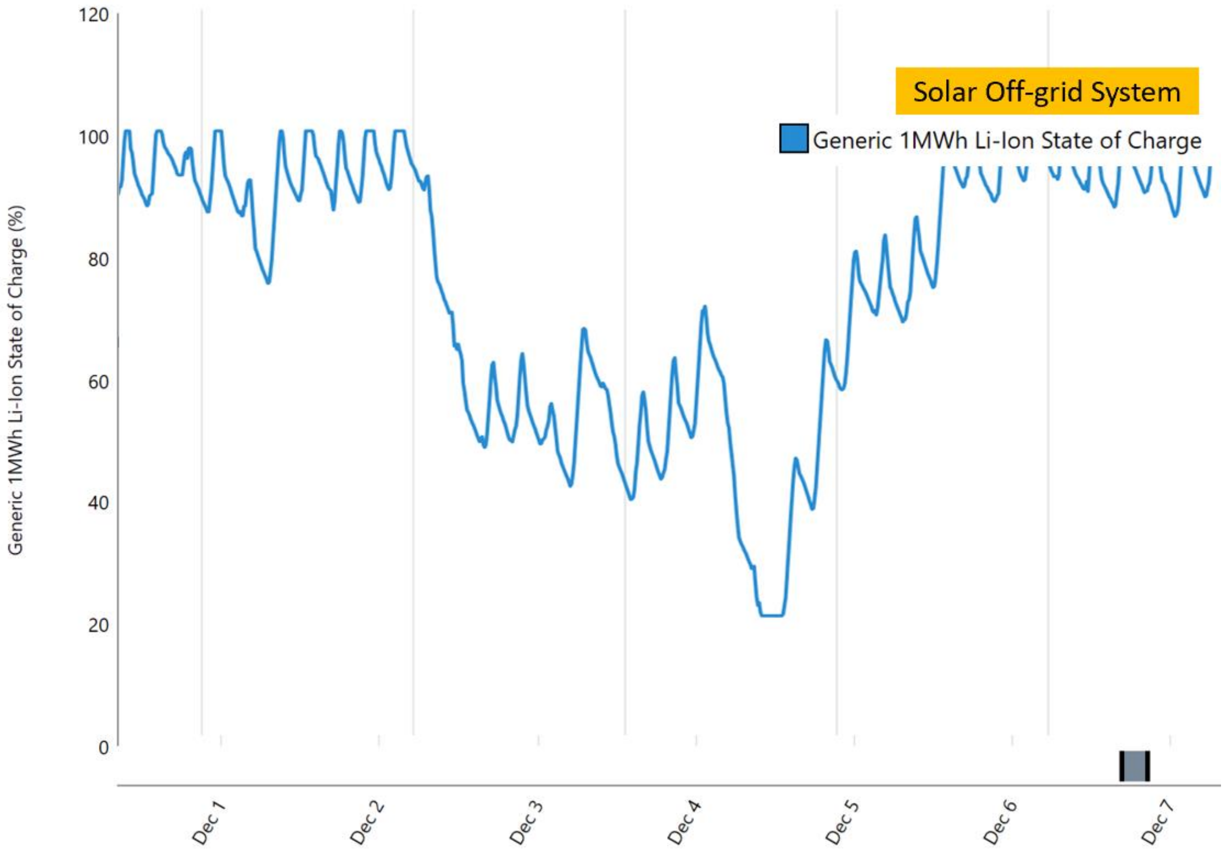


Figure 6.49 : The state of charge (SOC) of a solar off-grid system (Case 3 - on a cloudy day)

Figure 6.49 illustrates SOC's percentage, which refers to the remaining capacity level in an electric battery at a specific point. The unit of SOC is counted in the percentage (0% = empty; 100% = full). In this case, the %SOC of a battery normally works from 20% to 100%. When solar power is insufficient to supply the load, the battery will provide power from the SOC at 100%full to a minimum of 20%. When there is a surplus solar power, the surplus amount will be stored in the battery, which maintains the SOC from 20% to 100%.

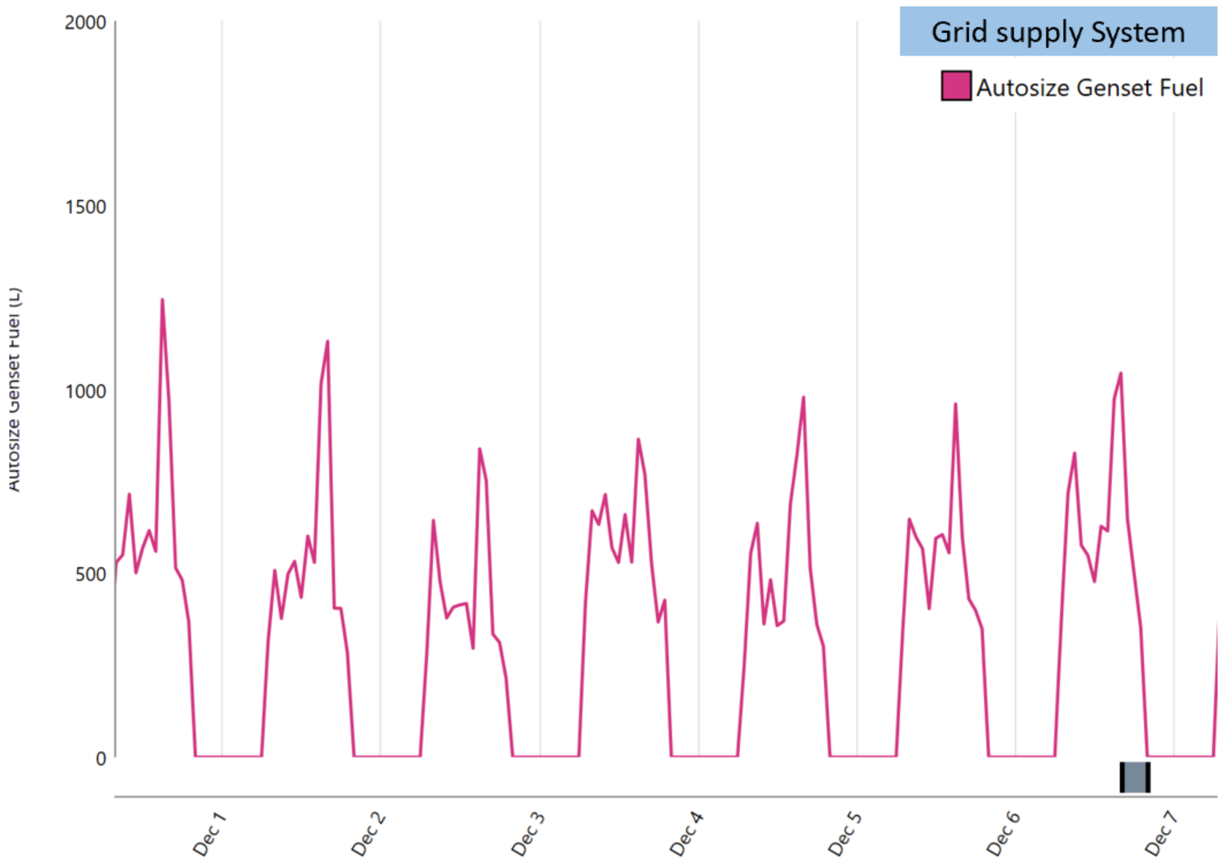


Figure 6.50 : Fuel consumption of a stand-alone grid system (Case 3 - on a cloudy day)

Figure 6.50 expresses fuel consumption of the national grid generation, which is represented by the generator. The fuel consumes from the operating setpoint 0 litre of diesel into more than 700 litres, and the peak is 1200 litres.

Quantity	Value	Units
Carbon Dioxide	0	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	0	kg/yr

Solar Off-grid System

Quantity	Value	Units
Carbon Dioxide	9,012,521	kg/yr
Carbon Monoxide	56,810	kg/yr
Unburned Hydrocarbons	2,479	kg/yr
Particulate Matter	344	kg/yr
Sulfur Dioxide	22,070	kg/yr
Nitrogen Oxides	53,367	kg/yr

Grid supply System

Figure 6.51 : The Emission

As depicted in Figure 6.51 the solar off-grid system is in comparison with the grid supply system. It is clear that the solar off-grid system can reduce carbon intensity more than 9,012,521 kg CO2 per year. Moreover, the annual of a carbon monoxide (CO), unburned hydrocarbons, particulate matter (PM), Sulfur Dioxide (SO2), and Nitrogen Oxides (NO2) decrease about 56,810 kg, 2,479 kg, 344 kg, 22,070 kg, and 53,367 kg respectively.

Case 4: All 1,380 cars are in size XL

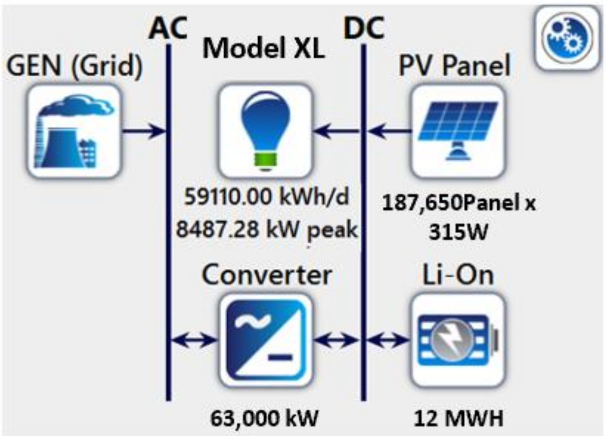


Figure 6.52 : The schematics of the system for Case 4

As depicted in Figure 6.52, the simulation shows the representative of EV's demand for an X-large size battery based on a battery capacity of around 100 kWh of the Tesla MODEL S. The number of vehicles is 1,380 cars/month. According to Table 6.2, the total monthly demand is 1,773,300 kWh. The EVs demand is 59,110 kWh/day with a peak of 8,487.28 kW. The assumption of SOC is in a range of 20%-100% of the battery. The peak time of the charging period is from 10.00 am.-10.00 pm. During the nighttime, the demand is not set to zero value as there are some of the EVs of the officers working in the shopping centre.

The simulation consists of two systems: a solar-car parking system and a stand-alone grid system which replaced by a diesel generator.

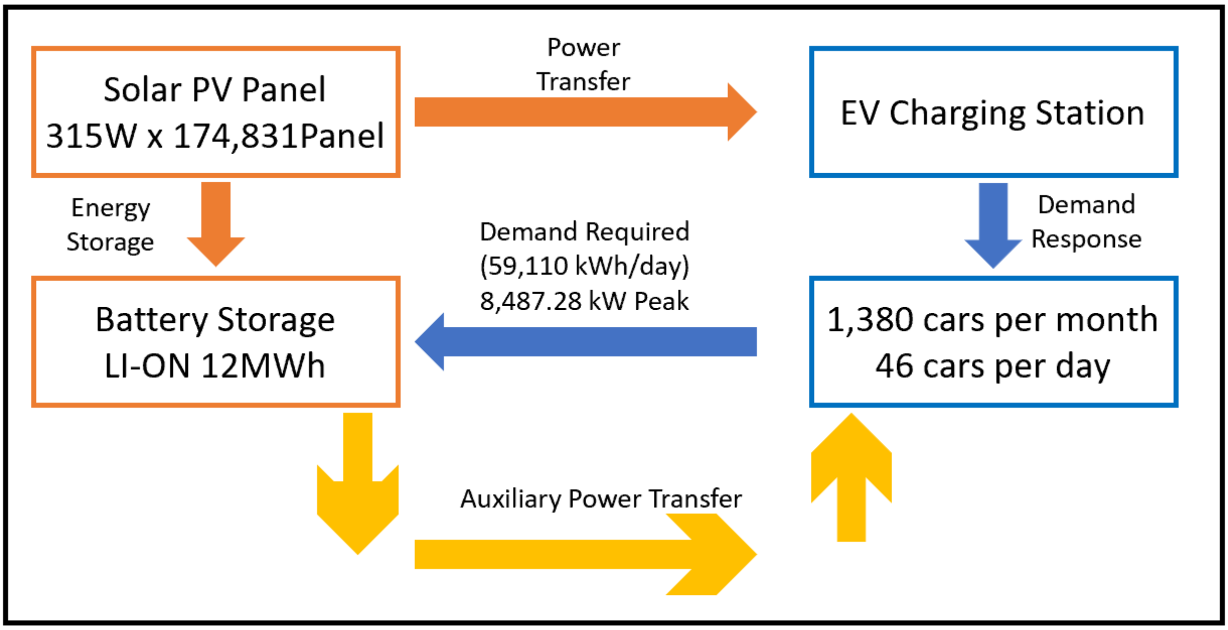


Figure 6.53 : The diagram of solar car parking system for Case 4

In Thailand, the standard PV panel used for commercial installation is a 315W PV panel. To calculate a quantity of solar panels, the electrical demand is to be divided by the standard of PV panel. In case 4 the quantity of PV panels is as follows:

55,072 kW/ 315W = 174,831 panels = 55 MWp

As for the battery capacity, normally it can be calculated by battery (Ah) = total demand (kW) / (Battery Voltage x0.6% x 0.85eff). However, this study selected to use a battery container size of Li-ON 12MWh which contains sufficient capacity for battery storage.

The component of a solar-car parking system comprises 315 W x 174,831 PV panels, 12MWh of Li-on Battery, and an electrical load of the model case. The total area for installing solar panel is 337,423 m2 which is 84% of shopping center.

The stand-alone grid system component consists of a diesel generator, a 59,110 kW converter, and 63,000 kW electric demands.

<u>Case 4 - On a bright day</u>

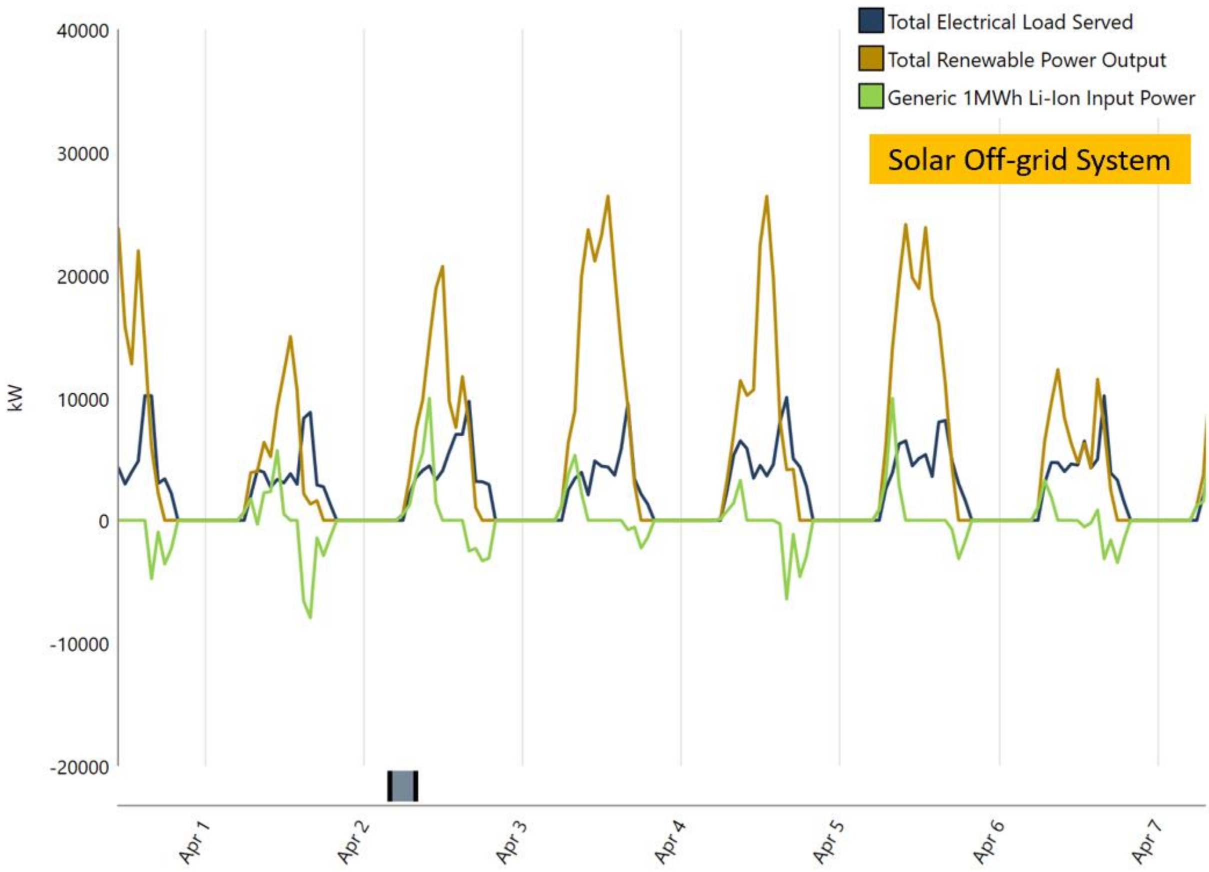


Figure 6.54 : The power from solar off-grid system (Case 4 - on a bright day)

Figure 6.54 demonstrates that the energy demand is 59,110 kWh, the average of EVs demand is 5,911 kWh/day, and the peak demand is 8,487 kWh. The upper plot shows that the PV farm, equipped with 200 pieces of 315 W PV panels, has an output power of about 63,000 kW/day. The surplus energy is around 2,187 kWh. The peak demand 8,487 kWh exceeds the solar output power. This results in an unmet electrical load. The system has battery storage with a size of 12 MWh (1 MWh x 12 pack of Li-On) which can support the solar system when there is no power output of the solar generation.

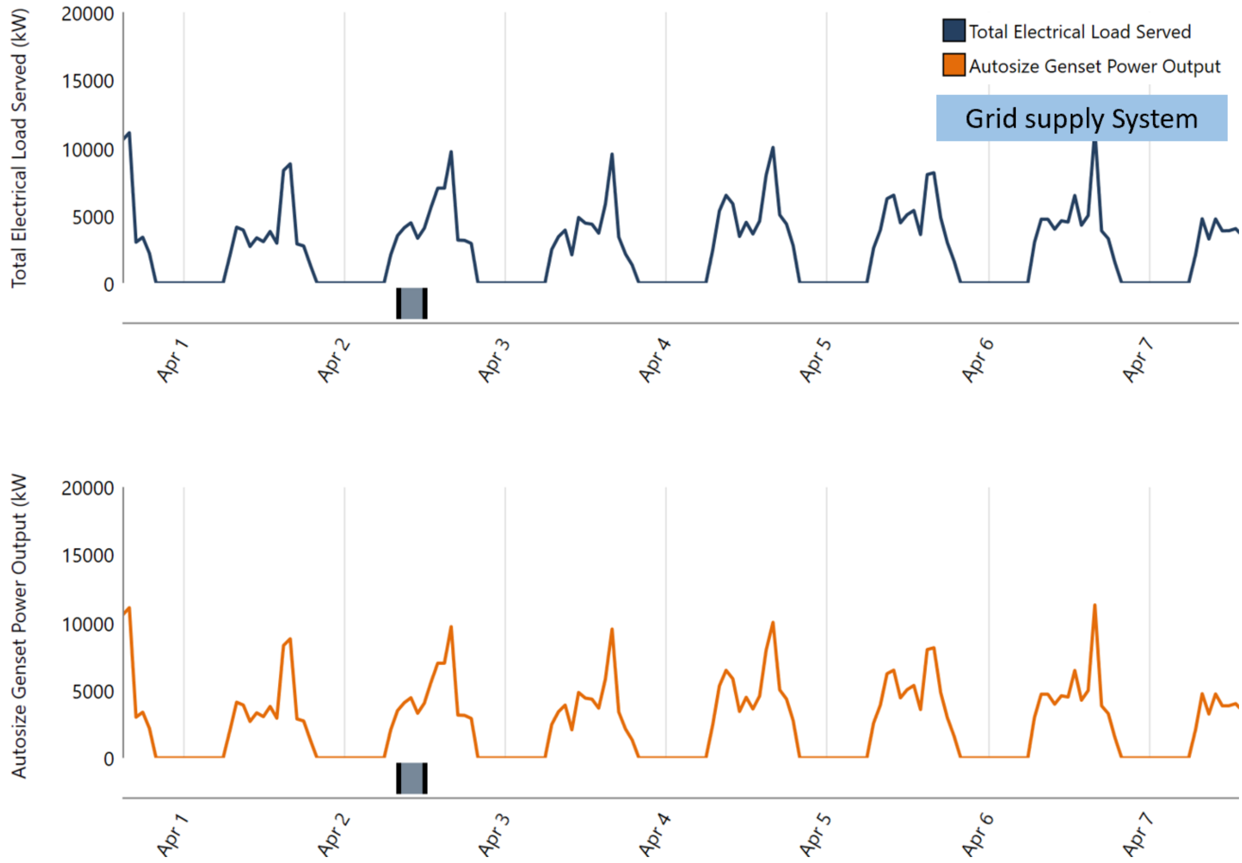


Figure 6.55 : The power from stand-alone grid system (Case 4 - on a bright day)

Figure 6.55 depicts the car parking system when there is no support from the solar farm. To supply the fleet demand, the system consumes power from the grid generation which generates power from non-renewable resources. This causes a high level of carbon intensity. In this simulation, the national grid is represented by GEN (a Generator). The grid can supply the total electric load 6,000 kW/day, but there is no storage system to support power during the peak demand or when there is a blackout.

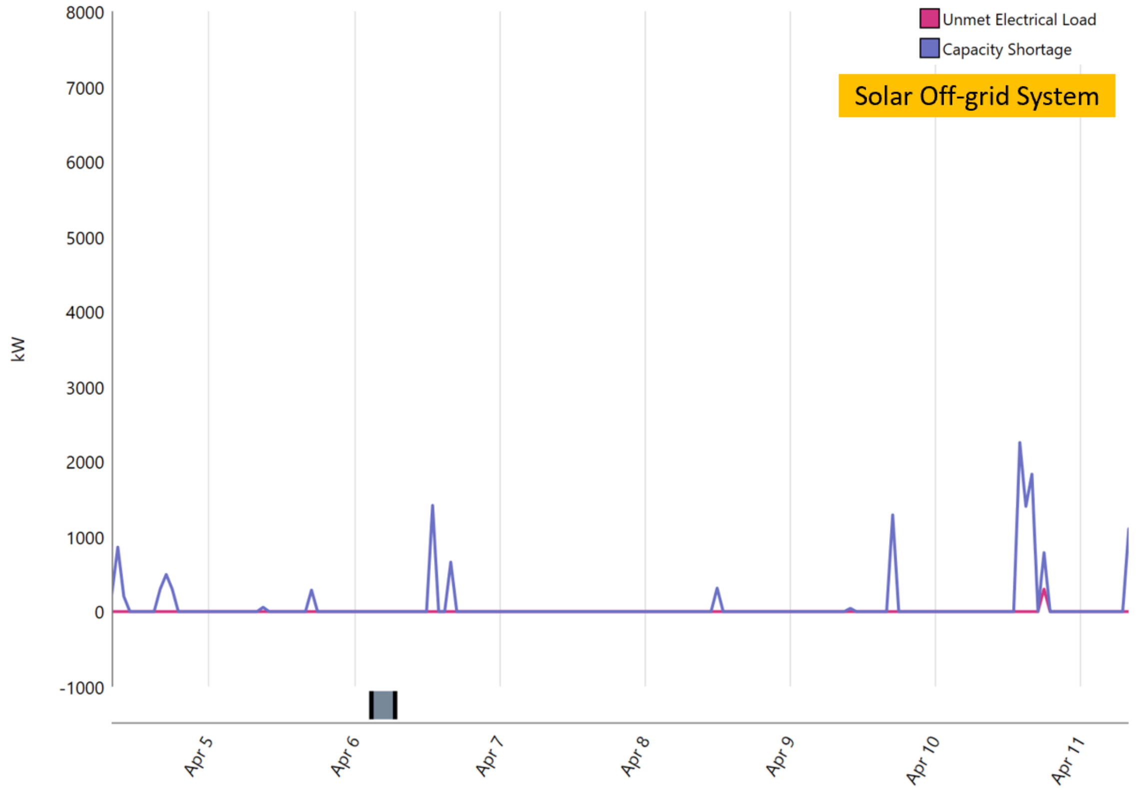


Figure 6.56 : The capacity shortage and the unmet electrical load of solar off-grid system (Case 4 - on a bright day)

Figure 6.56 indicates that there are a few unmet electric load and capacity shortage on cloudy days. The peak capacity shortage and the peak unmet load are 2,250 kW and 200 Kw respectively.

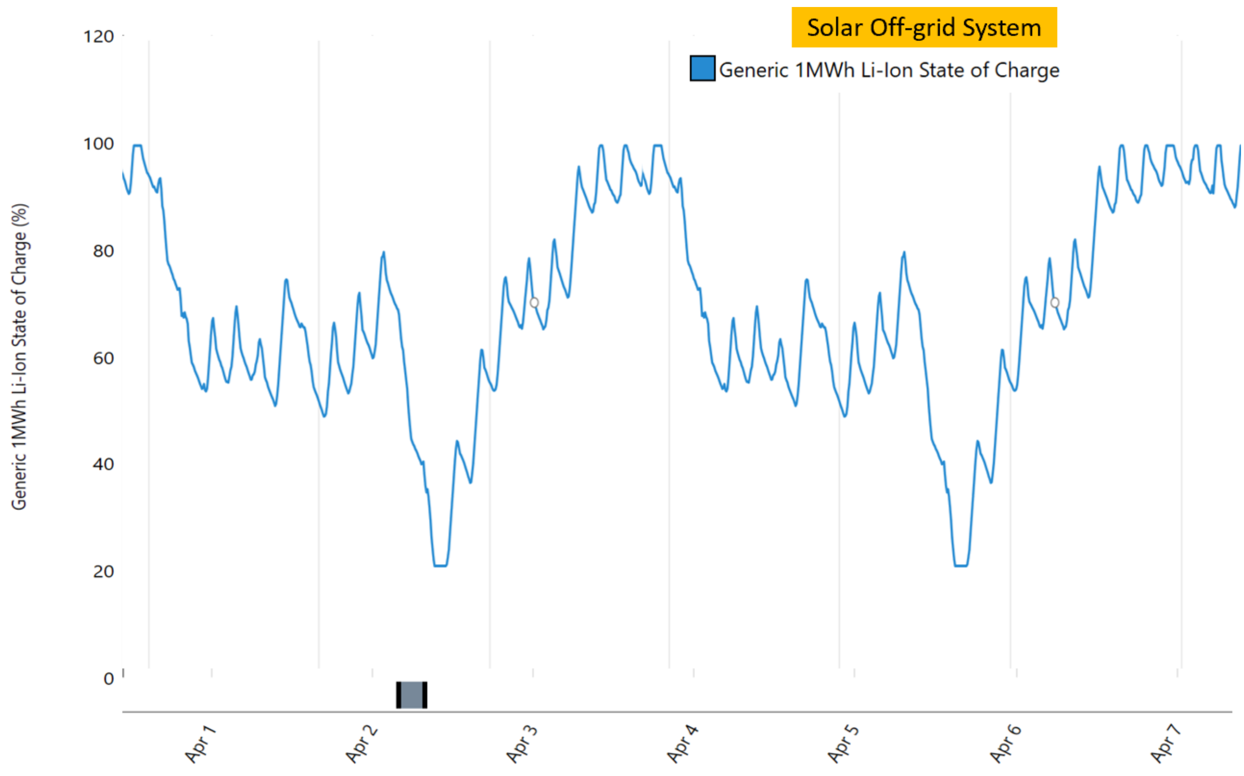


Figure 6.57 : The state of charge (SOC) of a solar off-grid system (Case 4 - on a bright day)

Figure 6.57 illustrates SOC's percentage, which refers to the remaining capacity level in an electric battery at a specific point. The unit of SOC is counted in the percentage (0% = empty; 100% = full). In this case, the %SOC of a battery normally works from 20% to 100%.

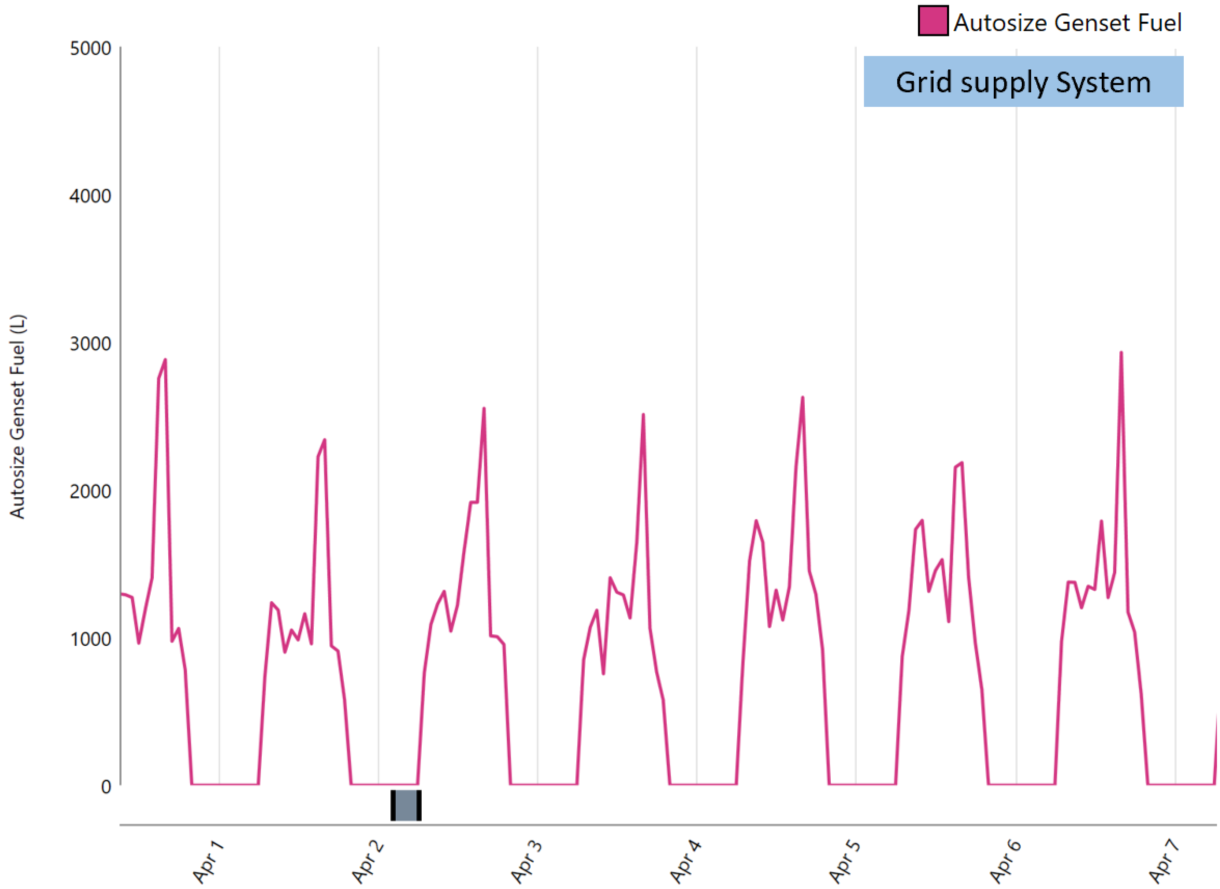


Figure 6.58 : Fuel consumption of a stand-alone grid system (Case 4 - on a bright day)

Figure 6.58 presents fuel consumption of the national grid generation, which is represented by the generator. The fuel consumes from the operating setpoint 750 litres of diesel into more than 1500 litres which is 4,020 kg CO_2 / hr.

Case 4 - On a cloudy day

The simulation on a cloudy day shows the worst case when the solar generation time and solar irradiation are lower than those of the bright day.

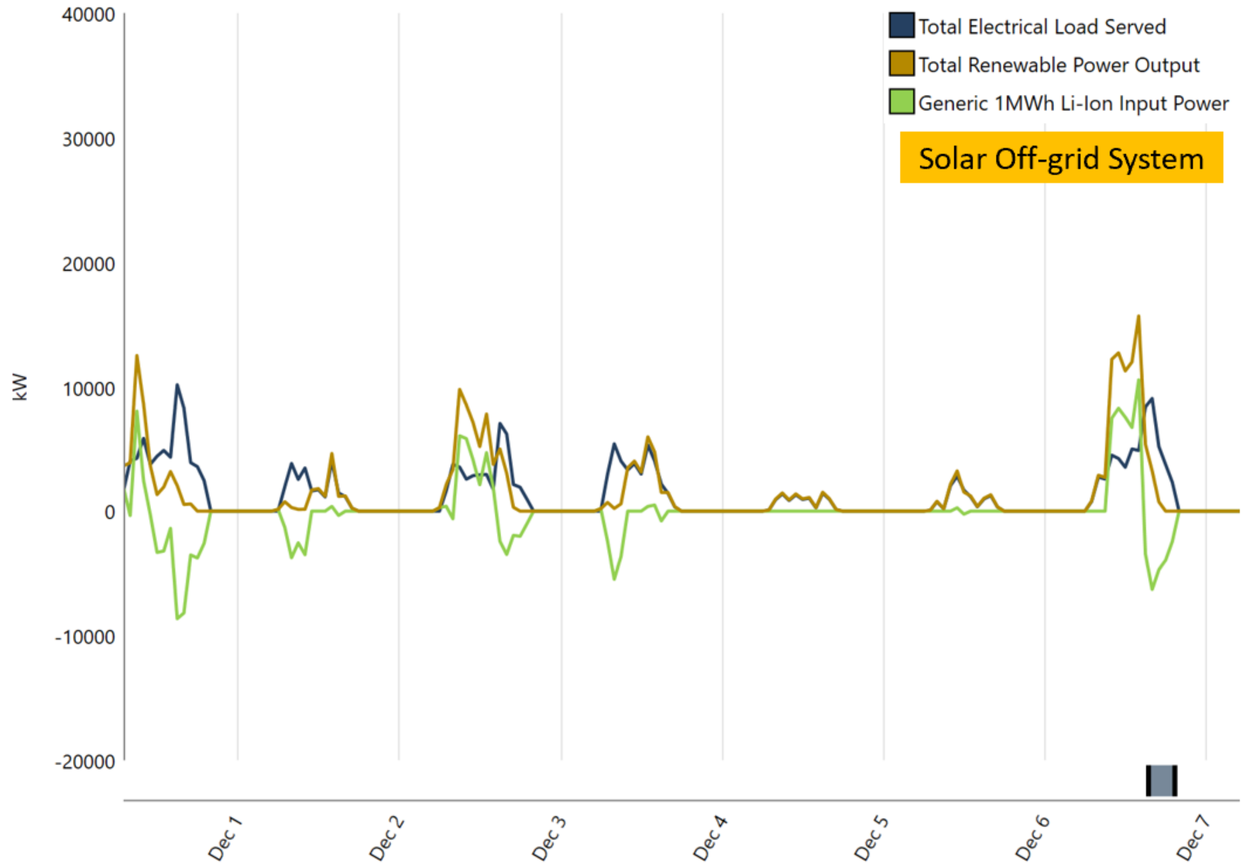


Figure 6.59 : The power of solar off-grid system (Case 4 - on a cloudy day)

Figure 6.59 depicts the entirety of the electrical load served, the renewable system's output, and the battery's input power. The solar system can provide the power to respond to the load.

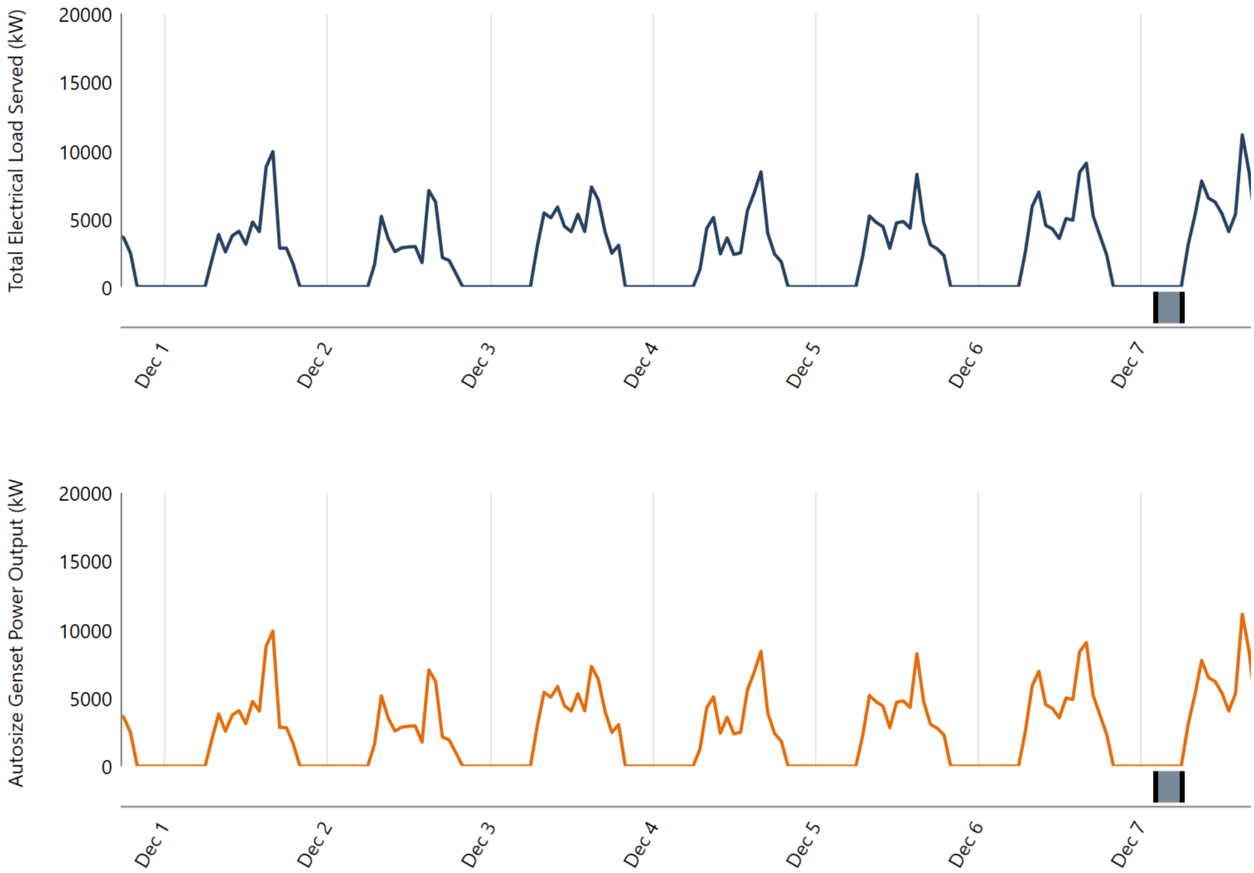


Figure 6.60 : The power from stand-alone grid system graph in (Case 4 - on a cloud day)

As depicted in Figure 6.60, the grid can supply the total electric load 5,911.1 kWh/day. The demand and supply graphs have the same value because the national grid operation supplies power equal to the demand of the load, as on a bright day.

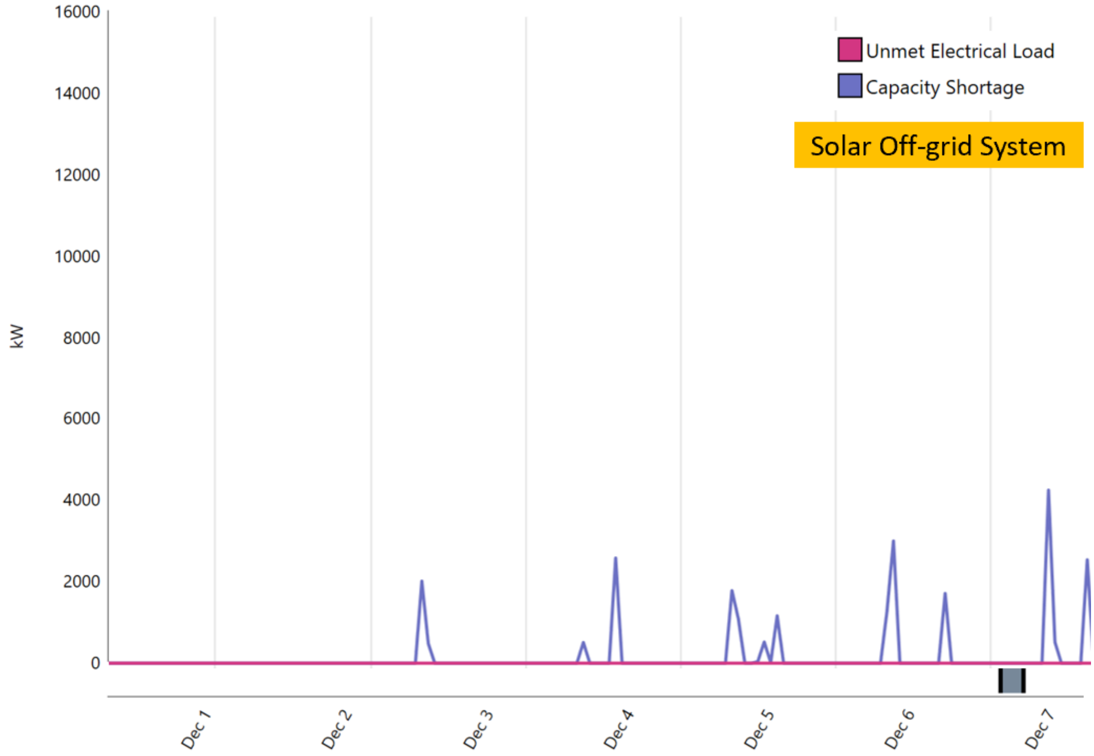


Figure 6.61 : The capacity shortage and the unmet electrical load of solar off-grid system (Case 4 - on a cloudy day)

Figure 6.61 indicates that there are a few unmet electric load and capacity shortage on cloudy days. The peak capacity shortage and the peak unmet load are 1850 kW and 660 kW respectively.

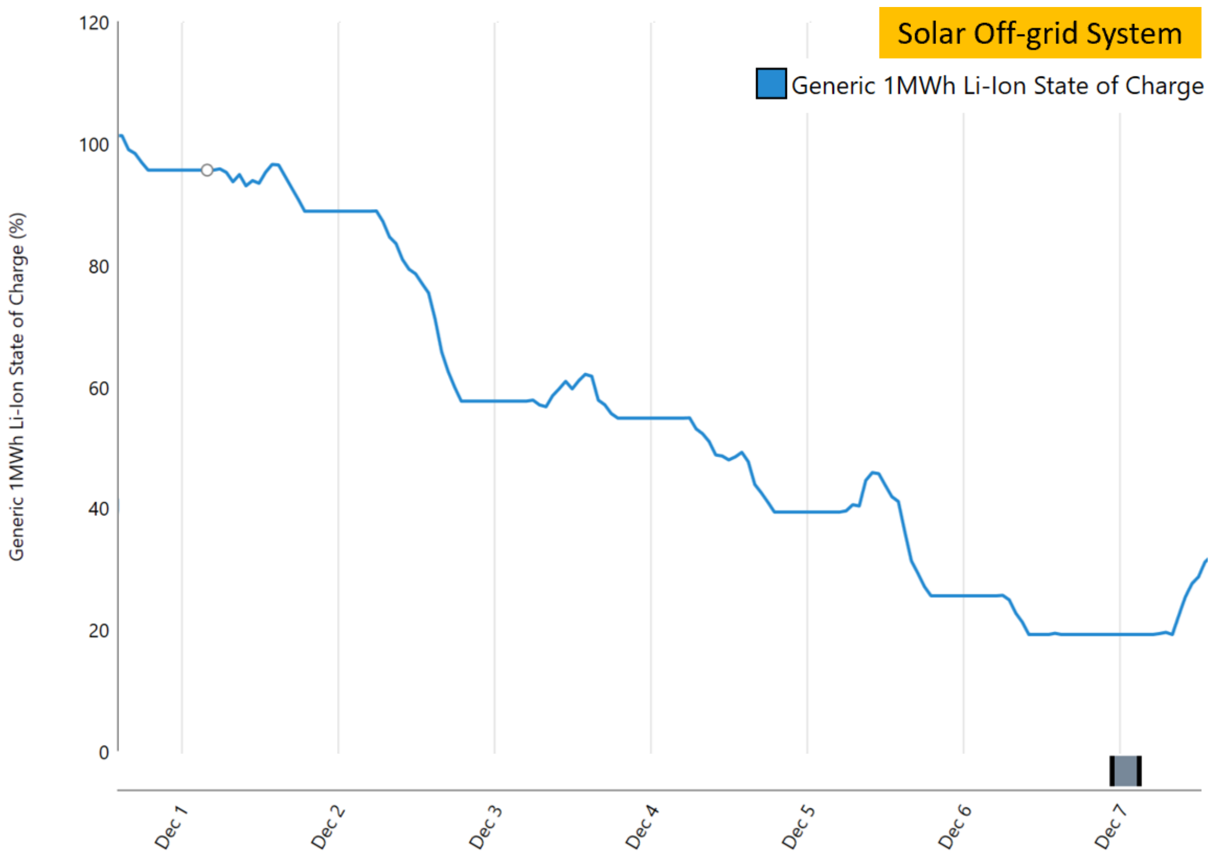


Figure 6.62 : The state of charge (SOC) of a solar off-grid system (Case 4 - on a cloudy day)

Figure 6.62 illustrates SOC's percentage, which refers to the remaining capacity level in an electric battery at a specific point. The unit of SOC is counted in the percentage (0% = empty; 100% = full). In this case, the %SOC of a battery normally works of 20% to 100%. When solar power is insufficient to supply the load, the battery will provide power from the SOC at 100%full to a minimum of 20%. When there is a surplus solar power, the surplus amount will be stored in the battery, which maintains the SOC from 20% to 100%.

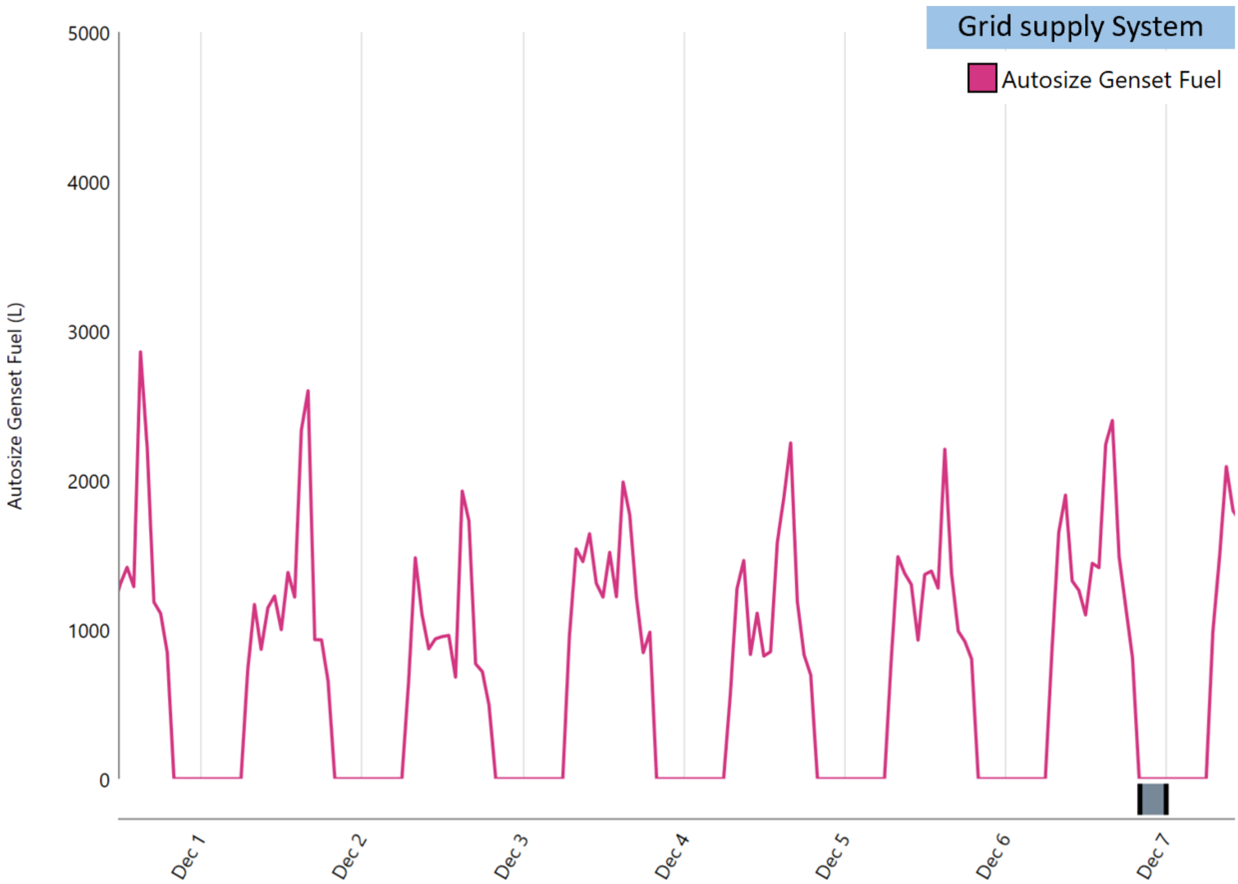


Figure 6.63 : Fuel consumption of a stand-alone grid system (Case 4 - on a cloudy day)

Figure 6.63 expresses fuel consumption of the national grid generation, which is represented by the generator. The fuel consumes from the operating setpoint 0 litre of diesel into more than 1700 litres and the peak is 2200 litres.

Quantity	Value	Units
Carbon Dioxide	0	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	0	kg/yr

Solar Off-grid System

Quantity	Value	Units
Carbon Dioxide	20,691,189	kg/yr
Carbon Monoxide	130,426	kg/yr
Unburned Hydrocarbons	5,691	kg/yr
Particulate Matter	790	kg/yr
Sulfur Dioxide	50,668	kg/yr
Nitrogen Oxides	122,521	kg/yr

Grid supply System

Figure 6.64 : The Emission

As depicted in Figure 6.64 the solar off-grid system is in comparison with the grid supply system. It is clear that the solar off-grid system can reduce carbon intensity more than 20,691,189 kg CO2/year. Moreover, the annual of carbon monoxide (CO), unburned hydrocarbons, particulate matter (PM), Sulfur Dioxide (SO2), and Nitrogen Oxides (NO2) decrease around 130,426 kg, 5,691 kg, 790 kg, 50,668 kg, and 122,521 kg respectively.

Case 5: The cars are mixed with size S, M, L, and XL

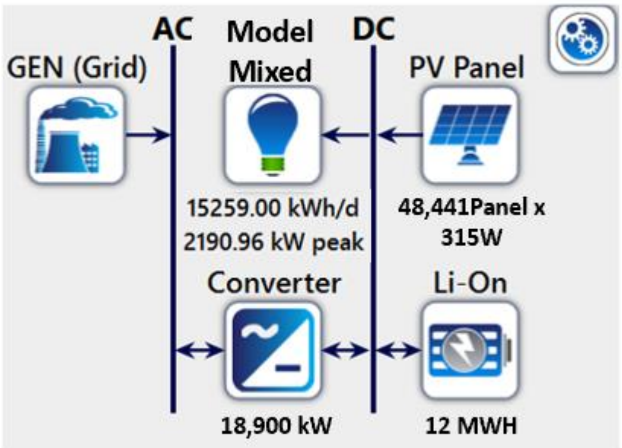


Figure 6.65 : The schematics of the system for Case 5

As demonstrated in Figure 6.65, the simulation shows the representative of EV's demand of a mixed-size battery based on the combined battery capacity of the FOMM One, Nissan Leaf, KIA E-SOUL, and TESLA model S. The number of vehicles is 1,380 cars/month. According to Table 6.2, the total monthly demand is 457,776 kWh. The EVs demand is 15,259 kWh/day with a peak of 2,190.96 kW. The assumption of SOC is in a range of 20%-100% of the battery. The peak time of the charging period is from 10.00 am.-10.00 pm. During the nighttime, the demand is not set to zero value as there are some of the EVs of the officers working in the shopping centre.

The simulation consists of two systems: a solar-car parking system and a stand-alone grid system which replaced by a diesel generator.

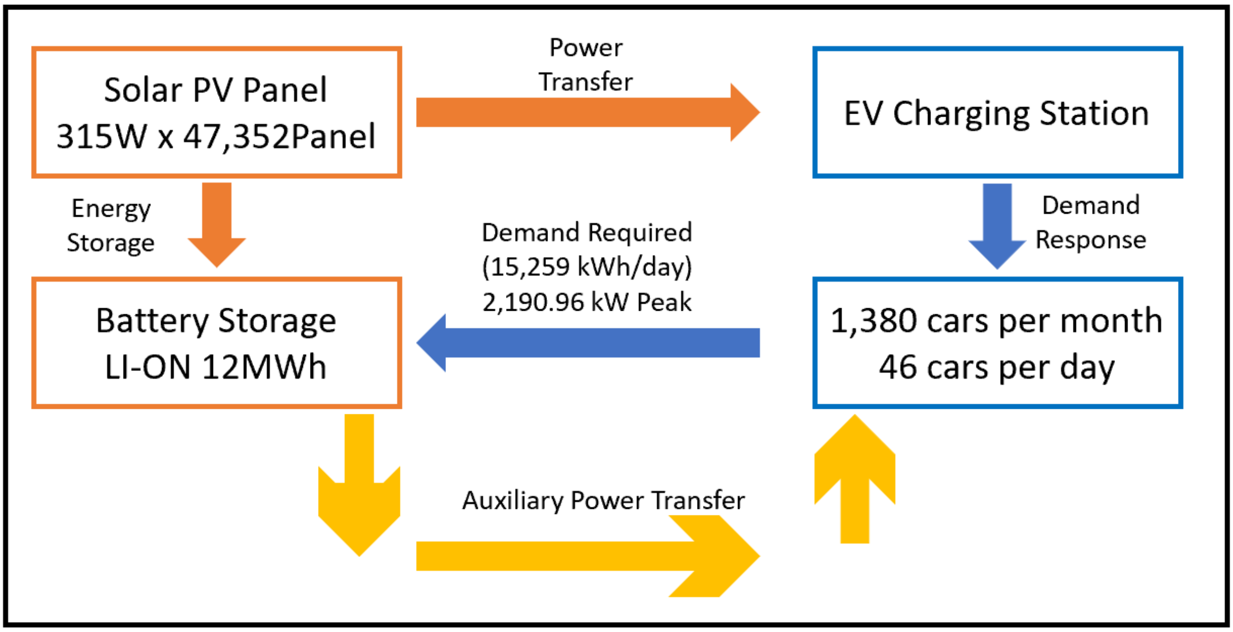


Figure 6.66 : The diagram of solar car parking system for Case 5

In Thailand, the standard PV panel used for commercial installation is a 315W PV panel. To calculate a quantity of solar panels, the electrical demand is to be divided by the standard of PV panel. In case 5 the quantity of PV panels is as follows:

14,916 kW/ 315W = 47,352 panels = 15 MWp

As for the battery capacity, normally it can be calculated by battery (Ah) = total demand (kW) / (Battery Voltage x0.6% x 0.85eff). However, this study selected to use a battery container size of Li-ON 12MWh which contains sufficient capacity for battery storage.

The component of a solar-car parking system comprises 315 W x 47,352 PV panels, 12 MWh of Li-on battery, and an electrical load of model case. The total area for installing solar panel is 91,389 m2 which is 22% of shopping center.

The stand-alone grid system component consists of a diesel generator, a 15,259 kW converter, an 18,900 kW of electric demand.

<u>Case 5 - On a bright day</u>

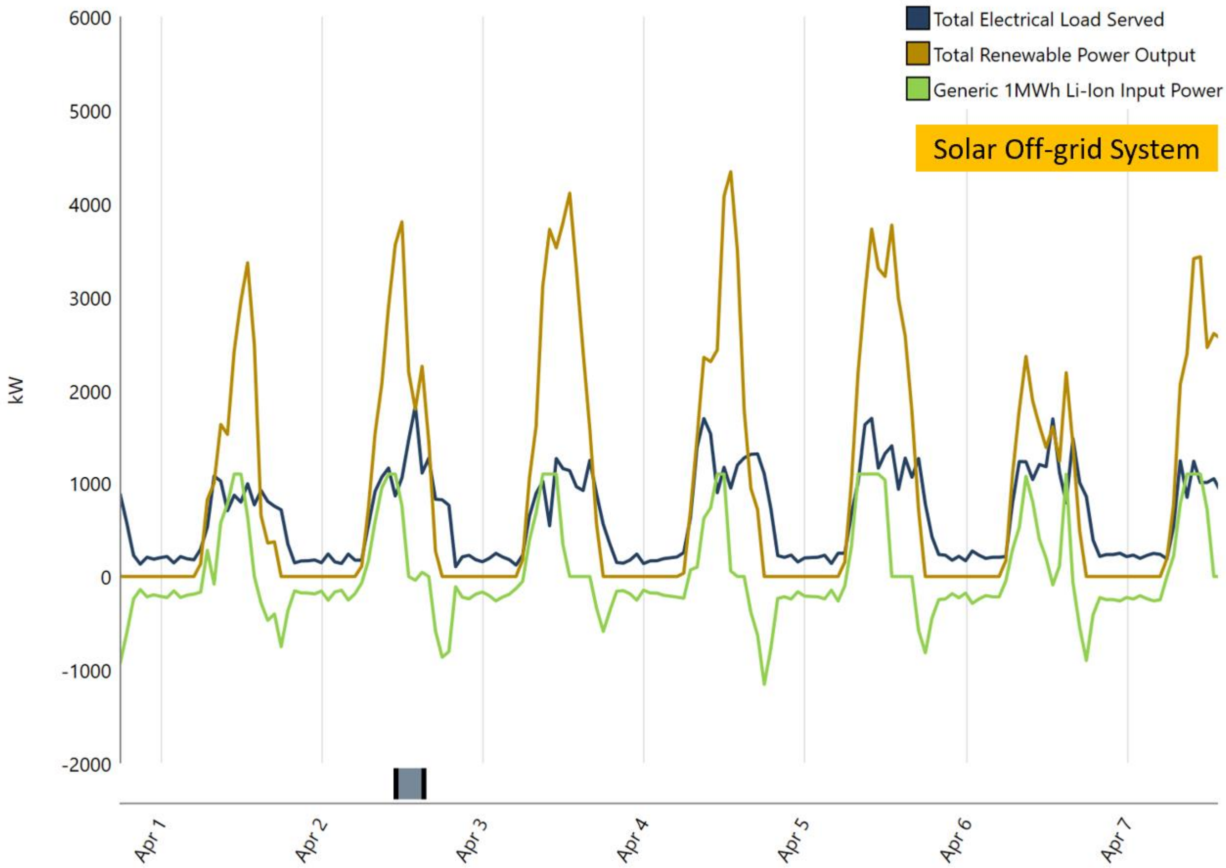


Figure 6.67 : The power of solar off-grid system (Case 5 - on a bright day)

As seen in Figure 6.67, the total energy demand is 15,259.2 kWh, the average of EVs demand is 1,525 kWh/day, and the peak demand is 2,190kW. The upper plot shows that the PV farm, which is equipped with 60 pieces of 315 W PV panels, has an average output of 18,900 kWh/day. The surplus energy is around 365 kWh. The peak demand of 2,190 kW exceeds the solar output power. This results in an unmet electrical load. The system has battery storage with a size of 12 MWh (1 MWh x 12 packs of Li-on), which can support the solar system when there is no power output of the solar generation.

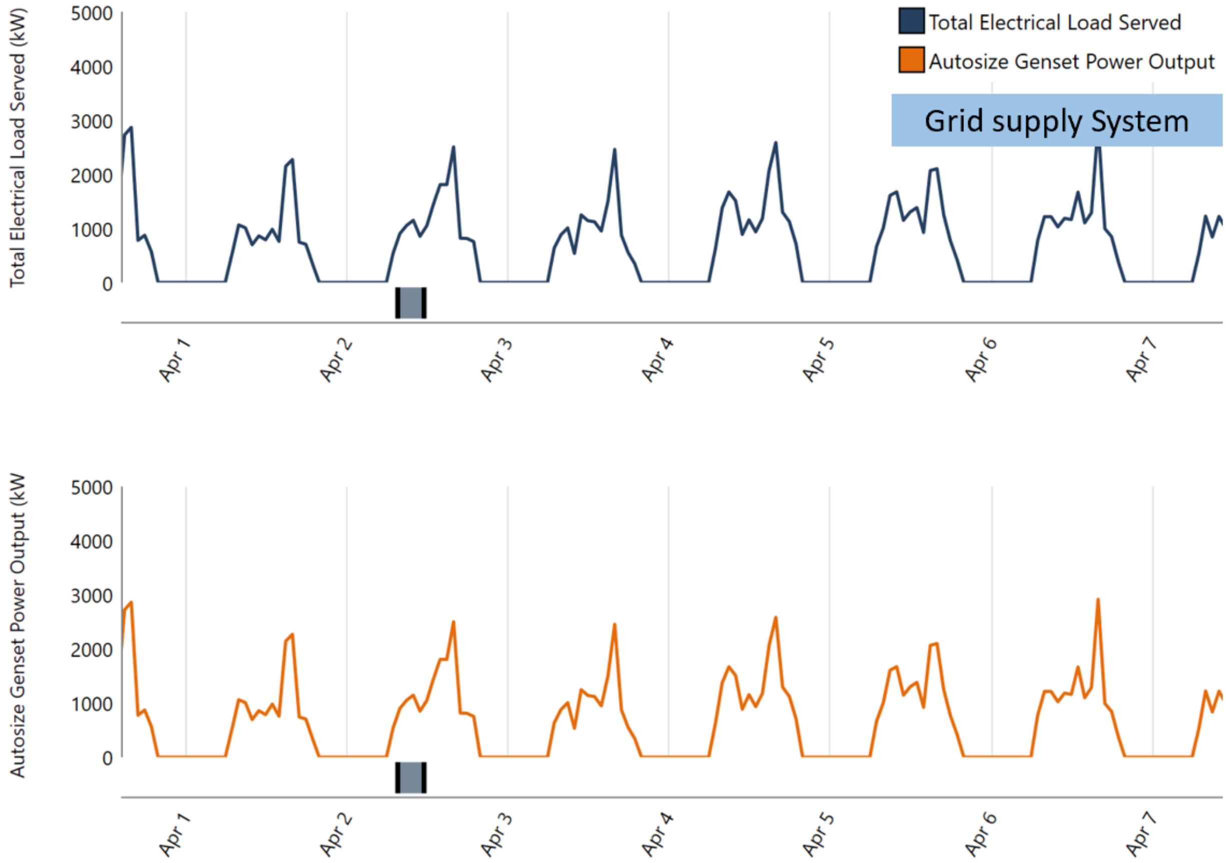


Figure 6.68 : The power from stand-alone grid system (Case 5 - on a bright day)

Figure 6.68 expresses the car parking system when there is no support from the solar farm. To supply the fleet demand, the system consumes power from the grid generation which generates power from non-renewable resources. This causes a high level of carbon intensity. In this simulation, the national grid is represented by GEN (a Generator). The grid can supply the total electric load 1,500 kWh/day, but there is no storage system to support power during the peak demand or when there is a blackout.

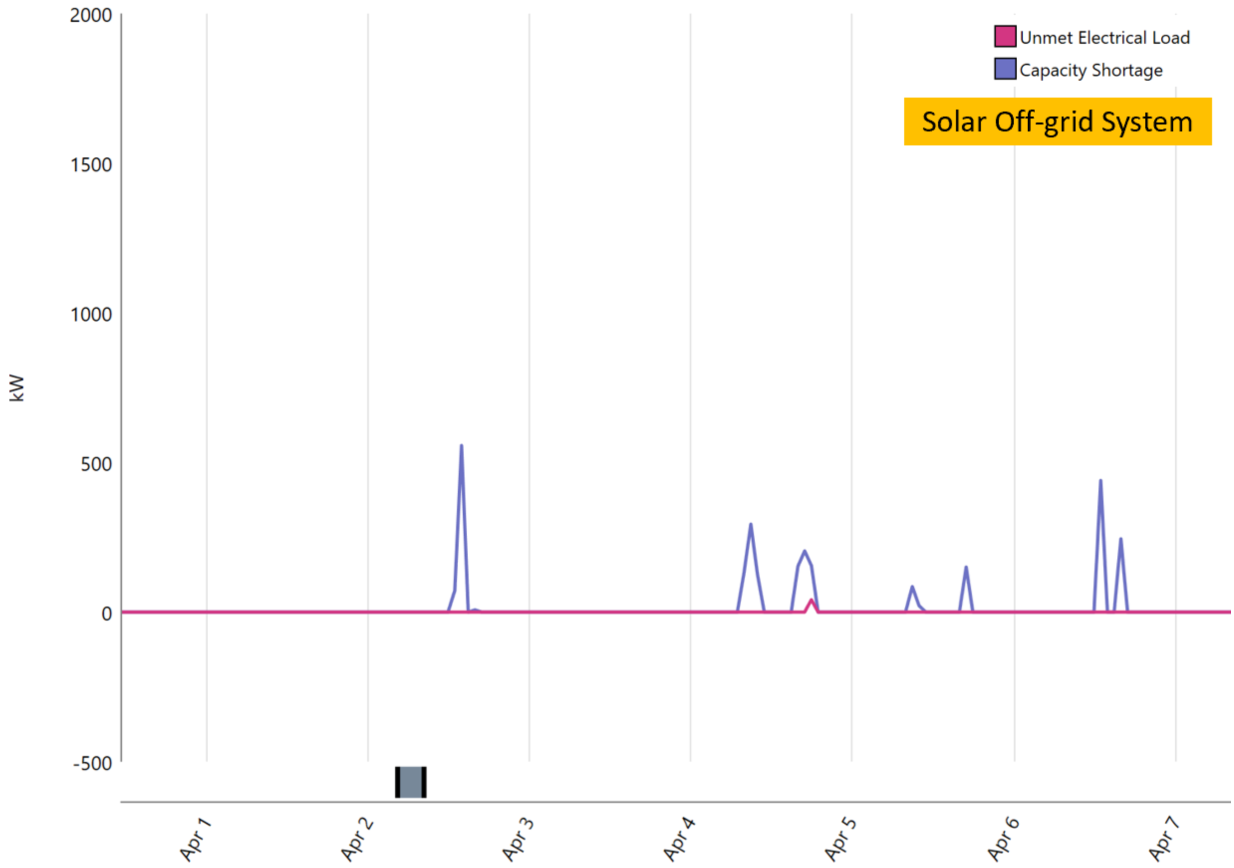


Figure 6.69 : The capacity shortage and the unmet electrical load of solar off-grid system (Case 5 - on a bright day)

Figure 6.69 indicates the deficiency of the expected minimum operating capacity and the real capacity that the system can operates. The capacity shortage from the upper plot reaches a peak of 500 kW. The unmet load is zero, as there is no excessive demand.

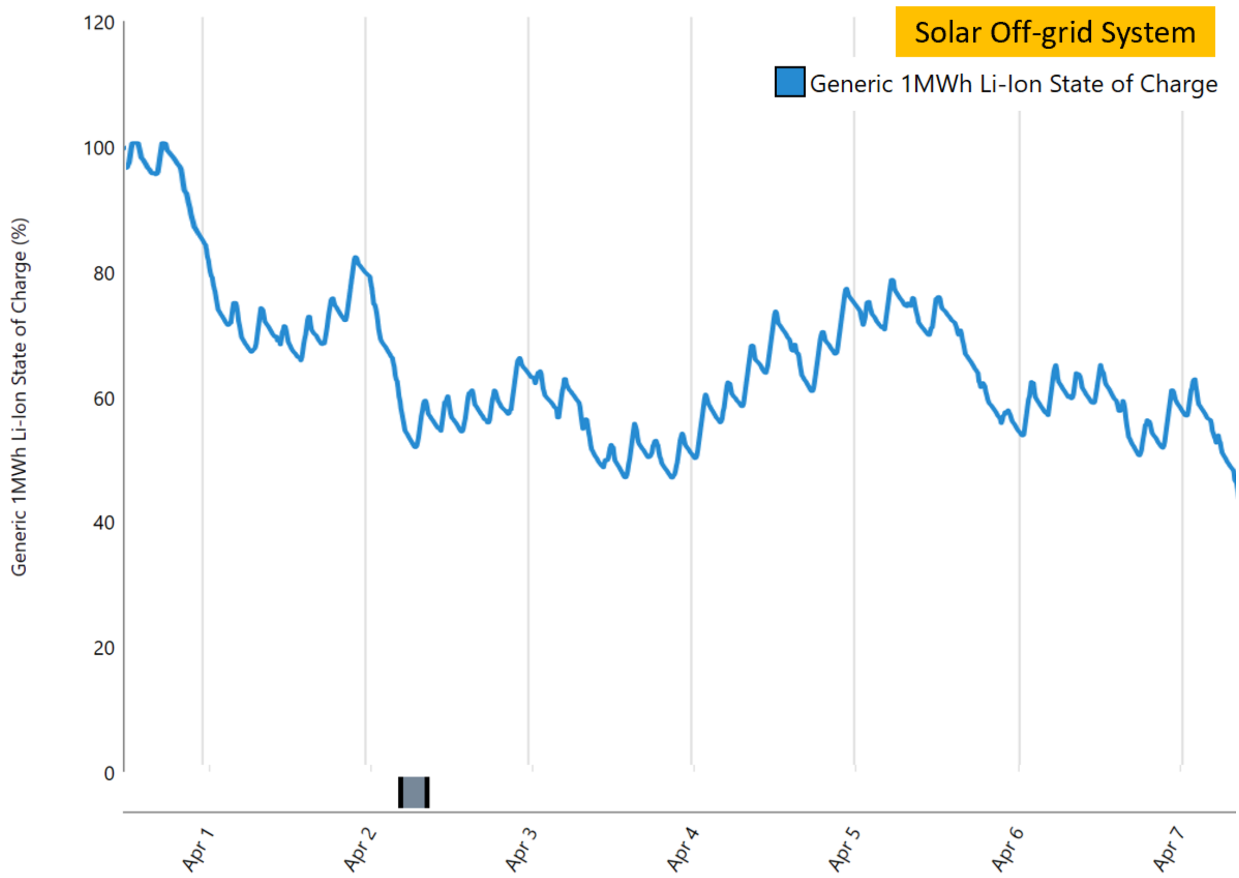


Figure 6.70 : The state of charge (SOC) of a solar off-grid system (Case 5 - on a bright day)

Figure 6.70 illustrates SOC's percentage, which refers to the remaining capacity level in an electric battery at a specific point. The unit of SOC is counted in the percentage (0% = empty; 100% = full). In this case, the %SOC of a battery normally works from 20% to 100%.

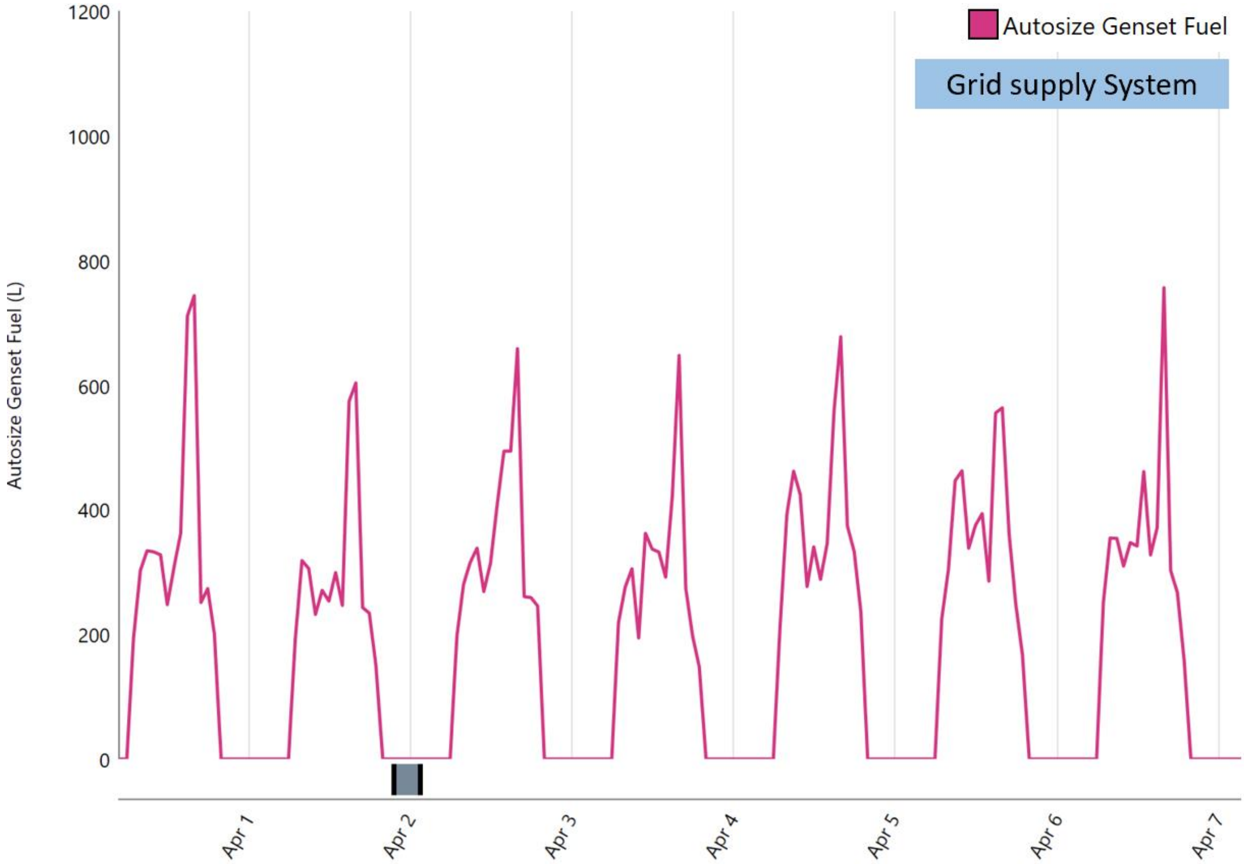


Figure 6.71 : Fuel consumption of a stand-alone grid system (Case 5 - on a bright day)

Figure 6.71 presents fuel consumption of the national grid generation, which is represented by the generator. The fuel consumes from the operating setpoint 180 litres of diesel into more than 440 litres which is 1,179 kg CO2 / hr.

Case 5 - On a cloudy day

The simulation on a cloudy day shows the worst case when the solar generation time and solar irradiation are lower than those of the bright day.

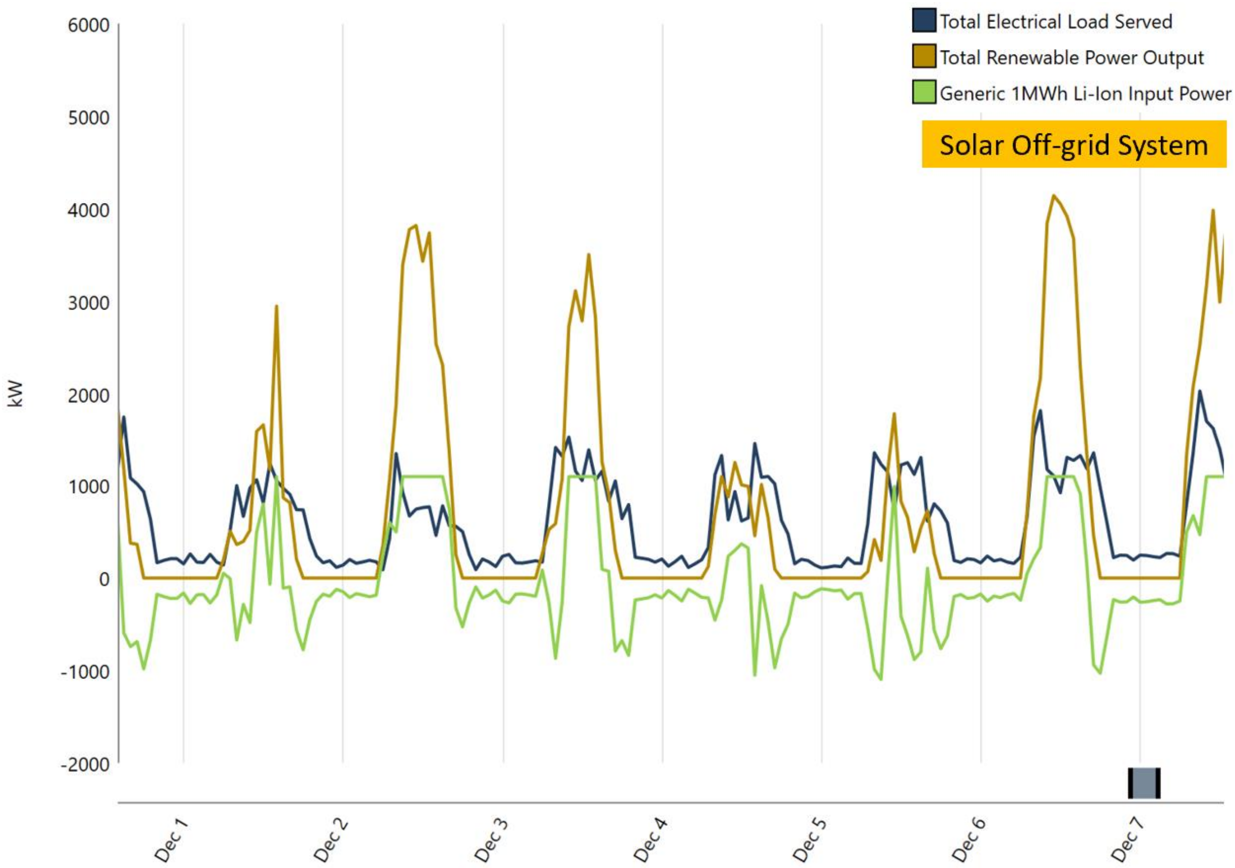


Figure 6.72 : The power from solar off-grid system (Case 5 - on a cloudy day)

Figure 6.72 depicts the entirety of the electrical load served, the renewable system's output, and the battery's input power. The solar system can provide the power to respond the load.

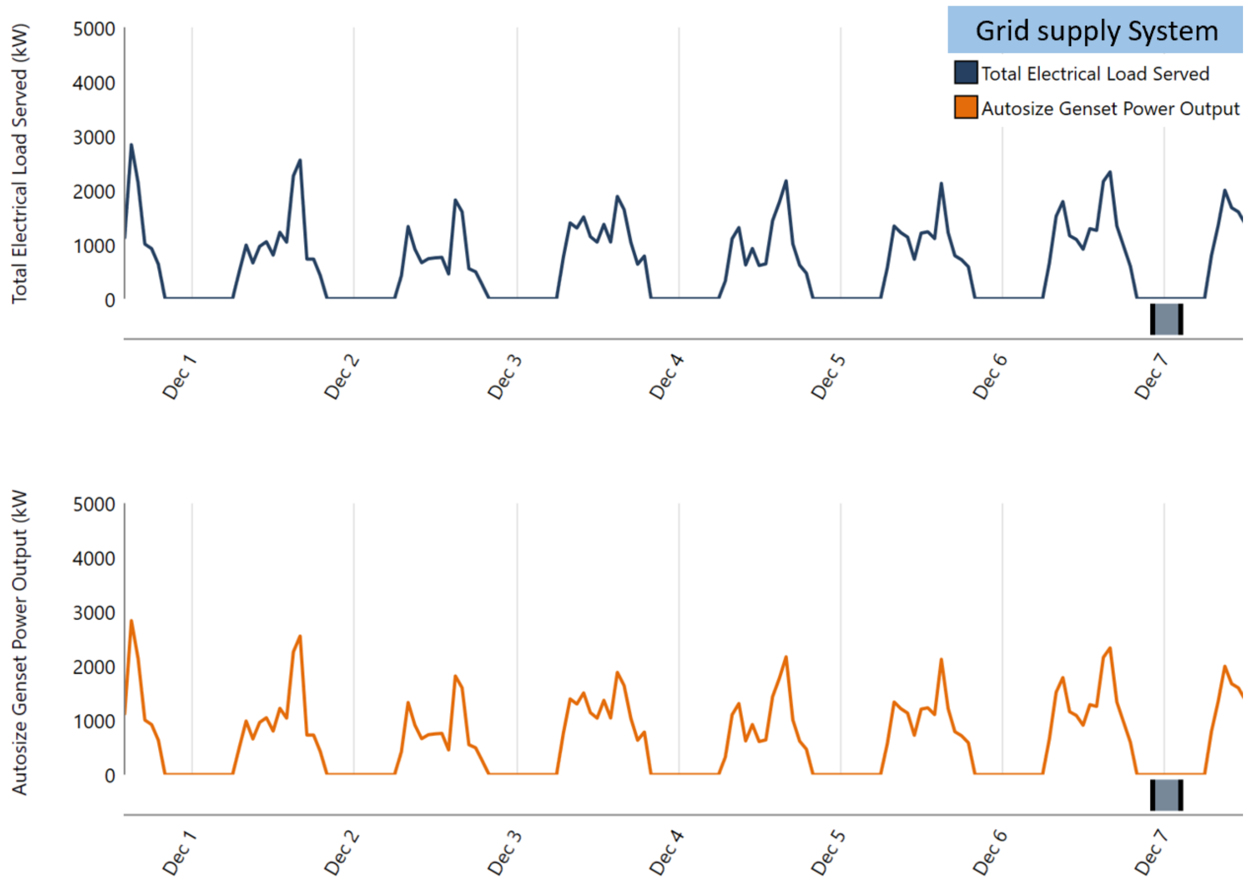


Figure 6.73 : The power from a stand-alone grid system graph in (Case 5 - on a cloudy day)

As shown in Figure 6.73, the grid can supply the total electric load with a 1529 kW/day. The demand and supply graphs have the same value because the national grid operation supplies power equal to the demand of the load, as on the bright day.

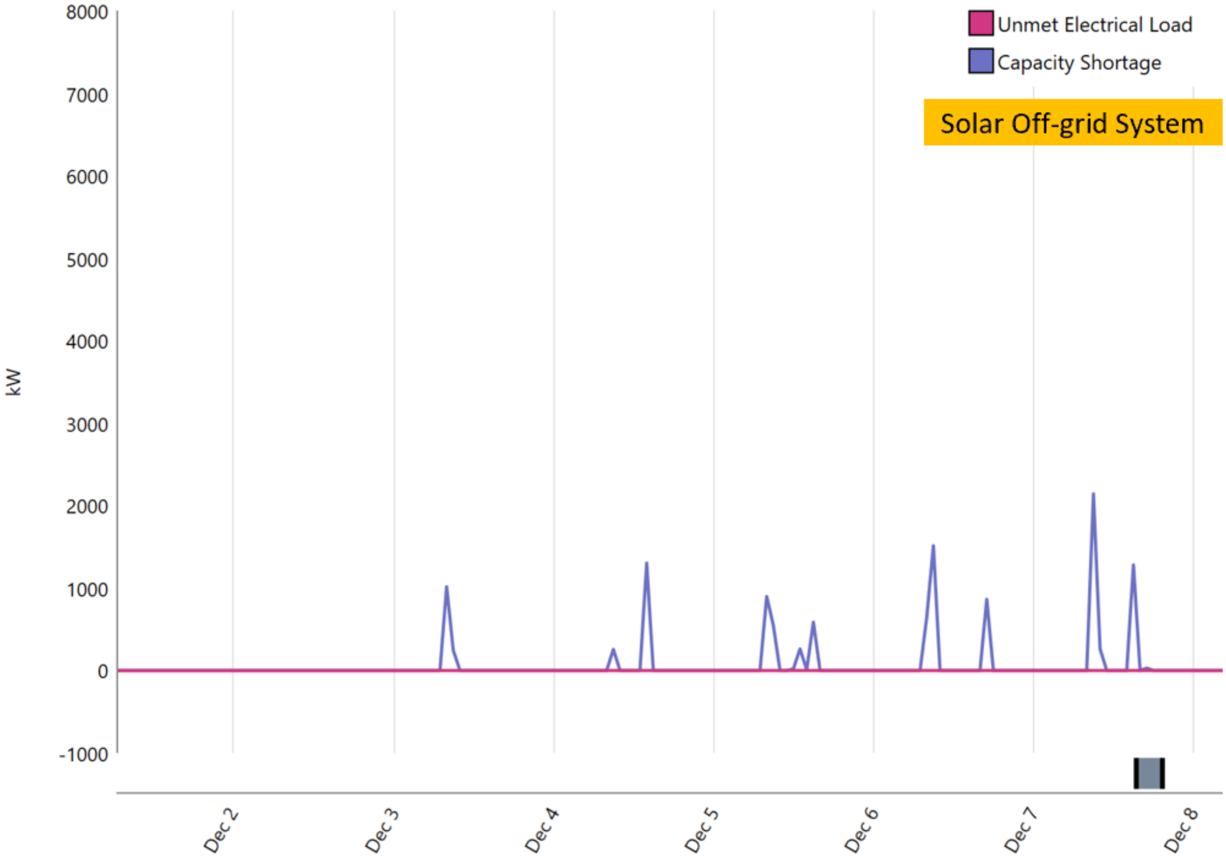


Figure 6.74 : The capacity shortage and the unmet electrical load of solar off-grid system (Case 5 - on a cloudy day)

Figure 6.74 indicates that there are a few unmet electric load and capacity shortage on the cloudy days. The peak capacity shortage and the peak unmet load are 850 kW and 660 kW respectively.

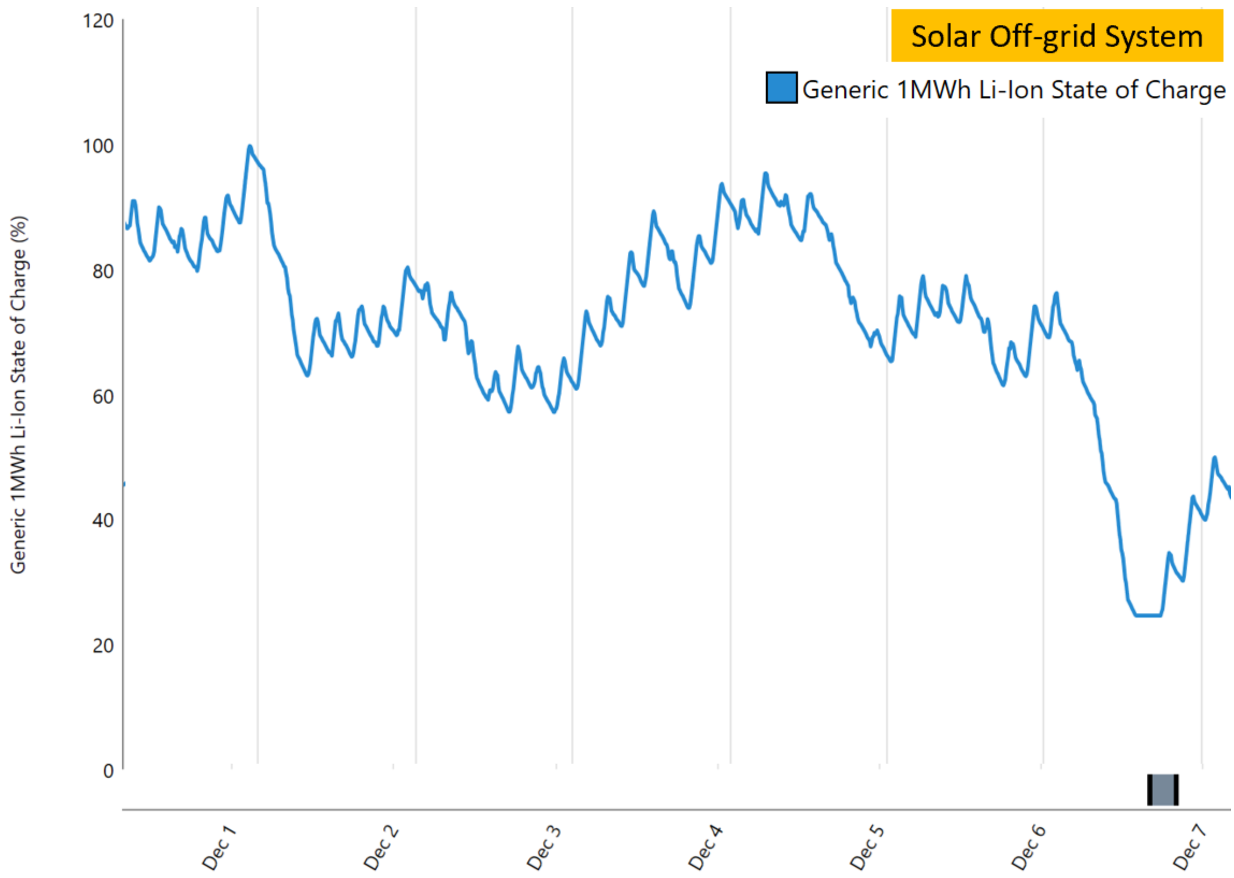


Figure 6.75 : The state of charge (SOC) of a solar off-grid system (Case 5 - on a cloudy day)

Figure 6.75 illustrates SOC's percentage which refers to the remaining capacity level in an electric battery at a specific point. The unit of SOC is counted in the percentage (0% = empty; 100% = full). In this case, the %SOC of a battery normally works from 20% to 100%. When solar power is insufficient to supply the load, the battery will provide power from the SOC at 100%full to a minimum of 20%. When there is a surplus solar power, the surplus amount will be stored in the battery, which maintains the SOC from 20% to 100%.

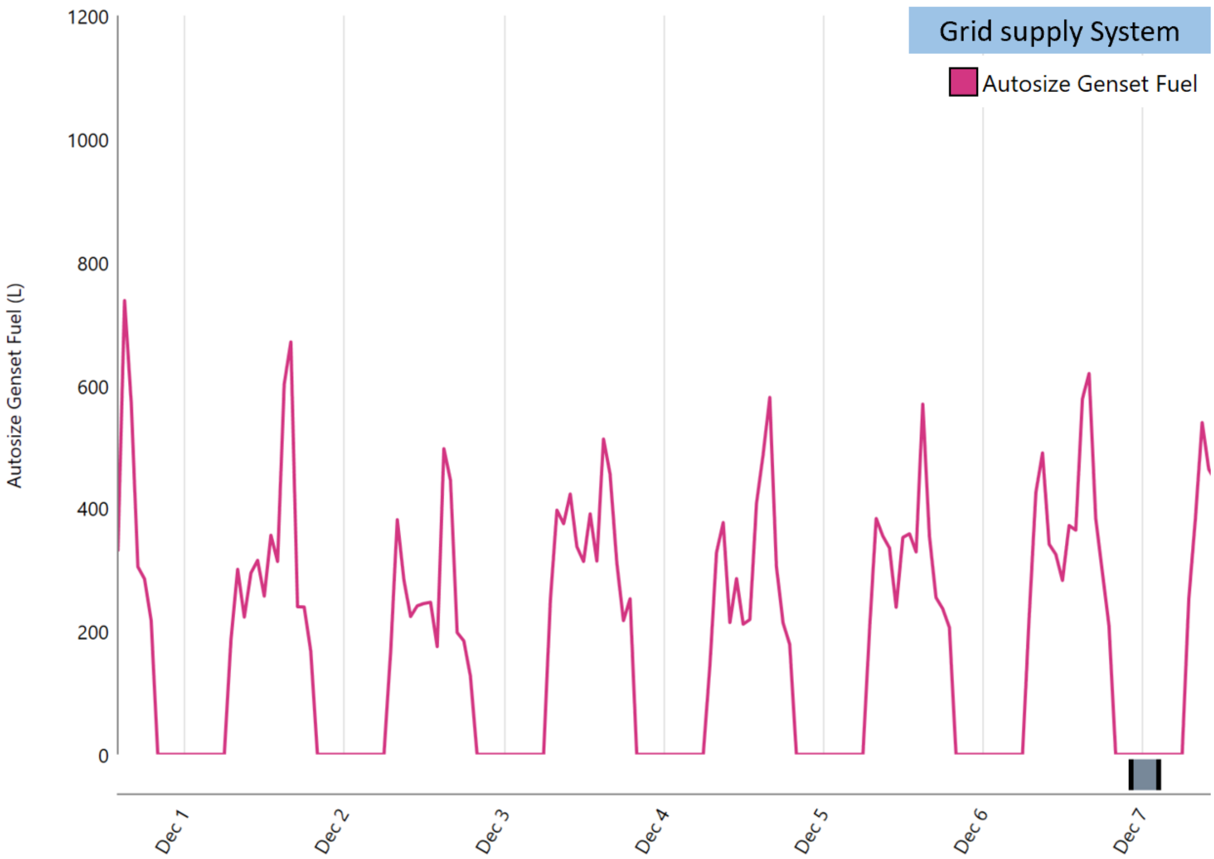


Figure 6.76 : Fuel consumption of a stand-alone grid system (Case 5 - on a cloudy day)

Figure 6.76 expresses fuel consumption of the national grid generation, which is represented by the generator. The fuel consumes from the operating setpoint 0 litre of diesel into more than 600 litres and the peak is 800 litres.

Quantity	Value	Units
Carbon Dioxide	0	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	0	kg/yr

Solar Off-grid System

Quantity	Value	Units
Carbon Dioxide	5,419,469	kg/yr
Carbon Monoxide	34,161	kg/yr
Unburned Hydrocarbons	1,491	kg/yr
Particulate Matter	207	kg/yr
Sulfur Dioxide	13,271	kg/yr
Nitrogen Oxides	32,091	kg/yr

Grid supply System

Figure 6.77 : The Emission

As depicted in Figure 6.77 the solar off-grid system is in comparison with the grid supply system. It is clear that the solar off-grid system can reduce Carbon intensity more than 5,419,469 kg CO2 per year. Moreover, the annual of a carbon monoxide (CO), unburned hydrocarbons, particulate matter (PM), Sulfur Dioxide (SO2), and Nitrogen Oxides (NO2) decrease about 34,161 kg, 1,491 kg, 207 kg, 13,271 kg, and 32,091 kg respectively.

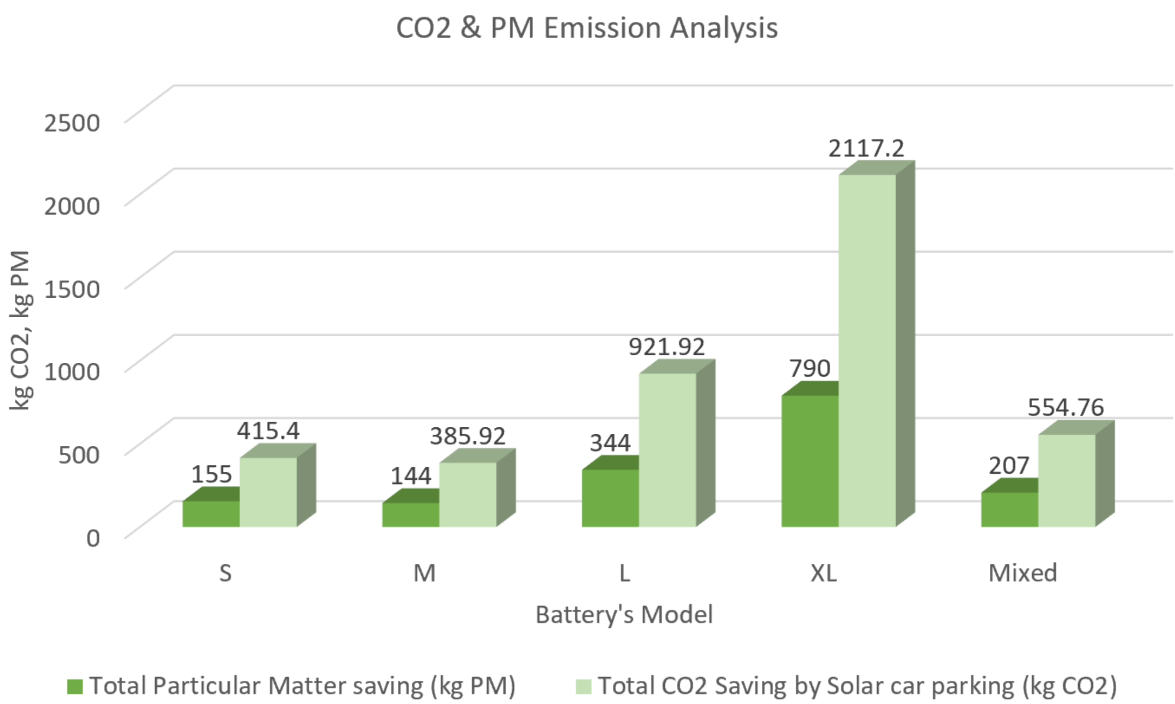


Figure 6.78 : Carbon and PM Analysis

As shown in Figure 6.73, the carbon and the particulate matter have been analysed in all EVs demand cases. The total of the particulate matter, which is the crucial air problem in Thailand in 2020, can be saved as per Case 1: All 1,380 cars are in size S = 155kg PM, Case 2: All 1,380 cars are in size M = 144 kg PM, Case 3: All 1,380 cars are in size L = 344 kg PM, Case 4: All 1,380 cars are in size XL = 790 kg PM, and Case 5: All 1,380 cars are in mixed-sizes = 207 kg PM. The total of the CO2 can be saved by using a solar-car parking system as per Case 1: All 1,380 cars are in size S= 415.4 kg CO2, Case 2: All 1,380 cars are in size M = 385.92 kg CO2, Case 3: All 1,380 cars are in size L = 921.92 kg CO2, Case 4: All 1,380 cars are in size XL =2117.2 kg CO2, and Case 5: All 1,380 cars are in mixed-sizes = 554.76 kg CO2.

The seasons resulting in designing the five EV's demand cases consist of winter, summer, and the rainy seasons, as shown in table 6-8. The model has been divided into a ratio of the state of charge of the electric vehicle's battery.

Scenario				
Small Model				
Season	% SOC Battery	Demand EV (kWh)	PV Delivered (kWh)	Surplus (kW)
Winter	0	1094.8	1147	52.2
	20	875.84	1147	271.16
	40	656.88	1147	490.12
	60	437.92	1147	709.08
	80	218.96	1147	928.04
Summer	0	1094.8	1260	165.2
	20	875.84	1260	384.16
	40	656.88	1260	603.12
	60	437.92	1260	822.08
	80	218.96	1260	1041.04
Rainy	0	1094.8	1214	119.2
	20	875.84	1214	338.16
	40	656.88	1214	557.12
	60	437.92	1214	776.08
	80	218.96	1214	995.04

Table 6-8 : Case 1 : All Cars are in Size S

In case 1: All 1,380 cars are in size S, the maximum and the minimum demand is 0% SOC at 1094.8 kWh and 80%SOC at 218.96 respectively. With 12,000 PV panels, the system can supply power 315 W. The surplus power from this charging process is with a maximum of 1041.04 kW and a minimum of 52.20 kW.

Scenario				
Medium Model				
Season	% SOC Battery	Demand EV (kWh)	PV Delivered (kWh)	Surplus (kW)
Winter	0	1444.4	1489	44.6
	20	1155.52	1489	333.48
	40	866.64	1489	622.36
	60	577.76	1489	911.24
	80	288.88	1489	1200.12
Summer	0	1444.4	1575	130.6
	20	1155.52	1575	419.48
	40	866.64	1575	708.36
	60	577.76	1575	997.24
	80	288.88	1575	1286.12
Rainy	0	1444.4	1543	98.6
	20	1155.52	1543	387.48
	40	866.64	1543	676.36
	60	577.76	1543	965.24
	80	288.88	1543	1254.12

Table 6-9 : Case 2 : All Cars are in Size M

In case 2: All 1,380 cars are in size M, the maximum and minimum demand is 0% SOC at 1444.4 kWh and 80%SOC at 288.88kWh respectively. With 15,000 PV panels, the system can supply 315 W. The surplus power from this charging process is with a maximum of 1286.12 kW and a minimum of 44.6 kW.

Scenario				
Large Model				
Season	% SOC Battery	Demand EV (kWh)	PV Delivered (kWh)	Surplus (kW)
Winter	0	2571.4	2610	38.6
	20	2057.12	2610	552.88
	40	1542.84	2610	1067.16
	60	1028.56	2610	1581.44
	80	514.28	2610	2095.72
Summer	0	2571.4	2835	263.6
	20	2057.12	2835	777.88
	40	1542.84	2835	1292.16
	60	1028.56	2835	1806.44
	80	514.28	2835	2320.72
Rainy	0	2571.4	2765	193.6
	20	2057.12	2765	707.88
	40	1542.84	2765	1222.16
	60	1028.56	2765	1736.44
	80	514.28	2765	2250.72

Table 6-10 : Case 3 : All Cars are in Size L

In case 3: All 1,380 cars are in size L, the maximum and minimum demand is 0% SOC at 2571.4 kWh and 80%SOC at 1028.56 kWh respectively. With 36,000 PV panels, the system can supply by 315 W. The surplus power from this charging process is with a maximum of 2250.72 kW and a minimum of 38.6 kW.

Scenario				
X-Large Model				
Season	% SOC Battery	Demand EV (kWh)	PV Delivered (kWh)	Surplus (kW)
Winter	0	5911	6024	113
	20	4728.8	6024	1295.2
	40	3546.6	6024	2477.4
	60	2364.4	6024	3659.6
	80	1182.2	6024	4841.8
Summer	0	5911	6300	389
	20	4728.8	6300	1571.2
	40	3546.6	6300	2753.4
	60	2364.4	6300	3935.6
	80	1182.2	6300	5117.8
Rainy	0	5911	5987	76
	20	4728.8	5987	1258.2
	40	3546.6	5987	2440.4
	60	2364.4	5987	3622.6
	80	1182.2	5987	4804.8

Table 6-11 : Case 4 : All Cars are in XL

In case 4: All 1,380 cars are in Size XL, the maximum and minimum demand is 0% SOC at 59,111 kWh and 80%SOC at 1182.2 kWh respectively. With 60,000 PV panels, the system can supply 315 W. The surplus power from this charging process is with a maximum of 4841.8 kW and a minimum of 76 kW.

Scenario				
Mixed Model				
Season	% SOC Battery	Demand EV (kWh)	PV Delivered (kWh)	Surplus (kW)
Winter	0	1525.92	1673	147.08
	20	1220.736667	1673	452.2633333
	40	915.5533333	1673	757.4466667
	60	610.3666667	1673	1062.633333
	80	305.1833333	1673	1367.816667
Summer	0	1525.92	1890	364.08
	20	1220.736667	1890	669.2633333
	40	915.5533333	1890	974.4466667
	60	610.3666667	1890	1279.633333
	80	305.1833333	1890	1584.816667
Rainy	0	1525.92	1796	270.08
	20	1220.736667	1796	575.2633333
	40	915.5533333	1796	880.4466667
	60	610.3666667	1796	1185.633333
	80	305.1833333	1796	1490.816667

Table 6-12 : Case 5 : All Cars are in Mixed-Sizes

In case 5: All 1,380 cars are mixed-sizes, the maximum and minimum demand is 0% SOC at 1525.92 kWh and 80%SOC at 305.18 kWh respectively. With 18,000 PV panels, the system can supply 315 W. The surplus power from this charging process is with a maximum of 1584.81 kW and a minimum of 147 kW.

The project does not focus on the calculating of the financial analysis, and others cost regarding the EV technology and the battery storage of Li-on due to the fluctuation in each year.

In conclusion, to use the parking space of the shopping centre as a solar farm for EVs charging via an off-grid system, the total area needed for solar panel installation is 400,000 square meters. The simulation of the unmet electricity load scenario demonstrated that the designed-solar panel installation is feasible. The solar panel installed and area for each case: Case 1: 34,920 panel, 67,395 m2, Case 2: 44,444 panel, 85,776 m2, Case 3: 70,619 panel, 136,294 m2, Case 4: 174,831 panel, 337,423 m2, and Case 5: 47,352 panel, 91,389 m2. The carbon dioxide (CO_2) and the particulate matter (PM2.5) savings are higher than 20,691,189 $kgCO_2$ per year and 790 kg PM per year. Applying the solar off-grid system to charge the EV battery will lessen the carbon content level caused by the national grid. Most of the shopping centres in Thailand provide a large parking space for their clients. Thailand has plenty of high-density solar irradiation throughout the year. Thailand can make the most of the enormous existing renewable energy resources in the country for environmental sustainability.

Chapter 7 : Conclusion and Future Work

7.1 Conclusion

The study aimed at designing the most suitable model that enhances the EV charging stations' renewable energy system, which are installed in the parking space of the shopping centres, to achieve the maximum electric power and the carbon saving.

The parking in the Megabangna Shopping Centre has been deployed as the charging stations and a solar farm. The area for the PV panel installation is with a total of 400,000 square metres. The simulations performed basing on the existing ten EV charging points, 1,380 cars/month. The input data for the simulation process comprised the EVs demand profile and the PV profile. The unmet electric vehicle load analysis scenario is conducted. Four models are employed for the simulations: FOMM ONE, Nissan Leaf, KIA E-SOUL, and Tesla model S. Each model represents a battery-size: S, M, L, and XL. Five cases have been defined: S, M, L, XL, and mixed sizes. To determine the list of the EV demand, each case has been simulated under two conditions: on a bright day and a cloudy day. The most suitable solar farm at the parking space has been designed to specify the proper panels needed for installation in the limited area, but achieve the highest power and the carbon savings. The PV panel installation was designed to suit to the area, the power demand, and the solar factors. Climate, temperature, seasons, and sunlight were taken into consideration. The polycrystalline was used as solar panels as its efficiency remains at the high temperature. Four assumptions were defined: seasons influence on solar power generation, Nissan Leaf is charged 0.40 hours per day, the electrical component in the solar off-grid system includes the inverter and the battery, and the total area for PV panel installation is 400,000 m2. The scenario performed using the HOMERpro software to define the practical model of the solar charging system. The unmet electric vehicle load analysis using the Thai simulation modelling has been employed to tackle the problem of the EVs fleet demand and to support the solar off-grid system in avoiding the connection between the grid and the EVs load. The carbon and the particulate matters have been analysed in all five cases. The off-grid system and the on-grid system are compared to evaluate and determine the difference between the carbon savings and the surplus energy in each case.

The study results signify that it is feasible to use the shopping centres' parking area in Thailand as a solar farm for the EV charging stations via an off-grid system. The simulation revealed that the designed-solar panel installation is feasible. The obtained electricity is adequate to supply the EV charging stations in the shopping centre. Surplus energy is available to support the shopping centre. The solar panel installed and area for each case: Case 1: 34,920 panel, 67,395 m2, Case 2: 44,444 panel, 85,776 m2, Case 3: 70,619 panel, 136,294 m2, Cas e4: 174,831 panel, 337,423 m2, and Case 5: 47,352 panel, 91,389 m2. The CO2 and the PM2.5 saving are higher than 20,691,189 kgCO2 per year and 790 kg PM/year. The best case with the highest surplus energy has been displayed. The results specified the capacity shortage and the unmet load in each case. The simulation results indicated that solar panels work better in the demand case 1: All 1,380 cars are in size S and the demand case 5: All 1,380 cars are in mixed-sizes because of the area limitation and the less demand consumption. The results showed that in winter there was less solar parameter for generating the power from the solar panels than in summer and the rainy season.

To sum up, charging the EV's battery using the solar off-grid system can lessen the drawback of the EVs' dump charging that causes trouble to the stability and the carbon content level of the national grid. Generally, most of the shopping centres in Thailand provide a huge parking space for their customers. Plenty of the high-density solar irradiation is available in Thailand all year round. Applying the existing renewable energy worthily in a cost-effective manner is one of the tools to compete with the climate changes. Thailand can make the most of the enormous existing renewable energy resources for environmental sustainability.

7.2 Future work

There are methods to restrict the carbon content on the grid that will occur due to the high EV's demand in the near future. The first method is setting the smart meter on the EVSE to monitor the carbon level. When the carbon reaches a higher intensity level, the EVSE does not allow the EV to be charged; otherwise, it will be more expensive. The second method is using a time-control device to manage the charging time period. Another method is to create a huge renewable energy farm on the national grid. This way needs a high investment cost, but it will generate power to support all the EVs demand.

This study has analysed the impact of the EV's demand and the carbon footprint on the grid in the aspect of the environmental impact assessment. In the future, more than 10 charging points can be installed in the shopping centre, which will help support the EVs fleet. Due to time pressure, the researcher could not perform the in-depth analysis. To build on this study, it is strongly recommended that the PV-sizing and the battery storage capacity should be thoroughly examined. The risk management of the solar off-grid system should be analysed. The financial analysis in the aspects of the solar off-grid system's O&M cost should also be undertaken.

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Appendix

Appendix A : Electric Vehicle's model

FOMM ONE : SMALL EV's Model

First One Mile Mobility

Announced in March, 2018

SIZE：length × width × height : 2585×1295×1550(mm)

Wheelbase：1,760mm

Minimum Ground Clearance：150mm

Tread：Front 1,110mm／Rear 1,110mm

Seating Capacity：4 persons

Motor Type：In-Wheel Motor

Maximum Power : 10kW

Maximum torque : 560Nm

Maximum Speed：80km

Cruising Distance：166km<NEDC>

Kerb weight : 620kg(With Battery and Option)

Battery：2.96kWh × 4（Li-ion)

Charging Time：7.5Hours

Nissan LEAF : Medium EV's Model

Body type: Hatchback
Doors: 5, **Seats**: 5
Length: 176.4 in / 4481 mm
Width: 70.5 in / 1791 mm
Height: 61.4 in / 1560 mm
Curb weight: 3467.87 lb / 1573 kg
Electric motor: 110 kW @ 3283 - 9795 rpm, 320 Nm @ 3283 rpm
Top speed: 89.5 mph / 144.0 km/h
Acceleration 0-60 mph: 7.50 s
Acceleration 0-100 km/h: 7.90 s
Drivetrain: Front-wheel drive (FWD)
Battery: 40 kWh, **Voltage**: 360 V

NISSAN LEAF

Charging type

Information about the different types of charging of this specific electric car.

Type	Interface	Voltage	Current	Power
EVSE cable	Type 1 (SAE J1772, IEC 61851-1, J Plug, Yazaki)	-	-	2.3 kW
Wall box	Type 1 (SAE J1772, IEC 61851-1, J Plug, Yazaki)	-	-	6.6 kW
Portable cable	Type 1 (SAE J1772, IEC 61851-1, J Plug, Yazaki)	-	-	7.4 kW
Fast charging station	Type 4 (IEC 62196-3 AA, CHAdeMO)	-	-	50 kW

Driving range

Information about the official driving range of the model according to EPA, NEDC, WPTL.

Standard	Range
NEDC (New European Driving Cycle)	234.9 mi / 378.0 km
EPA (Electric car range and efficiency)	151.0 mi / 243.0 km
WLTP (Worldwide harmonized Light vehicles Test Procedure)	167.8 mi / 270.0 km

KIA SOUL EV : Large EV's Model

Body type: Crossover
Doors: 5, **Seats**: 5
Length: 165.2 in / 4195 mm
Width: 70.9 in / 1800 mm
Height: 63.0 in / 1600 mm
Curb weight: 3708.18 lb / 1682 kg
Electric motor: 150 kW @ 3800 - 8000 rpm, 395 Nm @ 3600 rpm
Top speed: 103.8 mph / 167.0 km/h
Acceleration 0-60 mph: 7.30 s
Acceleration 0-100 km/h: 7.60 s
Drivetrain: Front-wheel drive (FWD)
Battery: 64 kWh, **Voltage**: 356 V

Driving range
Information about the official driving range of the model according to EPA, NEDC, WPTL.

Standard	Range
EPA (Electric car range and efficiency)	243.0 mi / 391.1 km
WLTP (Worldwide harmonized Light vehicles Test Procedure)	280.9 mi / 452.0 km

Charging type
Information about the different types of charging of this specific electric car.

Type	Interface	Voltage	Current	Power
Trickle charging at home	Type 1 (SAE J1772, IEC 61851-1, J Plug, Yazaki)	120 V	12 A	1.44 kW
Normal AC charging	Type 2 (IEC 62196-3 FF, CCS2)	240 V	30 A	7.2 kW
DC fast charging 50 kW	-	-	-	50 kW
DC fast charging 100 kW	-	-	-	100 kW

TESLA MODEL S : X-Large EV's Model

Body type: Sedan
Doors: 4, **Seats**: 5
Length: 196.0 in / 4978 mm
Width: 77.3 in / 1963 mm
Height: 56.5 in / 1435 mm
Curb weight: 4883.24 lb / 2215 kg
Electric motor #1: 285 kW @ 6850 rpm, 440 Nm
Electric motor #2: 193 kW @ 6100 rpm, 330 Nm
Top speed: 155.3 mph / 250.0 km/h
Acceleration 0-60 mph: 3.60 s
Acceleration 0-100 km/h: 3.80 s
Drivetrain: All-wheel drive (AWD)
Battery: 100 kWh, **Voltage**: 400 V

Charging type
Information about the different types of charging of this specific electric car.

Type	Interface	Voltage	Current	Power
NEMA 5-15	Tesla charging inlet	120 V	12 A	1.44 kW
SAE J1772 Adapter	Tesla charging inlet	240 V	24 A	5.76 kW
NEMA 14-50	Tesla charging inlet	240 V	40 A	9.6 kW
Wall Connector	Tesla charging inlet	240 V	48 A	11.5 kW
Supercharger	Tesla charging inlet	-	-	120 kW
Ssupercharger	Tesla charging inlet	-	-	200 kW

Driving range
Information about the official driving range of the model according to EPA, NEDC, WPTL.

Standard	Range
NEDC (New European Driving Cycle)	443.0 mi / 713.0 km
EPA (Electric car range and efficiency)	373.0 mi / 600.3 km

Energy efficiency
Information about the energy efficiency of the model in various measurement units according to EPA, NEDC, WPTL.

Standard	Driving	Rating
EPA (Electric car range and efficiency)	Combined	30 kWh/100 mi
EPA (Electric car range and efficiency)	Highway	107 MPGe
EPA (Electric car range and efficiency)	Combined	111 MPGe
EPA (Electric car range and efficiency)	City	115 MPGe

Appendix B : Solar PV Panel

Solar PV Panel 300W from SOLARTRON public company

SOLARTRON
PUBLIC COMPANY LIMITED

300W/305W/310W/315W/320W/325W
Multicrystalline Silicon Solar Module

Module Efficiency is up to 16%, minimizing installation costs and maximizing the output of the system.
992 x 1956 x 40 mm is suitable for power plant system .
Higher Durability, Certified to withstand 2400 Pa wind load and 5400 Pa snow load.
Higher Output, Improved ribbon layout and cable length, Enhanced fill factor, Increased power output up to 1% by reducing power loss.
Lower Junction Box Temperature, Separated junction box design, Better heat dissipation, Lower diode operating temperature and life time.

Warranty
10 years Product Workmanship Warranty
25 years Linear Power Output Warranty:
Output power shall not be less than 97.0 % in the first year
Loss shall not exceed 0.7% per year from year 2nd to 25th

Standards and Certification
ISO 9001:2015, ISO 14001:2015, TIS 18001:2554 and OHSAS 18001:2007 certified factories
CE Mark (EMC–Directive 2004/108/EC) certificate of European Conformity
RoHS certified of directive on the restriction of the use of certain hazardous substances
TIS 1843-2553 (IEC61215) Crystalline silicon terrestrial photovoltaic modules, Thai Industrial Standards
TIS 2580-2555 (IEC61730) Photovoltaic module safety qualification, Thai Industrial Standards
TÜV Rheinland IEC61215, IEC61730
UL 1703 by TÜV Rheinland
JETPVm certification (IEC61215,IEC61730)
MCS – PV0222
Green Industry, GI

TIS. 1843-2553 TIS. 2580-2555

Mechanical Characteristics

Solar Cell :	72 Cells, 156x156 multicrystalline	**Junction box :**	IP68Certified Junction Box
Dimension :	992 x 1956 x 40 mm	**Diodes :**	3 Schottky bypass diodes
Weight :	21.4 kg.	**Connector :**	MC4 compatible
Construction :	Front: High Transmission 3.2 mm. tempered glass; Rear: White PET; Encapsulant: EVA	**Output cables :**	4.0 mm^2 12 AWG cable. Cable length 315 mm
Frame :	Anodized Aluminium Alloy	**Fire rating Class :**	C

Appendix C : Battery Storage

A Lithium Ion Battery Container of TESLA public company

Overall System Specs

AC Voltage	380 to 480V, 3 phases
Communications	Modbus TCP/IP; DNP3; Rest API
Power	Up to 130 kW (AC) per Powerpack
Scalable Inverter Power	From 70kVA to 700kVA (at 480V)
Depth of Discharge	100%
Dimensions	**Powerpack Unit** Length: 1,317 mm (50.9 in) Width: 968 mm (38.1 in) Height: 2,187 mm (86.1 in) Weight: 2,199 kg (4,847 lbs) **Powerpack Inverter** Length: 1,044 mm (41.1 in) Width: 1,394 mm (54.9 in) Height: 2,191 mm (86.2 in) Weight (max): 1,120 kg (2,470 lbs)
Energy Capacity	Up to 232 kWh (AC) per Powerpack
Operating Temperature	-30°C to 50°C / -22°F to 122°F
Enclosures	Pods: IP67 Powerpack: IP35/NEMA 3R Inverter: IP66/NEMA 4
System Efficiency (AC) *	88% round-trip (2 hour system) 89.5% round-trip (4 hour system)
Certifications	Nationally accredited certifications to international safety, EMC, utility and environmental legislation.

Grid Interface

- Bi-Directional Inverter
- Powerpack Controller
- Software

Powerpacks

Powerpacks house the world's most sophisticated batteries. Each Powerpack is a DC energy storage device containing 16 individual battery pods, a thermal control system and hundreds of sensors that monitor and report on cell level performance.

Appendix D : The Excel Data supported by the Organisation

EV Specification												
Size	Model	Battery Capacity (kWh)	Time for full charging (hrs)		Norminal Voltage (V)	Rated Capacity (Ah)	Range in full charging (km)	Charger Compatibility			
			AC	DC				Slow	Fast	Rapid1	Rapid2
Small	FOMM ONE	11.8	4.45	0.21	315	37.46	90	Slow 3kW	Fast 7kW	Fast 22kW	
Medium	Nissan Leaf	40	11.45	0.4	346	115	220	Slow 3kW	Fast 50kW		
Large	KIA E-SOUL	64	10.3	0.44	356	180	335	Slow 3kW	Fast 50kW	Fast 175kW	
X large	Tesla Model S	100	7	0.38	400	250	525	Slow 3kW	Fast 50kW	Fast 175kW	RDC 350kW

Charging Station Level				
Charging time (hrs/100 km)	Power supply	Power	Voltage	Max current
6–8 hours	AC Single phase	3.3 kW	230 V AC	16 A
3–4 hours	AC Single phase	7.4 kW	230 V AC	32 A
2–3 hours	AC Three phase	11 kW	400 V AC	16 A
1–2 hours	AC Three phase	22 kW	400 V AC	32 A
20–30 minutes	AC Three phase	43 kW	400 V AC	63 A
20–30 minutes	DC (Direct current)	50 kW	400–500 V DC	100–125 A
10 minutes	DC (Direct current)	120 kW	300–500 V DC	300–350 A

Carbon Content's Thailand

EGAT FUEL CONSUMPTION IN POWER GENERATION

YEAR	FUEL OIL (M.LITRES)	DIESEL OIL (M.LITRES)	NATURAL GAS (MMSCFD)	LIGNITE (TON)
1986	865.866	7.903	257	4685127
1987	574.972	4.567	396	5726917
1988	830.745	4.528	473	5895752
1989	1195.148	17.419	484	6764206
1990	2531.549	163.259	473	9875324
1991	3163.739	61.604	606	11724691
1992	3718.52	71.283	640	12370539
1993	4321.9	287.763	725	11490328
1994	4789.169	474.331	820	12155884
1995	5258.376	755.646	838	13567494
1996	5068.31	1319.594	929	16405340
1997	4665.399	728.694	1170	18010806
1998	4252.592	305.725	1205	15388095
1999	3761.773	134.672	1206	13893584
2000	2364.065	28.853	1301	14120569
2001	647.01	74.948	1504	15744116
2002	499.419	41.255	1632	15035329
2003	604.944	22.615	1624	15406532
2004	1295.937	54.976	1675	16536694
2005	1850.695	49.188	1740	16571091
2006	1895.47	21.004	1766	15815374
2007	780.46	7.99	1714.61	15811050
2008	249.34	7.71	1557.91	16407465
2009	111.04	12.89	1540.72	15818265
2010	140	12	1879	16004196
2011	314	11	1591	17161168
2012	319	19	1789	16754281
2013	317	60	1692	16884947
2014	379	21	1657	17020425
2015	192	29	1659	14483502
2016	74	37	1439	16405949
2017	20	43	1161	15898285
2018	8	25	1144	14169492

CO2 Emission in Transport by Energy Type

UNIT : 1,000 Tons	Oil	Natural Gas	Total
1987	18092.01	0	18092.01
1988	21047.11	0	21047.11
1989	25202.41	0	25202.41
1990	28354.45	0	28354.45
1991	28978.1	0	28978.1
1992	30912.47	0	30912.47
1993	36534.39	0	36534.39
1994	40938.53	0	40938.53
1995	48210.82	0	48210.82
1996	52710.65	0	52710.65
1997	55235.12	0	55235.12
1998	46770.82	0	46770.82
1999	46916.55	0	46916.55
2000	45582.33	0	45582.33
2001	46551.34	5.56	46556.9
2002	49253.77	5.53	49259.3
2003	53023.71	6.61	53030.32
2004	56501.66	62.77	56564.42
2005	57411.82	136.89	57548.72
2006	54630.81	229.77	54860.58
2007	55074.78	500.01	55574.78
2008	50903.9	1647.04	52550.94
2009	53364.8	3032.99	56397.79
2010	53636.45	3845.28	57481.73
2011	54340.5	4900.96	59241.46
2012	55179.14	5919.08	61098.22
2013	51776.27	6524.49	58300.76
2014	48782.15	6728.93	55511.08
2015	54826.33	6455.33	61281.66
2016	60306.26	5924.08	66230.34
2017	62096.96	5157.21	67254.17
2018	63262.87	4665.52	67928.39

National Grid Profie's Thailand

POWER GENERATION BY TYPE

UNIT : GWH

YEAR	HYDRO	FUEL OIL	LIGNITE	NATURAL GAS	DIESEL	GEO THERMAL	EGAT NRE*	IMPORTED	DEDP	SPP	IPP	VSPP	TOTAL
1986	5531.7	3334.88	5541.28	10251.71	10.24			758.38					25428.19
1987	4056.23	2188.38	6698.01	15623.66	2.41			415.45	4.92				28989.06
1988	3718.17	3142.03	6799.5	18719.88	3.47			429.78	30.19				32843.02
1989	5512.21	4738.83	7869.57	19194.75	16.45			643.15	21.57				37996.53
1990	4900.11	10012.63	11052.85	17765.06	356.85	1.01	0.016	652.32	23.983				44764.829
1991	4505.35	12636.39	13785.22	19051.186	112.574	1	0.017	593.11	28.65				50713.497
1992	4158.94	14928.92	14815.05	22943.04	161.34	1.124	0.024	479.898	19.713				57508.049
1993	3612.501	17494.52	13503.754	27953.16	743.965	1.142	0.031	644.516	28.256				63981.845
1994	4403.602	19647.181	14130.908	30920.178	1385.176	0.901	0.044	870.815	36.516	13.301	564.627		71973.249
1995	6593.011	21711.89	15152.252	25377.378	2261.18	1.053	0.042	699.121	26.004	261.653	8352.744		80436.328
1996	7215.002	20983.731	17507.174	24722.174	4572.363	1.186	0.171	805.606	26.171	1232.926	10730.734		87797.238
1997	7082	19266.113	18924.578	28613.711	2440.679	1.279	0.221	745.628	27.185	2150.895	14154.616		93406.905
1998	5088.822	17534.1	16475.243	32702.156	988.973	1.297	0.24	1622.712	14.607	3191.846	13535.727		91155.723
1999	3409.668	15429.254	15418.909	32851.182	457.329	1.492	0.241	2255.661	34.492	8353.154	14259.568		92470.95
2000	5891.444	9611.418	15852.167	35642.218	107.948	1.645	0.326	2966.253	25.635	10175.54	18212.924		98487.518
2001	6174.345	2419.961	17722.357	34786.989	248.063	1.503	0.459	2881.714	31.077	11644.291	27958.142		103868.901
2002	7366.94	1969.385	16651.861	35251.595	150.983	1.436	0.311	2812.175	31.707	12548.249	34469.227		111253.869
2003	7207.755	2434.279	16856.156	31694.402	75.296	1.613	0.238	2473.412	32.294	13303.228	44332.768		118411.441
2004	5896.294	5467.672	17993.553	30901.096	232.949	1.261	0.871	3377.854	25.5	13440.601	50172.863		127510.514
2005	5671.181	7640.002	18334.501	33064.851	176.848	1.452	0.812	4371.885	17.404	13546.611	51972.648		134798.195
2006	7950.05	7808.44	18027.677	33962.666	76.922	1.722	0.846	5151.854	44.79	13530.951	55362.651		141918.569
2007	7961.357	2966.571	18497.679	36501.685	28.238	1.837	0.808	4488.358	21.701	14439.45	62118.21		147025.894
2008	6950.69	990.083	18679.296	37260.978	23.282	1.303	0.703	2783.573	28.77	14036.433	67465.82		148220.931
2009	6965.736	448.231	17922.09	41761.015	45.071	1.406	1.864	2451.41	24.039	13896.541	64840.709		148358.112
2010	5346.753	558.31	17987.629	50802.504	41.585	1.642	5.654	7253.784	23.639	13870.809	67775.987	1160.509112	164828.8051
2011	7934.922	1294.893	18835.626	45863.417	35.977	1.823	6.218	10774.409	33.689	14936.197	62625.967	1746.777774	164089.9158
2012	8431.217	1299.956	18802.01	52568.772	62.762	0.866	2.873	10527.426		15134.221	70143.037	2510.468883	179483.6089
2013	5412.084	1238.445	19097.976	50202.113	179.138	1.25	4.365	12571.79		22602.708	66088.614	3806.968327	181205.4513
2014	5163.573	1580.519	19370.819	50825.918	62.598	1.433	4.84	12259.713		25957.586	65718.057	5078.837391	186023.8934
2015	3760.733	771.506	16932.304	51494.541	125.7	1.347	3.975	14414.486		28219.425	70799.54	5722.857267	192246.4143
2016	3543.078	296.488	19059.428	47963.633	173.69	1.392	5.007	19825.355		33337.461	67893.741	7554.601226	199653.8742
2017	4687.186	105.191	18897.778	39939.964	197.782	1.552	11.045	24427.424		39992.019	63635.906	9269.683966	201165.531
2018	7597.013	35.797	17698.437	38872.315	111.772	1.49	9.307	26669.441		48683.671	54285.408	10340.92569	204305.5767

PEAK, DEMAND AND LOAD FACTOR

MONTH	PEAK (MW)	GENERATION (GWh)	LOAD FACTOR (%)
1986	4219.6	25429.24792	68.79
1987	4886.8	28989.06772	67.71
1988	5444	32843.18563	68.68
1989	6336.6	38005.5085	68.46
1990	7221.3	44764.70986	70.76
1991	8045	50713.45575	71.96
1992	8903.5	57509.27776	73.53
1993	9839.4	63981.84511	74.23
1994	11064	71973.25186	74.26
1995	12267.9	80436.32722	74.84
1996	13310.9	87797.27581	75.08
1997	14506.3	93407.38938	73.5
1998	14179.9	91155.68297	73.38
1999	13712.4	91413.89674	76.1
2000	14918.3	98487.38568	75.15
2001	16126.4	103855.9004	73.51
2002	16681.1	111255.8301	76.13
2003	18121.4	117290.4405	73.88
2004	19325.8	121534.4868	71.59
2005	20537.5	134798.1912	74.92
2006	21064	141918.5631	76.91
2007	22586.1	147025.8921	74.3
2008	22568.2	148264.316	74.79
2009	22044.9	145158.6728	75.17
2010	24009.9	160151.615	76.14
2011	23900.21	158936.7737	75.91
2012	26121.1	173319.9598	75.54
2013	26598.14	173377.4368	74.41
2014	26942	177261.2738	75.11
2015	27346	183186.9054	76.47
2016	29618.8	188935	72.6
2017	28578	188970.22	75.48
2018	28338	191109.81	76.99

Charging Profile		[redacted]	Charging Point				
Time	Profile		Time	Profile			
Hours	EV kW		Hours	emand (kW	Charging	Queue	Charged
1/1/2019 0:15	0.00		0h15m	0	0	0	0
1/1/2019 0:45	0.00		0h45m	0	0	0	0
1/1/2019 1:15	0.00		1h15m	0	0	0	0
1/1/2019 1:45	0.00		1h45m	0	0	0	0
1/1/2019 2:15	0.00		2h15m	0	0	0	0
1/1/2019 2:45	0.00		2h45m	0	0	0	0
1/1/2019 3:15	0.00		3h15m	0	0	0	0
1/1/2019 3:45	0.00		3h45m	0	0	0	0
1/1/2019 4:15	0.00		4h15m	0	0	0	0
1/1/2019 4:45	0.00		4h45m	0	0	0	0
1/1/2019 5:15	0.00		5h15m	0	0	0	0
1/1/2019 5:45	0.00		5h45m	0	0	0	0
1/1/2019 6:15	0.00		6h15m	0	0	0	0
1/1/2019 6:45	0.00		6h45m	0	0	0	0
1/1/2019 7:15	0.00		7h15m	0	0	0	0
1/1/2019 7:45	6.35		7h45m	6.35	1	0	0
1/1/2019 8:15	0.00		8h15m	0	0	0	1
1/1/2019 8:45	7.00		8h45m	7	1	0	1
1/1/2019 9:15	1.89		9h15m	1.89	1	0	1
1/1/2019 9:45	7.00		9h45m	7	1	0	2
1/1/2019 10:15	5.70		10h15m	5.7	1	0	2
1/1/2019 10:45	14.00		10h45m	14	2	0	3
1/1/2019 11:15	21.00		11h15m	21	3	0	3
1/1/2019 11:45	22.86		11h45m	22.86	4	0	3
1/1/2019 12:15	11.40		12h15m	11.4	2	0	5
1/1/2019 12:45	14.00		12h45m	14	1	0	6
1/1/2019 13:15	7.00		13h15m	7	1	0	7