MARCH 29, 2019

DESIGN OF A STANDALONE, SOLAR POWERED COMMERCIAL BANK WITH ELECTRIC VEHICLES FOR PUBLIC TRANSPORT

BY H00308077

AREE FINAL SUBMISSION

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1 INTRODUCTION

1.1 Overview and Problem

Nigeria has a population of over 180 million people who rely solely on non-renewable energy despite its vast potential in renewable sources such as solar and hydro [1][2]. The total potential of these renewables is estimated at over 68,000MW, which is more than five times the current power output[1]. Nigeria's installed electricity capacity is 12,522MW, well below the current demand of 98,000MW. The actual output is about 3,800MW, resulting in a demand shortfall of 94,500MW throughout the country[3]. As a result of this wide gap between demand and production, only 45% of Nigeria's population has access to electricity [3][4].

There have been some efforts made by the Nigerian governments towards renewable forms of electricity in the country. As an example, in 2006, the Ministry of Environment with the support of the united nations development programme (UNDP) implemented the renewable energy master plan (REMP), which was aimed to increase the contribution of renewable energy to Nigeria's total energy production [5].

As one of the highest producers of oil and gas in Africa, the government was unable to achieve its objective due to a weak commitment to the proposed plans and fear of losing its primary source of income, which is the exploration of the oil and gas [1]. These create a void, which can be filled by any available opportunity.

1.2 Motivation

The commercial enterprises, both private and public sectors in Nigeria have made the diesel-powered generators as their primary energy source to complement the incompetency of the national grid. Also, transportation sectors rely heavily on fossil fuel. Nigeria is one of the highest producers of petroleum in the world making this CO_2 emitting product readily available for consumption at an affordable price [6][1].

This motivated a desire to develop a system that will solve these two major problems of electricity inadequacy to the masses and emission of carbon in the country, by establishing a renewable energy system powered commercial sector with electric vehicles (EV) for public transport.

The attainment of a self-sustaining commercial sector will reduce their power demand from national generation making power more available to the domestic users, and the introduction of electric vehicles will reduce the emission by the transportation companies. This system, when adopted by commercial enterprises, has the potential of increasing the organisation's sales as companies can declare themselves as a clean organisation which will improve their reputation.

1.3 Choice of Site (Bank)

Finance plays a significant role in the implementation of renewable energy technologies (RET). The government of Nigeria shows little investment in Renewable Energy

Technology (RET) [1]; therefore, a private organisation with strong financial capabilities will be required to finance such an endeavour. The services sector of the country contributes 50% of the annual Gross Domestic Product of the country with banking been the major service sector of the country [7]. There are currently 21 major banks in Nigeria with over 100,000 branches across the nation; each bank requires a minimum capital base of $70million (Minimum deposit of each bank before an operation) set by the Central bank of Nigeria [8]. Nigeria banks show great financial power which will be sufficient for RET investment.

Besides, the banking sector requires an uninterrupted power supply at all time; this has led to the heavy reliant of the bank's energy requirement on diesel-powered generators [9]. Most RET can compete with diesel powered and, in most cases, might be cheaper than diesel generators [10]. This will reduce banks cost of electricity generation and redeem their image by generating electricity from a clean source. These two factors led to the decision of making bank as the preliminary site of implementation and which can be extended to any other companies with huge financial power.

1.4 Site of Study

The project site is located at Lekki, Lagos state in Nigeria, which is one of the most populous residential areas and with the highest commercial activities in the country [11]. The site location is 5Km away from the Atlantic Ocean to the south with latitude 6.42 and longitude 3.84, falling in the region of tropical savannah climate exhibiting a period of both wet and dry seasons throughout the year [12][13]. The average of the daily sums of global horizontal irradiation for the location is between the ranges of 4500-5000Wh/m^2 as seen in figure 1.1, and with annual average temperature ranging between 27°C-30°C [5]. The aerial view of the site is shown in appendix A, and the total rooftop area is 291m^2. All these properties indicate that it is a site with the potential for harnessing solar energy.

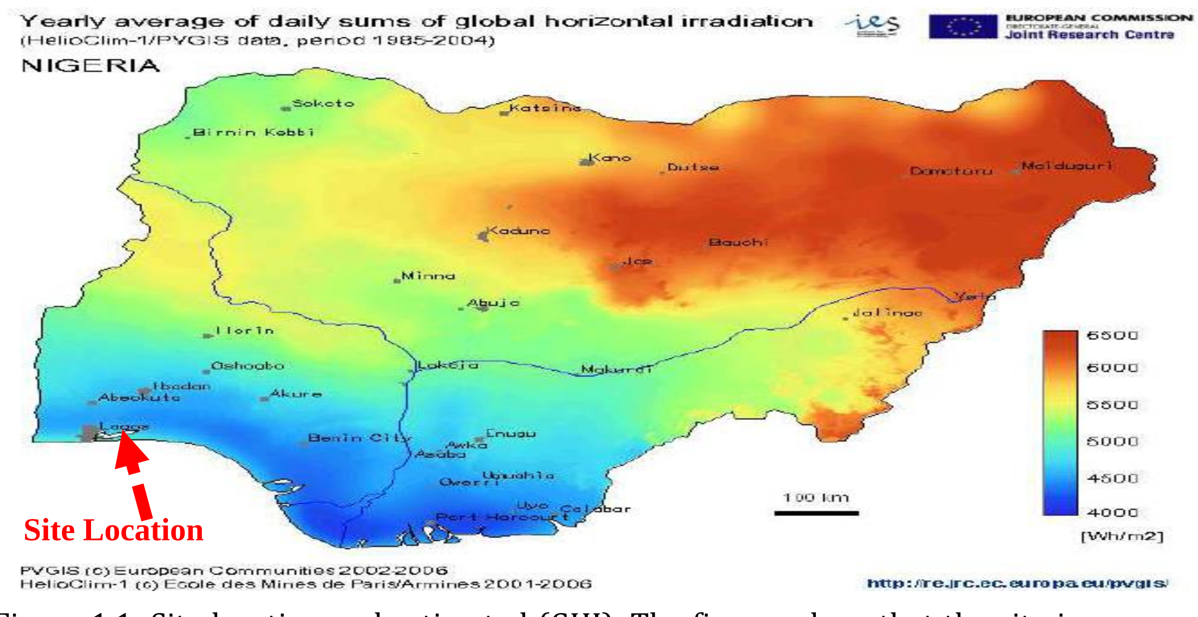

Figure 1.1: Site location and estimated (GHI). The figures show that the site is average daily sums of global radiation is in the range of 4500-5000Wh/m^2 [14]. (See Appendix A for the aerial view of the site).

2 METHODS

2.1 Resources

This section presents the resource data acquisition strategy and its analysis. The analysis involves yearly, monthly, and daily evaluation with a final deduction for the system design is made based on the observations from the analysis.

2.1.1 Data Acquisition

Accurate and sufficient resource data of lowest available time frames for as many years as possible is required to estimate the probable energy attainable in a location. The in-situ data for the site is not available; therefore the satellite data obtained from PVGIS is used [15]. PVGIS is an online simulation software for the design of solar systems with various solar resource data [15]. This data was obtained from satellite sensors capable of providing hourly resolution with reasonable accuracy for up to five years. The hourly data for the site location was downloaded and analysed in Excel.

2.1.2 Yearly Analysis

The average monthly solar irradiance (AMR), which indicates how much sun is received each day in the months in years (2007-2011) for the location is shown in figure 2.1; the graph shows a fluctuation in the average daily solar irradiance for every month of the years plotted. The highest AMR (KWh/m^2/day) was observed in the months November to April (4.5-5.5), with a significant fall in May (3.5-4.0) reaching the lowest in the year in the months June and July (2.5-3.5). There is a gradual rise in August through September (4-4.5) reaching peak in December. This trend was observed for all the year plotted to show that a similar observation might be experienced in the future; therefore a detailed analysis of this observation is required before system sizing.

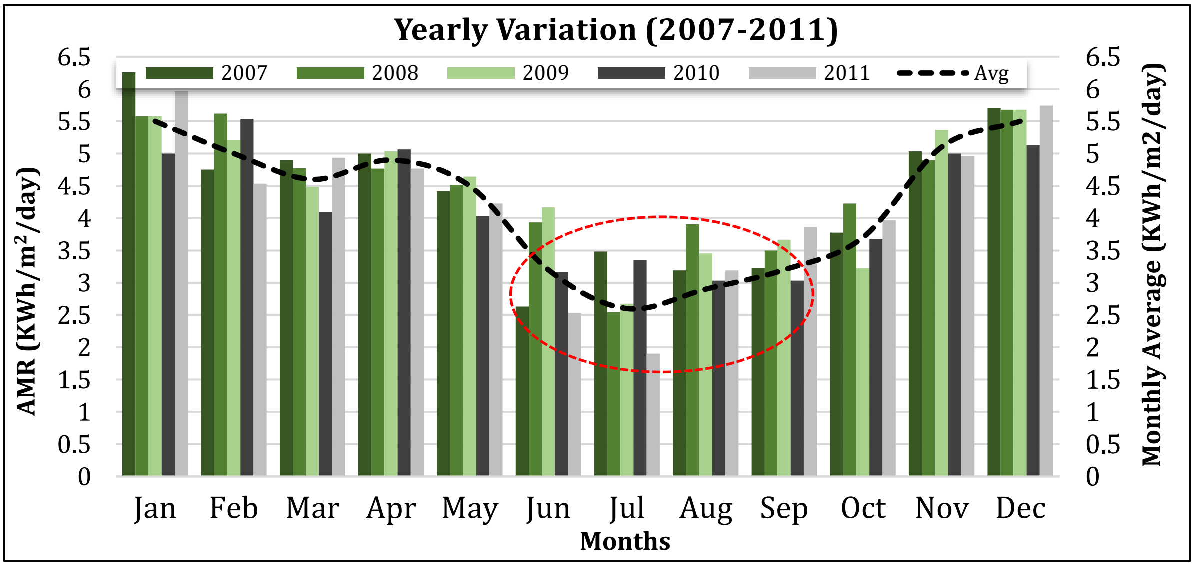

Figure 2.1: 5-years (2007-2011) monthly solar irradiance (KWh/m^2/day) for the site. This shows a constant dip in June – August for all the five years plotted. Detailed analysis is needed to understand this dip before sizing the system. (See deduction)

2.1.3 Monthly Analysis

The year with the lowest AMR, 2009 (obtained using the MIN function in excel) is used in this study to give a worst-case scenario for the design. Figure 2.2 shows the monthly solar irradiance (MSR). It indicates that MSR (KWh/m^2) from November through March is within the ranges of 300-350 with a mean value of 350. The size of the box (interquartile range) shows where most of the values fall. The box for November through March is relatively small and fell at the upper limit of the graph; this shows that higher irradiance is observed for this months and most of the values are relatively high; therefore higher energy output will be experienced for this months.

There is a gradual fall in the mean starting from April with larger interquartile range been observed for April and May, denoting a drop in the irradiance spreading over lower values. The least mean and median was experienced in June and July (200) indicating the period of with high rainfall and cloud cover. Finally, a gradual increase again in August and September with the lesser interquartile in the range of more substantial irradiance.

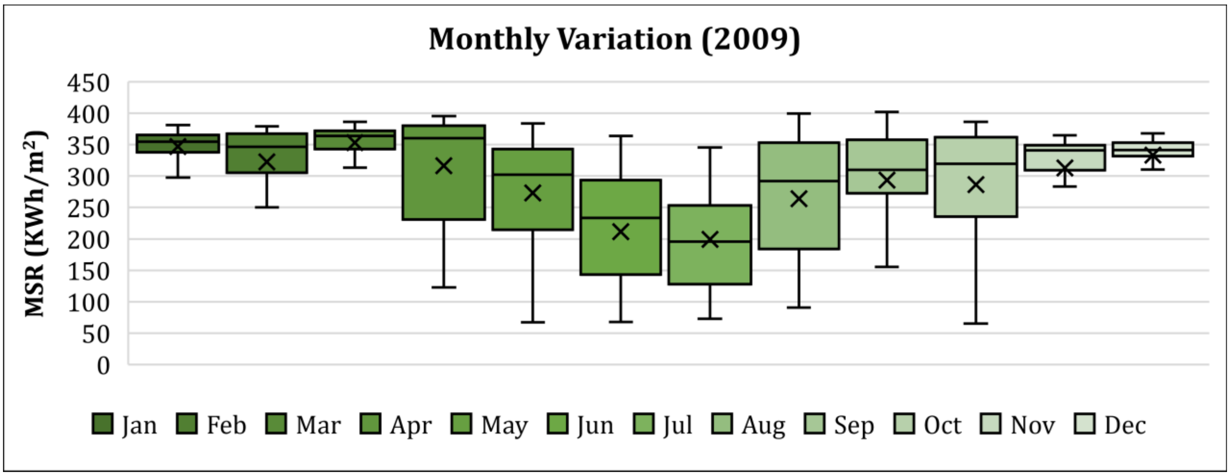

Figure 2.2: Monthly average daily solar irradiance for the year 2011. This shows small boxes at the upper limit of the graph for November – March denoting the months with the most significant irradiance while larger boxes were experienced for April – October indicating a drop in irradiance. The (X) sign indicates the mean of the values; therefore, the months with the lowest (X) experienced the least mean irradiance (June and July). (See deduction)

2.1.4 Daily Analysis

Six days from six months (three in rainy and three in the dry season) were selected to observed daily irradiance of the sites. The irradiance for the 15th day in six months of the year 2011 was plotted in figure 2.3. This shows that little or no energy can be harness during the early hours of the morning and late in the evening as no substantial irradiance was experienced for all the days plotted.

July and October show a substantial drop in the irradiance compared to other months. This observation supports the Monthly and Yearly observations of drop in solar irradiance in these months. A deduction will be made based on the three analysed scenarios in the next section.

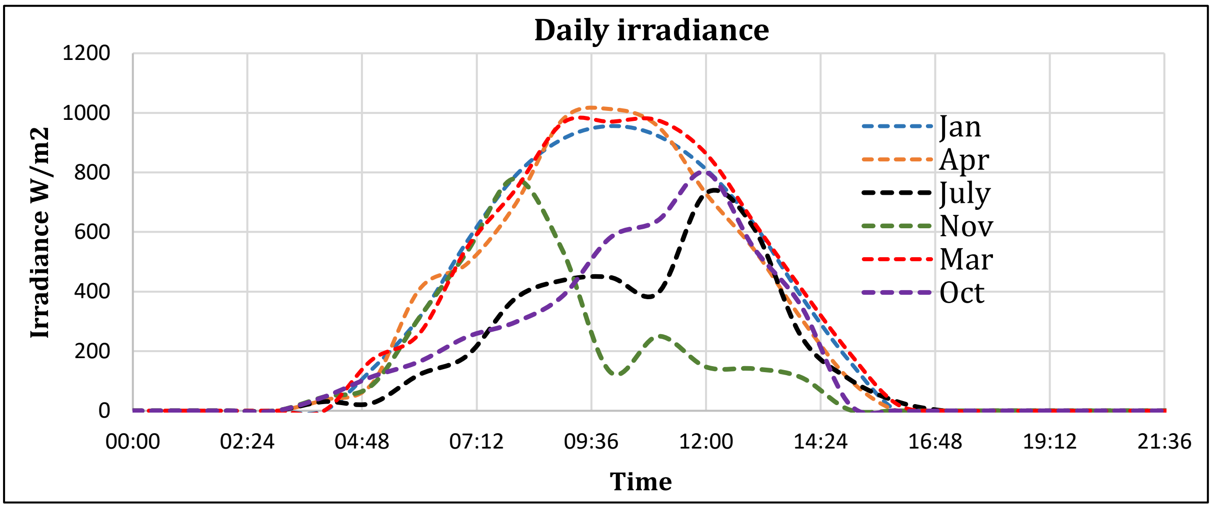

Figure 2.3: Daily irradiance for six selected days in the year 2011. Little or irradiance at all during the early hour of the morning and late in the evening and drop in irradiance for July and October denoting raining seasons.

2.1.5 Final Deduction

Prior studies [13][12][16] suggested that the reduction in the AMR for the observed months was as a result of the change in season. Two seasonal are observed in this location, which is rainy season and dry season [16][13]. During the raining annual there is fewer hours of sunlight and a high possibility of cloud covering, while during the dry seasons, there are more extended hours of sunshine and less cloud cover. Hence, it can be deduced that the months with peak AMR are the dry season and the months with significant fall in AMR are the raining season.

Both seasons are outstanding factors in harnessing solar energy, such that, there is higher energy during the dry season in this site and the water during the raining season will help in washing away dust from the surface of the panels if tilted at an appropriate angle which will reduce operational and maintenance cost.

Based on the analysis of the daily, monthly, and yearly irradiance, it can be deduced that the system can be sized for two seasons (Raining and Dry Seasons). In designing a self-sustaining system, the raining season is needed to be used, which will result in the use of many solar PV to generate the required energy during this time and result in an excess generation of energy that can be sold during the dry season.

The location of design will be a constraint being in a residential environment rather than an open space, there won't be enough spaces for the installation of PV panels to sustain the rainy seasons; therefore, the design will be based on the dry seasons to give lower PV panels installation, which will be self-sustaining during the dry season and will require an alternative power supply to meet the demand during the raining season. This alternative energy can also serve as the backup with a battery during the early hours of the or late in the evening. This will result in lower investment cost and less excess energy.

2.2 Demand

This section analysed the demand requirement of the system. There are two demands to be served by the system, the bank and the electric vehicles (EV). These two demands are analysed in the first two subsections and the last subsection gives the aggregate demand.

2.2.1 Bank's Load

The bank demand is currently being met with two 25 kVA generators that run interchangeably with a 15-KWh battery and an inverter system. Most commercial enterprises in Nigeria has resolved to this pattern of energy usage due to their requirement of an uninterrupted power supply which cannot be achieved using the power supply from the national grid[17]. The bank demand is well understood, is a commercial centre with almost the same daily routine. Appendix B shows all the equipment used by the bank with their average runtime as obtained by the technician of the bank.

2.2.1.1 Bank's Power

The bank's power demand for a day is plotted in figure 2.4, this shows a sharp increase from time 7:00 to 9:00, rising to a peak of 11 KW at 9:00, this is because of the gradual increase in demand of the bank, as people come in to start the day's work. After this time, the power experiences a gradual increase in power reaching a peak at 16:00 (13KW) been the working hours. After 16:00, there is a gradual fall in power as the bank close for the day and the staff leaves their desk one after the other. The minimum was observed at the time 23:00 which was relatively constant throughout the early morning (6:00) as the bank is not in operation at this time and power is only needed for the devices that require 24 hours runtime such as servers, CCTV and security lights.

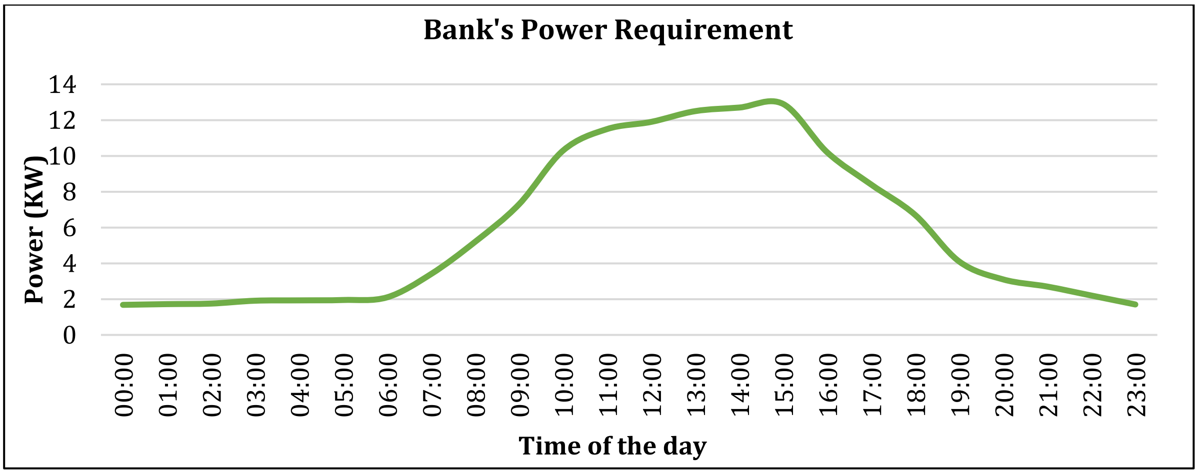

Figure 2.4: The bank's power requirement. Relatively low demand, which is constant through the early hours of the morning (22:00- 06:00)-Bank closed, gradual increase (06:00 -10:00) -Open hour, relatively constant demand (10:00- 16:00)-working hour and gradual decrease in demand (16:00-22:00) - closing time.

2.2.1.2 Bank's Energy

The data for the monthly demand for the banks was copied from the meter provided by the technicians. Figure 2.5 shows the annual energy demand of the bank for all the months; this indicates that there is an insignificant change in demand during each month as almost same runtime time is required for the all the devices irrespective of the seasons. There's a slight reduction in energy consumption during the raining season which might be attributed to slightly lower runtime for the air conditioners in the bank as a result of lower temperature during this time in the year.

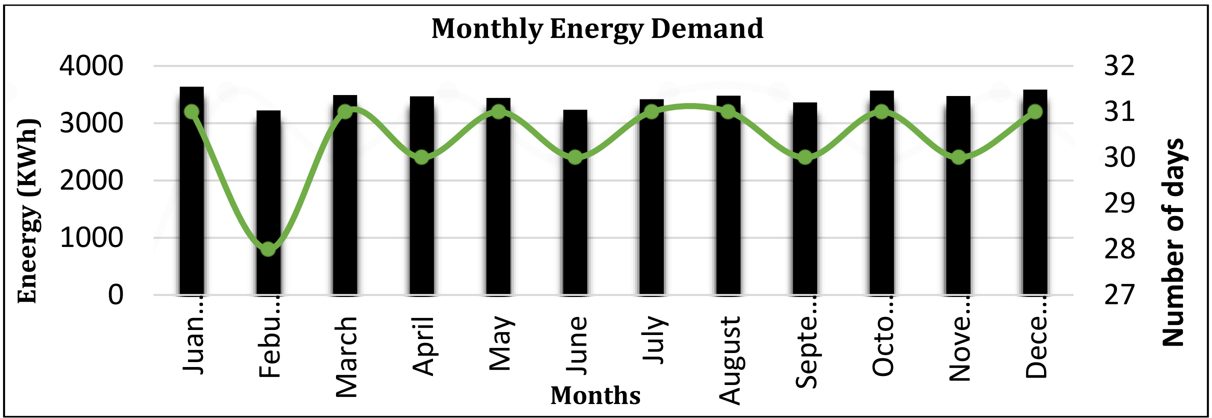

Figure 2.5: The monthly energy requirements of the bank for a typical year. Relatively constant demands for all the months in the year. The months with lower days experienced lower energy, e.g. February with 28 days and every other month with 30 days. The slight difference in monthly demand is because of the number of days in each month.

2.2.2 Vans Demand

This study will use two Nissan e-NV200, which is one the largest EV's van currently on sales, the specification for the vans was provided by the manufacturer [18]. It is a 40-kWh lithium-ion battery EV with an estimated drive range of 125 -184 miles when fully charged [18], the least driving range will be used in this study to allow for uncertainty on the road and balance for possible higher consumptions that might arise due to increasing in acceleration and weight carried by the vehicles [19][20]. The vans possess lithium batteries and to achieve a longer life for such batteries - the maximum depth of discharge (DOD) of 80% is recommended [21][22]. For a battery of 40 KWh and 80% DOD; therefore, the maximum usable power is 32 KWh.

The vehicle allows for two types of charging; the standard charge is a 6.6KW charging point/cable and a rapid charge of 50KW [18]. Taking into consideration the losses during charging efficiency of the charging tools, a charging efficiency of 90% is taking; consequently, the charging time and energy requirements for both charging conditions and energy consumption for a full charge will be different from the values provided by the manufacturer. The new energy specification is provided in Table 2.4, which is slightly higher than the manufacturer values. (See Appendix C for detailed calculation)

Table 2.1: Van's charging specification and power consumption [18]. This shows that there is a possibility for energy consumption higher than the prediction from the manufacturer.

	Power Specification (KW)	Charging Time Hours (hr)	Energy Requirement for a Full Charge. (KWh)
Normal Charging	6.6	7.13	47
Rapid Charging	50	0.94	47

2.2.2.1 Mileage Calculation and Consumption

Due to the novelty of this project in the choosing area, there is no transit timetable currently in use for the route chosen for the operation of the two vans; therefore, one was created for the two vans (see appendix D). The total travel distance and energy consumptions were estimated according to appendix D.

The timetable (appendix D) shows that the two vans will operate during the early hours of the morning moving in an opposite direction and transporting staffs to work with a partial charging (rapid charging) when most staffs are at work. The vans will also operate at the early hours of the closing hour through the evening moving staff back home. Then stop work after moving staffs back home to charge overnight (normal charge). The Van1 will start at Route1 and Van2 at Route2 with both going in the opposite direction at all time through their time in operation (see Appendix D).

Luckily, there are dedicated lanes for the current transit vans (BRT) [6], which allows the public transits only access to these lanes. The study vans (Nissan e-NV200) will also use these dedicated lanes, which will allow free flow of travel without any cause for traffic, which might cause unexpected power consumption.

The manufacturer suggested a power consumption of 0.259KWh/Km on the specification [18], but previous studies have shown that EV's energy consumption is not entirely constant throughout a trip, increase in acceleration, and weight carried by EVs also affect the energy consumption [19][20]; therefore a round-trip efficiency of 85% for each van. The power consumption is now 0.3KWh/Km. [see appendix D for calculation]

Using a DOD of 80% for the EV's battery to allow for better life cycle, the maximum energy usage from the battery is 32KWh and maximum travel distance allowable is approximately 107 Km before recharge. [See Appendix D for calculation]

2.2.2.2 Power

The hourly power requirement for the two vans is plotted in figure 2.6. At early hours of the day (00:00 - 5:00), the vans will be plugged in the system to charge using the standard charge (6.6KW); therefore two 6.6KW charging ports will be needed at this time. It is estimated to be fully charged during this period (5 hours) and ready for the day's operation.

At 06:00 -12:00, the two vans will be in service to move workers to work. The two vans will stop running between the hours of 12:00 – 15:00 to allow for a rapid charge of one hour, at this time most workers are expected to be at work. A single 50KW charging port is sufficient at this time as the two vans have 3 hours for charging before the evening transit. This operation will be constant every day of the year except for weekends where it is not economical to use the vans because the workers are not going to work these days.

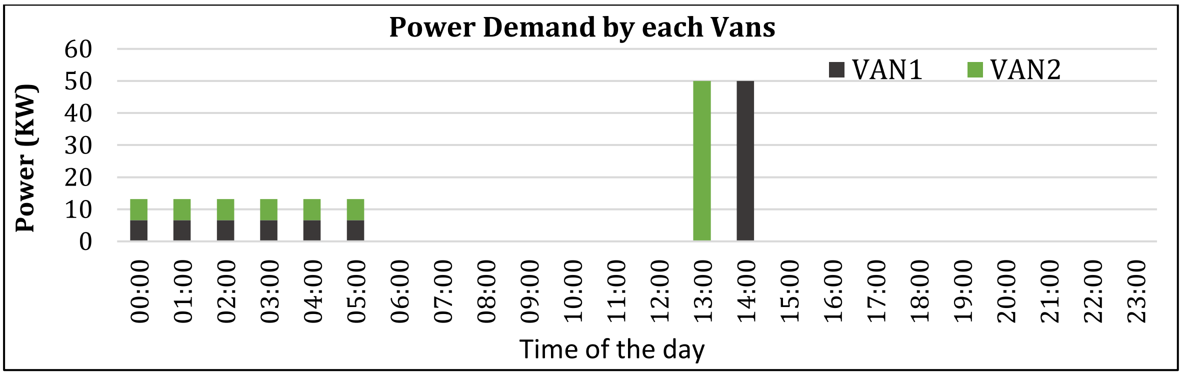

Figure 2.6: The power requirement for the two vans at each hour of the day. The power demand is 13.2KW for hours (00:00 – 05:00) – normal charge and a rapid charge for each van when staff are at work in the after (13:00 - 14:00).

2.2.2.3 Energy

The daily energy requirements of the EVs is plotted in figure 2.7, and this shows similar behaviour with the power representation in figure 2.6. Both Vans start charging at the time 00:00 and 1:00 respectively, to attain a full charge by 05:00 and 06:00 respectively consuming total energy of 74KWh (see appendix D).

Van1 starts operation by time 06:00 while Van2 start operating at 07:00 which will result in the discharge of the battery until 12:00 and 1:00 respectively before charging in the afternoon (12:00-13:00). They both start the afternoon operation again by 14:00 and 15:00 which results in discharge through the evening attaining a minimum battery capacity of 8.5KWh denoting a maximum DOD of 80%.

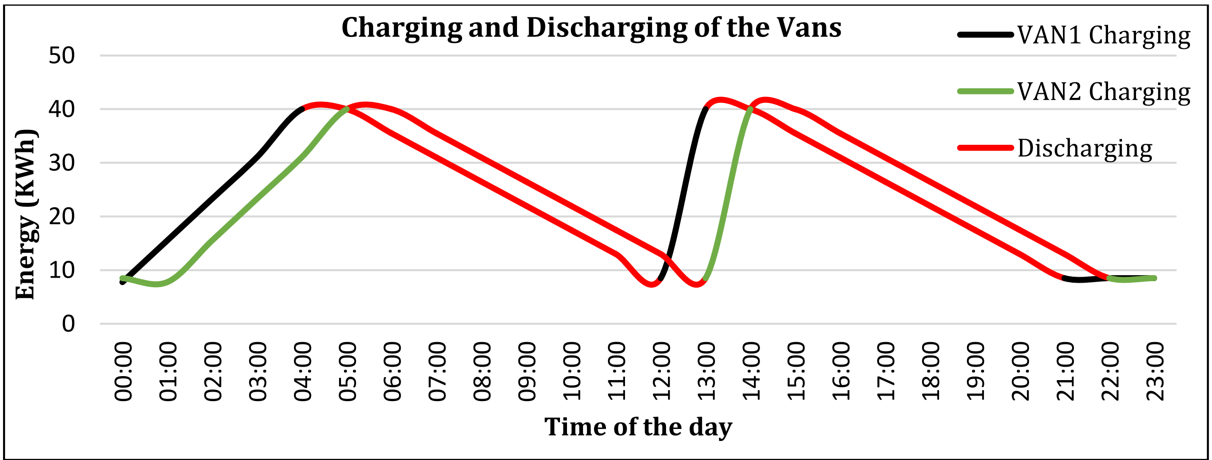

Figure 2.7: The charging and discharging of the Vans. This shows that the vans will never discharge completely because the DOD is 80% (8KWh).

2.2.3 Overall Demand

The two demands of the system have been analysed above. It was observed that the daily demand power requirements of both systems are relatively constant throughout the year, and therefore their energy required per day throughout the years is almost constant, but the design will consider degradation, emergency and opportunity for expansion during design. The next subsection presents the aggregate of both demands.

2.2.3.1 Weekly Aggregate

Figure 2.8 shows the daily demand through the week required for the design; it shows that the maximum demand is slightly over 280KWh from Monday to Friday and lower demand during the weekends in the ranges of 60KWh. The vans will only run during the working days of the week as it will be uneconomical during weekends because little or no commuters will be observed during weekends for a commercial centre.

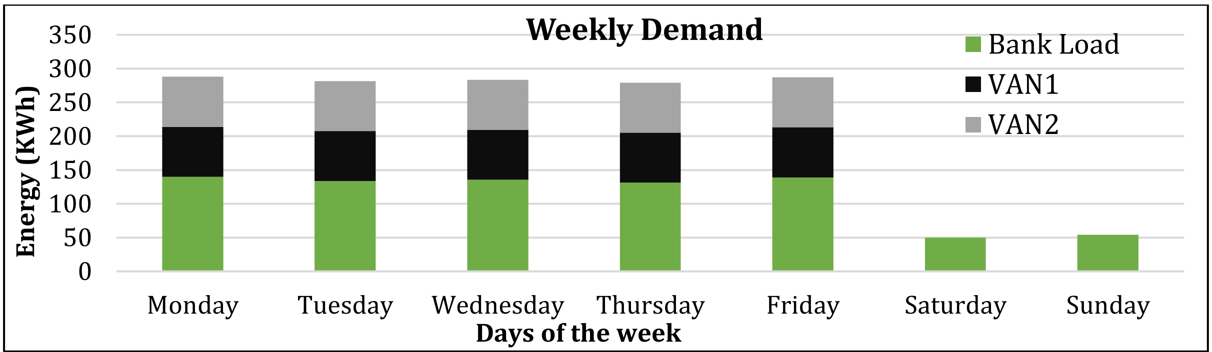

Figure 2.8: The total demand for both the bank and EV's load. Working days demand is relatively constant, and the maximum daily demand is 288KWh, which will be the basis for the system design with consideration for an emergency.

2.2.3.2 Annual Aggregate

Figure 2.9 shows the aggregate overall demand that needs to be met by the system; the monthly bank is the only variable factors as the vans are assumed to be the same for all days in the years. It's observed that the overall monthly demand is relatively the same throughout the year. The maximum demand was seen in October might due to being the hottest month [13] when more energy is used for cooling and minimum February because of lesser days in the month. The total energy consumption for the year is 98,000KWh.

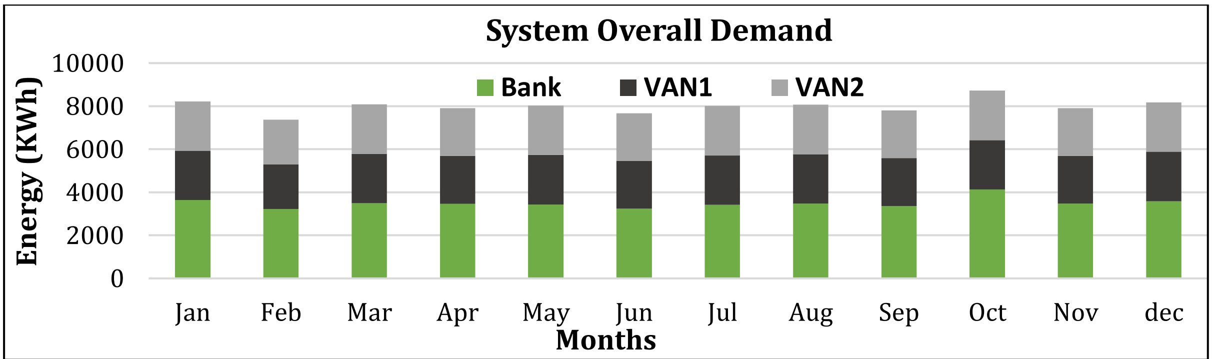

Figure 2.9: The total monthly demand for the bank and EVs load. The demand is relatively constant through the months (average of 8200KWh) and October (hottest month) been the highest demand of 8400KWh where more energy is used for cooling.

2.3 Design

This section presents the design of the system with all the system components sizing.

2.3.1 System Overview

The design aims to make the commercial bank buildings and EVs extract most of their energy requirement from the renewable energy source (Solar). Figure 2.10 shows the system overview, the battery will serve as a storage medium, and the diesel generator will serve as the backup. The maximum power point tracking (MPPT) will hold the system algorithm, serve as the charge regulator for the battery and DC-DC converter. The diesel generator will be the current 2 X 25KVA been used by the bank.

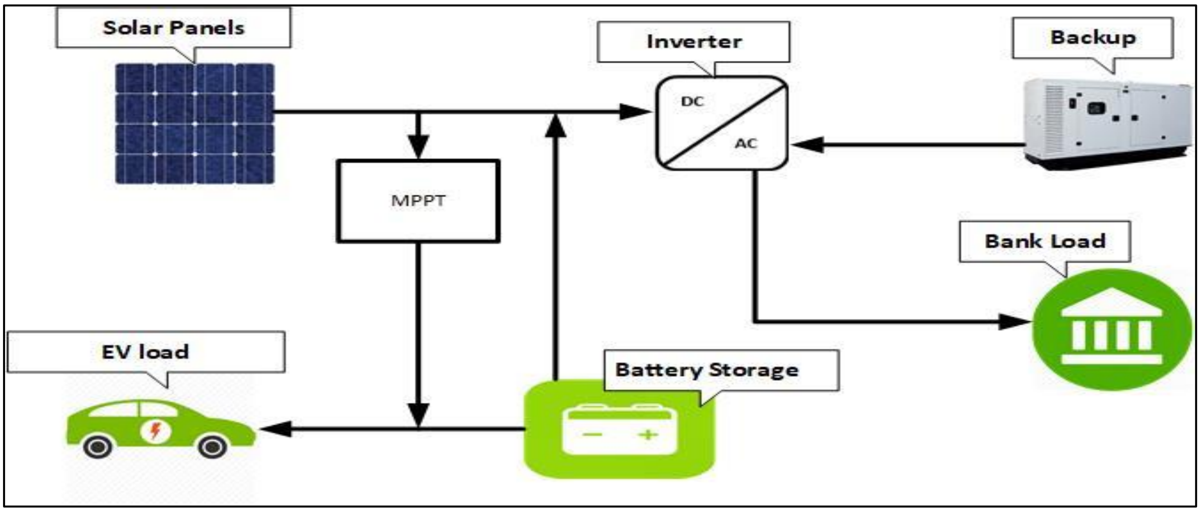

Figure 2.10: Proposed System Design. The system consists of solar PVs, batteries, Inverter, maximum power point tracking (MPPT) serving as a DC-DC converter and a charge regulator. The arrows show the direction of energy.

2.3.2 Solar PV

The intermittency of renewable energy sources such as solar energy has motivated different research in developing an analytical model in predicting the solar PV generation. The steady-state model for calculating PV generation is a widely used model and will be employed in this project [23][24]. Solar simulation software such as PVGIS and PVSYST applied this model in calculating PV generation [25][15].

The model uses the equation below in predicting the output:

$$P_{pv} = P_{sn} * {}^{G_t}/_{G_{stc}} \; [1 + K\,(Tc - Tr)] \qquad [24]$$

(Equation 1)

$$\text{Where} \quad Tc = Ta + \frac{(Tr-20)}{80} G_t$$

Where, P_{pv} = solar PV output power, P_{sn} =solar PV rated capacity
G_t = forecasted irradiance, G_{stc} = irradiance at STC (standard test conditions),
Tc = solar PV working temperature, Tr = reference temperature,
Ta = ambient temperature, K = power-to-temperature coefficient.

2.3.2.1 System Losses

The model calculation is based on solar irradiance of the site temperature and the ambient temperature of the weather forecast which can be obtained from the PVGIS data, but other environmental and physical factors affect the actual output of the panel. Some are:

- The cell operating **temperature** is a significant dependence on the production of the panel, which might cause losses; this has been incorporated in the model used in calculating the output [24][23].
- **Shading**: This is caused as a result of object such as trees or buildings near the array of installed panels casting shadow on it resulting in lower energy generating due to reduction in current falling in the section, the site of installing is not in a residential environmental with little or no shading, therefore a value of 1% will be used for the design [26][27].
- **Soiling:** These are losses due to the accumulation of particles such as dust on the solar panels, it is expected to be moderate in the site of study as it a location with medium population and, activities and pollution, the value of 5% is used [28][26].
- **Mismatch**: These are the losses due to imperfections and discrepancies of the voltage and current characteristic variance; this is inevitable, as no advanced technology has been developed to construct a device with specific I-V characteristics. 2% will be used in this study [26][27].
- **Resistive losses**: These losses occur in the wiring of the modules and the wiring connecting modules to the inverters and other components in the system. It occurs as a result of the resistive characteristics of the wires used. The value of 2% is used [26][29].
- **Ageing and weathering:** The power rating of the PV panel reduces over time due to the effect of weathering and material disintegration. the value 2% will be used [26][15].
- **Availability and others:** The value of 2% will be taken for availability and other losses that might arise such as maintenance and others[30].

The total estimated losses equal to **14%**; other losses in the system will be estimated during the design of each component.

2.3.2.2 PV Estimation.

The Solar PV that will be used is the Trinasolar 320w Solar which is readily available for purchase in Nigeria. The characteristics are provided by the manufacturer presented in Table 2.2 [31]:

Table 2.2: Typical data for the PV at STC [31].

Nominal Peak Power (W)	Max. Power Voltage (V)	Maximum Power Current (A)	Efficiency (%)	Length x Width (mm)
320	37.1	8.63	16.5	1956 x 992

STC at 1000W/m^2, irradiance level AM 1.5 and Tc =20.

The initial estimation of the PV panels is required before using the model to calculate the output; this can be obtained using the required demand. The maximum daily energy requirement is 288KWh, for emergency and future expansion, this will be approximated to 300KWh per day. The estimated system loss is 14%, making the energy required to be

342KWh/day, dividing this by the solar panel efficiency (16%), the total daily requirement is for the PV is **2138KWh**. The scaled annual solar irradiation is **5KWh/m²/day,** which is the average for the dry season.

$$\text{area required} = \frac{\text{energy required}\left(\frac{\text{KWh}}{\text{day}}\right)}{\text{average solar rad}\left(\frac{\frac{\text{KWh}}{\text{m2}}}{\text{day}}\right)} \qquad [15]\ (\text{equation } 2)$$

Using the above equation, the area required is 427.6m². The PV panel's area is 1.94m²; Therefore the total number of panels for the initial design is 220 modules.
The initial installed power is = 320*220 = 70KW.
The model (equation 1) will use P_{sn} = 70KW in the calculation of the solar output.

2.3.3 Roof

The area of 427.6m² is the total module areas, this does not evaluate the gaps between panels to avoid shading, and the spacing is calculated to give the total area of the roof.

Fixing a solar tracker with the solar panels will increase the costs of installation, additional energy generated due to the solar tracker might not be able to compensate for the extra cost of installation [32]; therefore, the optimum angle as suggested in previous studies will be used. The tilt angle used is 6^0; this will enable wash down of the surface during raining seasons and reduce the accumulation of dust during the dry season and azimuth is 0 [33][34]. Figure 2.11 shows the arrangement of the PVs on the roof with the parameter to be used in equation 3 for the row spacing calculation.

$$\text{Row spacing} = x * \frac{\cos(\text{azimuth angle})}{\tan(\text{altitude})} + \text{Height} = 1.956\text{m} + 0.1\text{m} \quad [35]\ (\text{equation } 3)$$

X = the tilted height of panel when erected at 6^0 tilt is 0.306m, altitude angle = 63.
Total area required = 220 * (1.956 + 0.1) * 0.992 = **449m²**

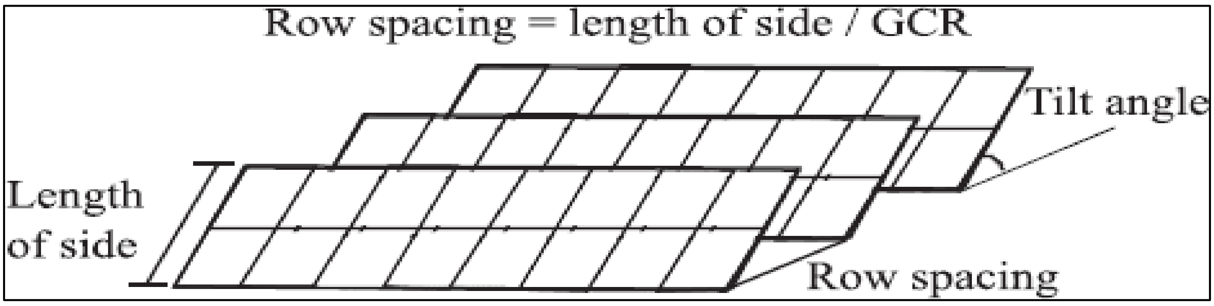

Figure 2.11: The arrangement of PVs on the roof [23].

The total area required for the installation of the 70KW chosen solar panel is 449m², the roof of the bank is 291.8m² (142 modules), and therefore 157.2m² (78 modules) more is required. There is currently no parking lot for vehicle in the bank, a parking lot with a height equals the height of the bank to prevent shading will be used which will also serve as the parking space for the EVs.

2.3.4 Inverter

The inverter is an essential component in the design of a solar powered system. It helps in converting DC from PVs to a clean AC for the use of the AC appliances. This study will use the optimised inverter sizing method rather than the conventional method will be used because there have been studies suggesting it to have higher performance, cost-effective and produces higher annual energy yield [36].

The equation used is:

$$Rs = {}^{\mathrm{Ppv}}/_{\mathrm{Pinv}} \quad \text{(equation 3)} \qquad [37]$$

Rs= sizing ratio, Ppv = rated solar power, Pinv = inverter rating.
The value of 0.9 is used for Rs to allow for a surge in current during period high sunlight [37][36]. The inverter is needed for the eight strings containing 28 modules each.
The rated Power per array string is 28*320 = 8960W.
V_{max} of a string solar panels = 28 * 37.1 = 1036V (voltage per strings)
I_{max} = 8.63 per string. Pinv = 8960/0.9 = 10KW.
The Sunny Tripower 10000TL [38] inverter is chosen which is relatively cheap and offers rating matching the required design.

2.3.5 Battery

The solar generation will not always coincide with demand at all-time therefore the stand-alone solar system will require a storage system to store excess energy and release during the period of low productions.

The lithium-ion battery provides the best characteristics such as higher life cycle, higher round trip efficiency and higher charge retention compared to other rechargeable batteries [39][40], but it has a higher initial cost compared to lead-acid batteries and is not readily available in the Nigeria market [39][41]; therefore the lead-acid battery which has a lower cost of installation and readily available in Nigeria market will be used [39].
The battery capacity is usually measured in Ah (Ampere-Hour) and will be calculated using equation 4 as supported by [42][43]

$$\text{Battery Capacity (Ah)} = \frac{\mathrm{N*Pt}}{\mathrm{Efficiency*DOD*Vbat}} \quad \text{(equation 4)} \qquad [43][42]$$

Where efficiency is the roundtrip efficiency of the battery (85%) [39].
N = is the number of days for autonomy; this will be taken as one since the battery is only needed to power the system during the hours with no sunlight.
The Sun Power VR l 6-370 will be used in this study. Table 2.3 shows its specification[44].
The DOD of 50% is used to allow for more life cycle, which increases the batteries life span [45][39].

Table 2.3. The Sun Power VR l 6-370 battery specification [44].

Battery Capacity (Ah)	Length (m)	Vbat (V)	Width (m)	Area Required(m^2)
400	0.38	6	0.205	23

Using equation 4, the required battery capacity is 120,000Ah (see Appendix G for detailed calculation and arrangement of the battery).

2.3.6 Maximum Power Point Tracking (MPPT)

MPPT is a device used as voltage control embedded with a specific algorithm to deliver maximum power to the battery or load when certain pre-defined conditions are met [46]. This device will also serve as the charge controller for the battery. The solar charge controller MPPT 360V/40A by SU-KAM is used for this study [47].

The MPPT will be embedded with the algorithm depicted in figure 2.12. This algorithm will be primarily based on the state of charge of the battery (SOC). The bank required an uninterrupted power supply at all-time; therefore, the bank's demand is the primary priority to be fed by the system. The power supply will be majorly supplied by the solar PVs and the battery while the backup will only be required when these two conditions are not met: (a) Battery SOC>50% and (b) Solar energy is sufficient.

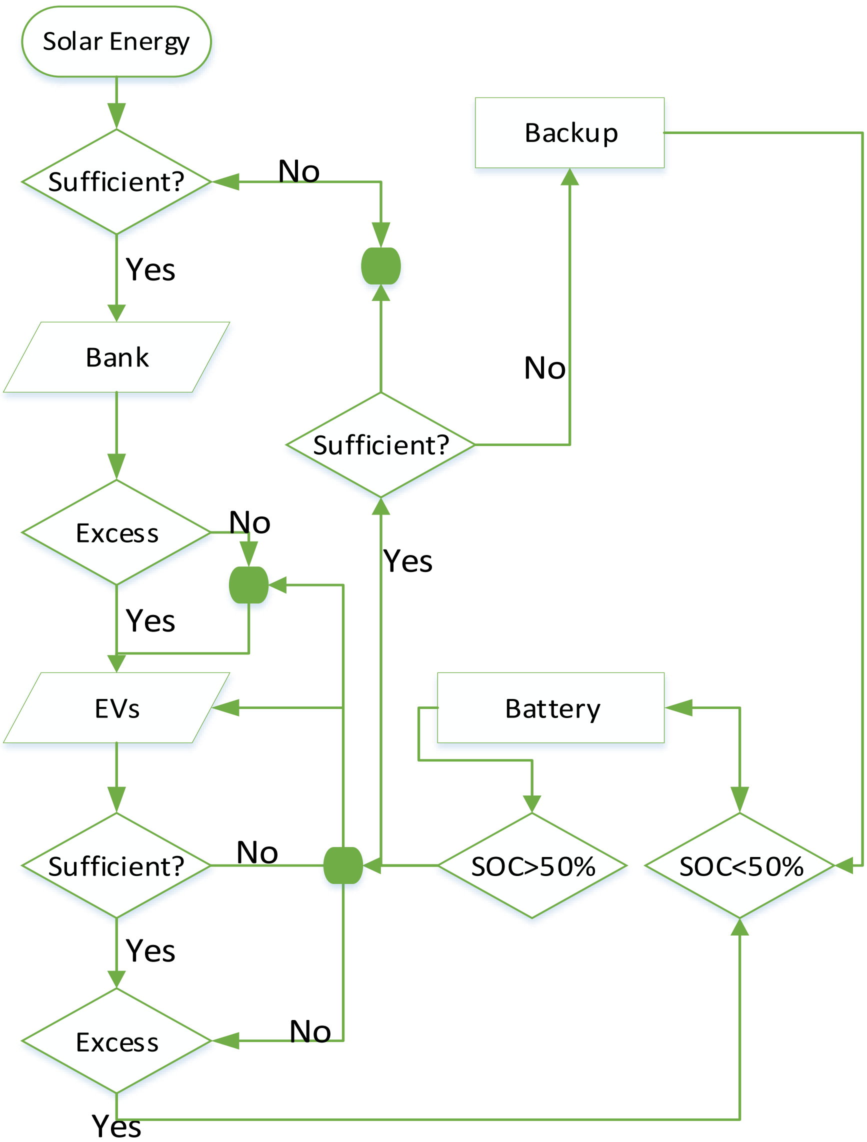

Figure 2.12: The algorithm of the system. The algorithm uses solar energy to supply the bank (priority). If the solar energy is insufficient and battery SOC is less than 50%, the backup (Diesel generator) will come to serve the insufficient energy but if excess energy is available and SOC<100, it charges the battery. The diesel generator will guide against any system failure.

2.3.7 Overall System Design

Figure 2.13 is the overall system arrangement, with voltage conversion at each stages of the arrangement. 8 X 28 PVs arranged in series, each array

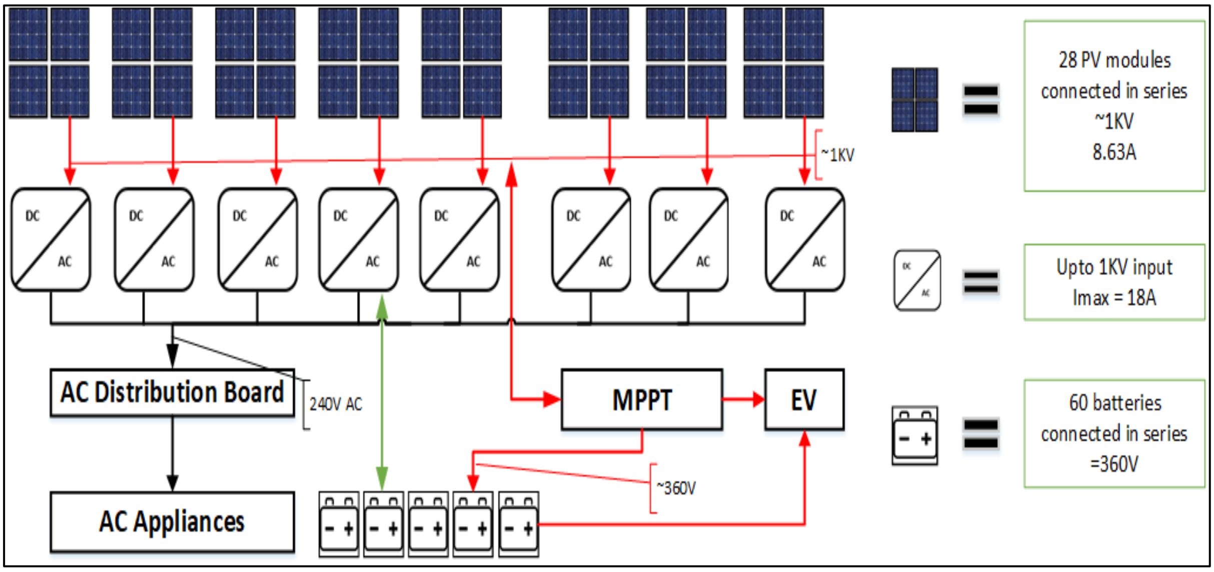

Figure 2.13: The whole system design and arrangement of all components on site. The overall design and arrangement consist of 28 X 8 PV panels with 8 inverters and 300 batteries.

NB: the red marker denotes DC flow, black for AC flow and the green for the flow of excess energy from the battery into the DC input of the inverter.

3 RESULT

3.1 Output Calculation

This section presented the calculated production of the solar PV and compared it to the demands of the system and with the result of energy simulation using PVSYST.

3.1.1 Calculated Production

The output of the solar PV is calculated in excel using equation 1 with consideration to all the losses factors (14%) using the data obtained from PVGIS. The installed PV is 71.68KW (28*8*320W), an efficiency of 16%. The daily and monthly production is plotted below in figure 3.1; the monthly output is well above required 8500KWh for most months of the year while June and July observed lesser production as predicted and the average daily output per month shows the similar trend (figure 3.1). This is observed as the system is designed to be self-sufficient using solar energy during the dry season and uses the backup (diesel generator) during the raining season to achieve a lower number of PV panels and investment cost.

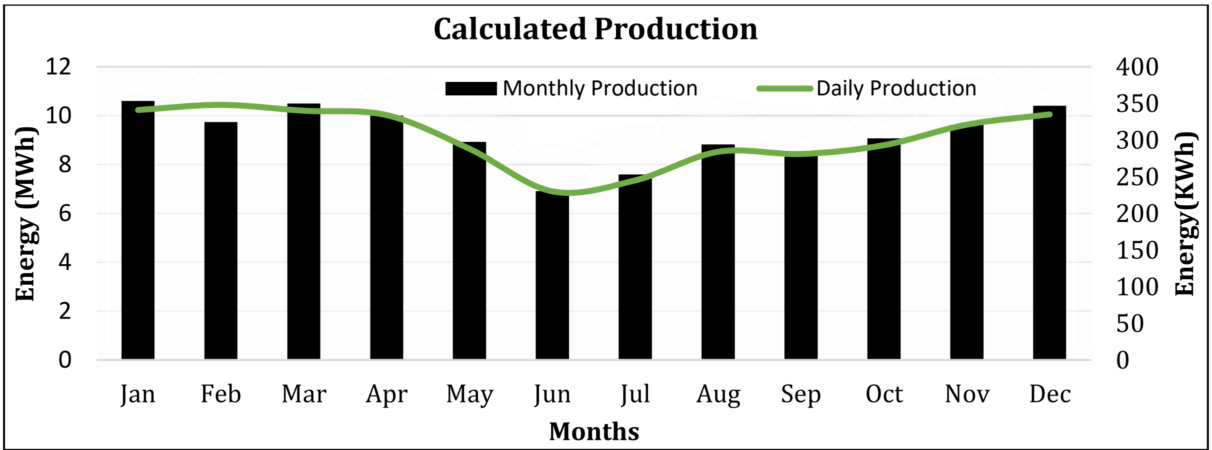

Figure 3.1: The daily and monthly production by the 71.68KW PVs on-site location. Both monthly and daily production show sufficient (>8500KWh) energy production during most months except for June and July.

3.1.2 Daily Matching

Daily production and demand are plotted in figure 3.2. It shows that excess demand is produced for October through May; therefore the system will not require any backup at this time as the solar energy and battery will have enough daily energy to supply the system (>100% supply). For September and October, figure 3.2 shows that the few excess energy will be produced daily which might not be reliable enough to power the system; therefore the backup will be used in case there is any need in these months (=100% supply). Lastly, the month of June and July (85-90% supply) does not have enough energy daily as expected, an average of 50-100KWh daily from the diesel generator is needed to balance the system (85-90% supply).

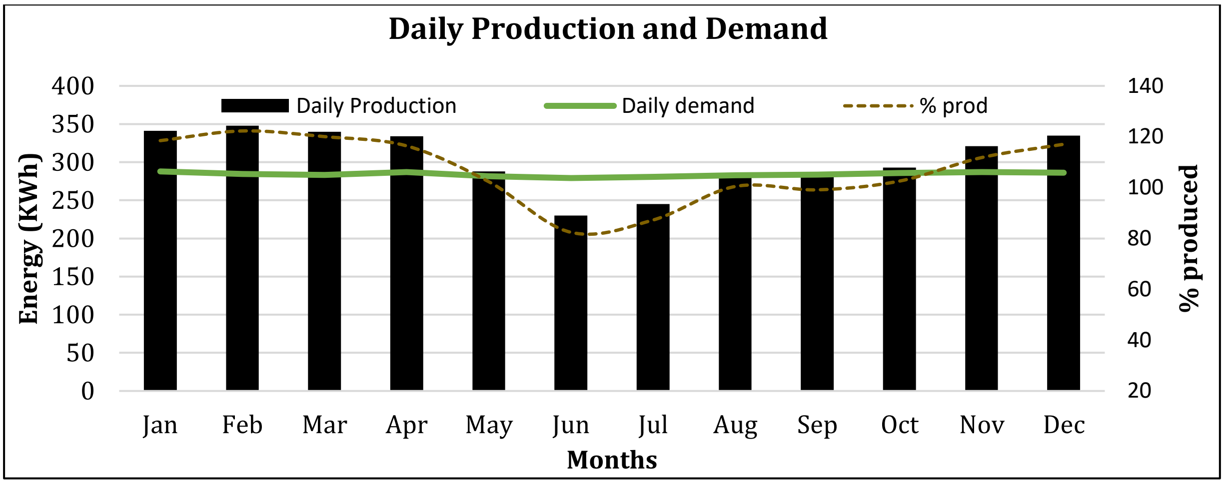

Figure 3.2: The daily production and the daily demand with the percentage production. The system will have enough energy for August through May. June and July will have output 85-90% compared to supply.

3.1.3 Monthly Matching

Figure 3.3 shows that for the ten months of August through May, the system will be able to supply 100% monthly requirements, while the system will be able to deliver 90-95% monthly requirement in June and July. The annual production is 100MWh.

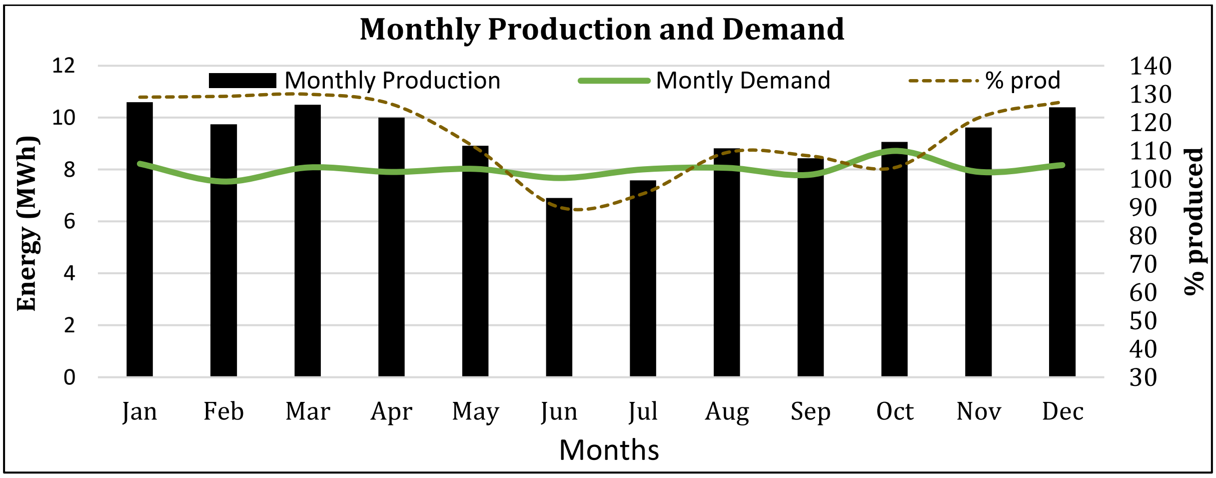

Figure 3.3: The monthly production and monthly demand with the percentage production — the same analysis as the daily matching.

3.2 Energy Simulation

This section presents the energy simulation and the behaviour of some of the components such as the State of charge (SOC) of the battery.

3.2.1 PVSYST Simulation

The energy simulation was done using the industrial standard software PYSYST [25]. The stand-alone functionality of the system was used in modelling the system as shown in figure 3.4. The exact parameter as designed in the design section is configured in the software (see appendix F).

The simulation estimated an annual energy production of 105MWh/year, which shows a 95% correlation to the calculated energy in this study. The 5% difference is due to the system configuration difference by the PVSYST and because PVSYST used different data.

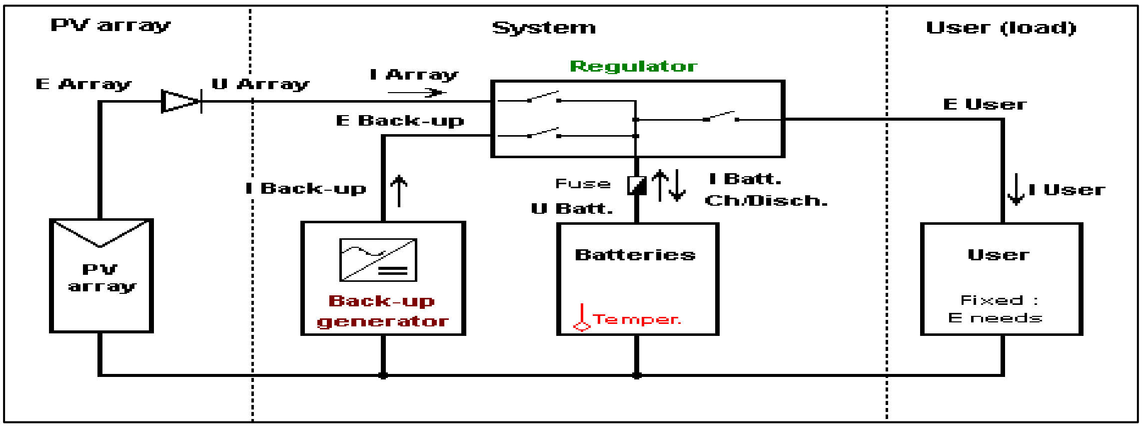

Figure 3.4: A typical layout of a stand-alone system in PVSYST [25]. The arrangement is equivalent to the system schematic proposed with the regulator the same as the MPPT.

The simulation also shows an excess energy loss of 5310KWh/year, this excess energy was generated during the dry and cannot be transferred to the raining season; therefore, the backup (Diesel generator) was able to supply this required energy during the raining season. This shows that the aim of reducing solar PVs by designing for the dry season is achieved as earlier stated during the initial resource analysis.

The backup (Diesel Generator) supplied 6.6MWh/year, which is 6% of the total yearly demand showing a minimal contribution, this energy was provided in June and July to ensure battery does not discharge beyond the rated SOC.

The economic was also model inside the PVSYST to give the exact values calculated in this study; it shows a used energy cost of £0.15/KWh, which is also same as calculated in the economic section of this report.

3.2.2 Daily Energy Production

Figure 3.5 shows the daily energy production provided by the simulation. This indicates that the average production for the Jan to April and September to Dec is 300KWh; this provides a strong correlation between the calculated and the required demand.
The production during May through August span over a lower range of values denoting lower production. This also shows a correlation for the design aim since the design aim at providing sufficient energy during the dry season and use the diesel generator as the backup during the raining season.

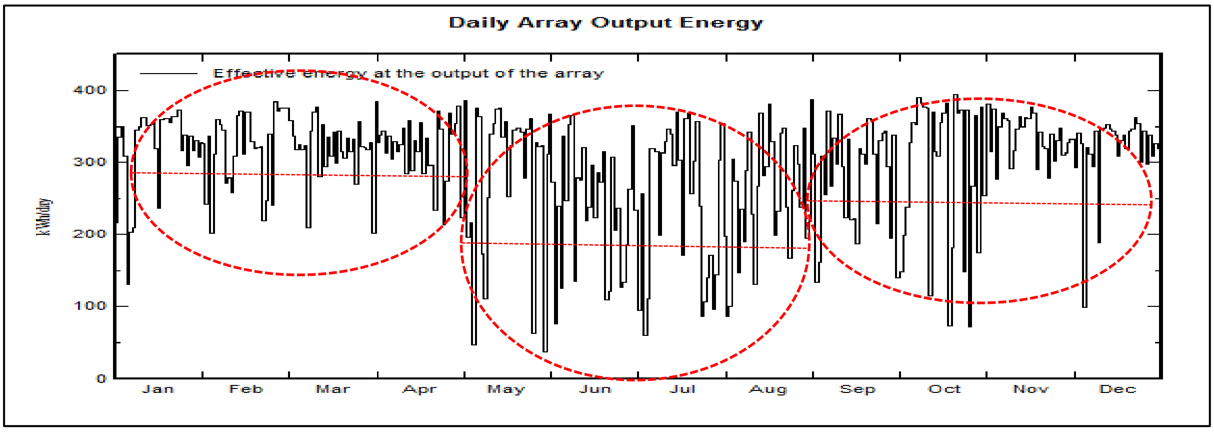

Figure 3.5: The daily energy production for a typical year [25]. The figure shows the daily energy simulation as given by PVSYST. The average daily energy production from September to April is 300KWh while the average production for May to August is 250KWh. This correlated with the demand and the design aim.

3.2.3 Battery Performance

The battery configuration used for the simulation is the same as the estimation during the battery design (see Appendix E) and the same type of battery. Figure 2 shows the state of charge (SOC) for the battery for one year. It indicates that the SOC during the dry seasons (October to May) is relatively high in the ranges of 80% as expected while the SOC during May to September is usually low because of low irradiation during this month. This simulation shows that the battery will never discharge beyond 30% at any time of the years as the back-up generator will be able to prove any require energy to avoid SOC < 30%. This will guide the battery against excess discharge that may damage the battery.

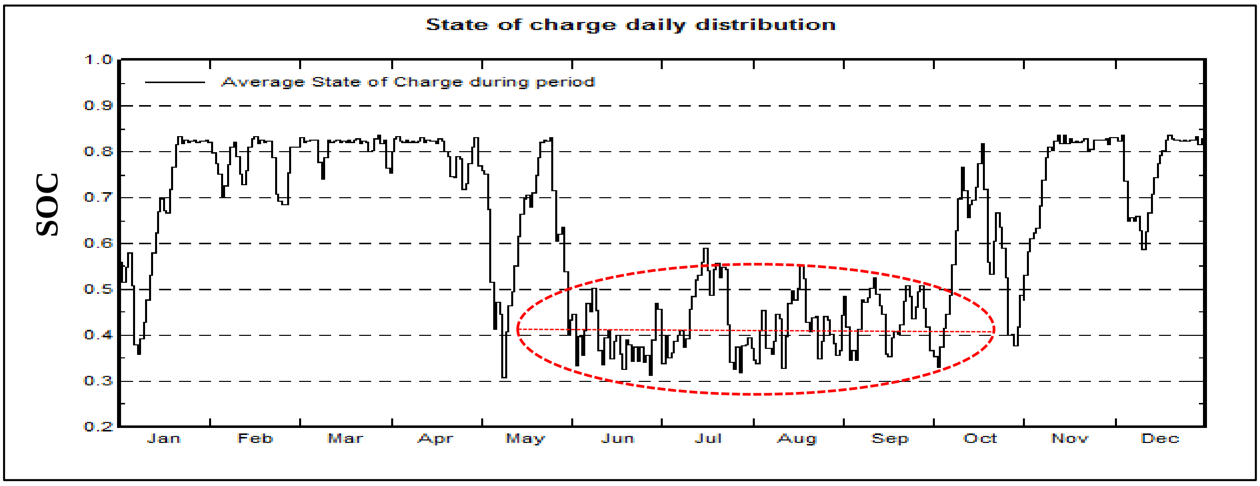

Figure 3.6: Battery's state of charge for the installed battery [25]. This shows the dry battery have relatively high SOC during the dry season and lower during the rainy season and will never discharge beyond 30%.

4 DISCUSSION

4.1 Economics

This section presents the financial analysis of the system with a unique analysis to attract investors.

4.1.1 System Cost

Table 4.1 shows the total cost of investment of the system by calculating each price of the components and their operational cost throughout 25 years. It also included the replacement cost of devices that can have less than 25 years of the life cycle. The 25 years was taking because the solar PV was estimated to have a lifecycle of 25 years and every other device with lower lifecycle will be replaced.

Table 4.1: Total investment cost. The total cost of the system is sized to 25 years for all the components.

Devices	Quantity	Price/Units (£)	Total Cost (£)	Life Span(Yrs.)
PV Panels	224	146 [31]	32704	25
MPPT	1	130 [47]	130	12.5
MPPT (Replacement)	1	100 [47]	100	12.5
Batteries	300	520 [44]	153300	12.5
Batteries (Replacement)	300	520 [44]	139300	12.5
Inverters	8	1412 [38]	11296	25
Cabling + Miscellaneous	-	30/KW [48]	2100	25
Installation Cost	-	40/KW [48]	2800	25
Operational/ Maintenance (O/M)	-	11.5/KWDC/ Yr. [49]	20125	25
Contingency	-	8/KWDC/Yr. [49]	14000	25
Total System Expenditure			**376122**	
Transportation				
Vans	2	20741 [18]	41482	12.5
Vans (Replacement)	2	20741 [18]	41482	12.5
O/M	2	1000/Annum	50000	25
Transit Investment			153705	
Total Expenditure			**529,827**	

4.1.2 Comparison with other Technology

The cost of electricity (COE) for the system is compared with different technologies. COE is the minimum electricity price to break even over the lifetime of the system [50]. Table one provides the total value of the devices in the system throughout 25 years which is equal to £376,122. The annual electricity generated per by the system is 100,000 KWh.

$$\text{COE} = \frac{\text{the total cost of the system over its lifetime (£)}}{\text{total electricity generated over a lifetime (KWh)}} = \frac{376122}{100000*25} = £0.15/\text{KWh} \qquad [50]$$

Converting the system COE to dollar equivalence using Xrate currency converter [51], the COE is $0.19. The value of $0.19/KWh is consistency with the prediction made by international renewable energy agency (IRENA) for large solar system panels on the rooftop as seen in figure 4.1. This value ($0.19) is slightly cheaper than the lowest price of electricity in Nigeria £0.153 = $0.2/KWh [3][17]; therefore the project is financially feasible in the location.

Nigeria does not have geothermal potential, and the no hydro potential is available at the location [2][1]. However, the biomass would have been a better option but the no proper policy in place for harnessing this potential and some biomass plants might not suitable for the location been a residential environment [17][52].

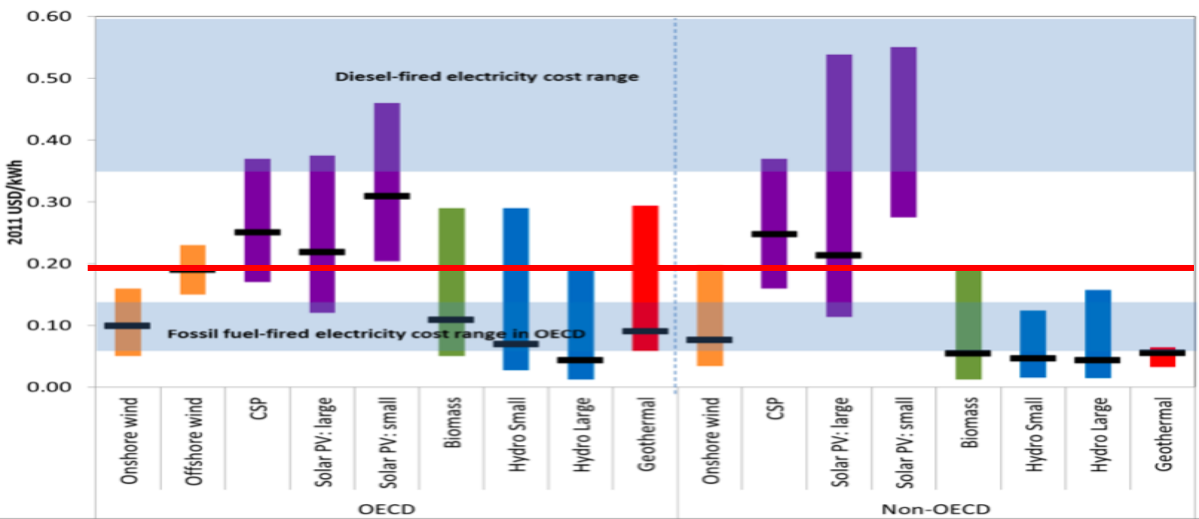

Figure 4.1: Cost of energy ranges for different technologies [10]. The red line shows the cost of electricity for the system. This indicates that the COE is in lower boundary of the IRENA's prediction and the upper boundary of the Biomass prediction. It also shows that the system will be cheaper than the diesel-fired electricity been used by the bank.

4.1.3 Payback Period

Figure 4.2 shows the payback period for different scenarios. The actual payback period for the systems is 17 years. This is high due to the cost of the battery, but there is a possibility for a lower payback period which is discussed below.

The solar PV helps in the reduction of CO_2 which is a tradable commodity [53]; the IRENA estimated a carbon footprint factor of 0.4759 $kgCO_2$.eq/KWh [53]. The system is generating 100,000KWh every year; therefore the carbon saving is 47.59tonnes/year. The EIA also estimated the £22.7/CO_2tonne saved [54]; consequently, the system should earn £27,000 throughout its lifetime through carbon savings.

The highest costing device in the system is the battery and its replacement, which contributed 78% of the total cost. It has been predicted that the lead-acid will fall in price by 32% by 2025 [55][56]; therefore the system cost will reduce by 25% (see Appendix H for detailed calculation).

Lastly, there is currently no subsidies nor incentives offer to this kind of system in Nigeria matching this system[57][5], but there is a possibility of such policies in future which will further help in making the system economically feasible [57][5]. Developed countries offer varying discount rates as a subsidy for large renewable energy ref, assuming an 8% discount rate been the average offered worldwide [58][59].

Figure 4.2 shows the impact of the explained possible cost reduction scenarios on the payback period. The actual payback is 17 years but the discount rate of 8% only, the payback period will be 15 years. If the project is delayed till the year 2025, there is a possibility for lower battery cost which will make the payback period 14 years. The combination of 8% discount rate and battery in 2025 will make the payback period 11 years as seen in figure 4.2.

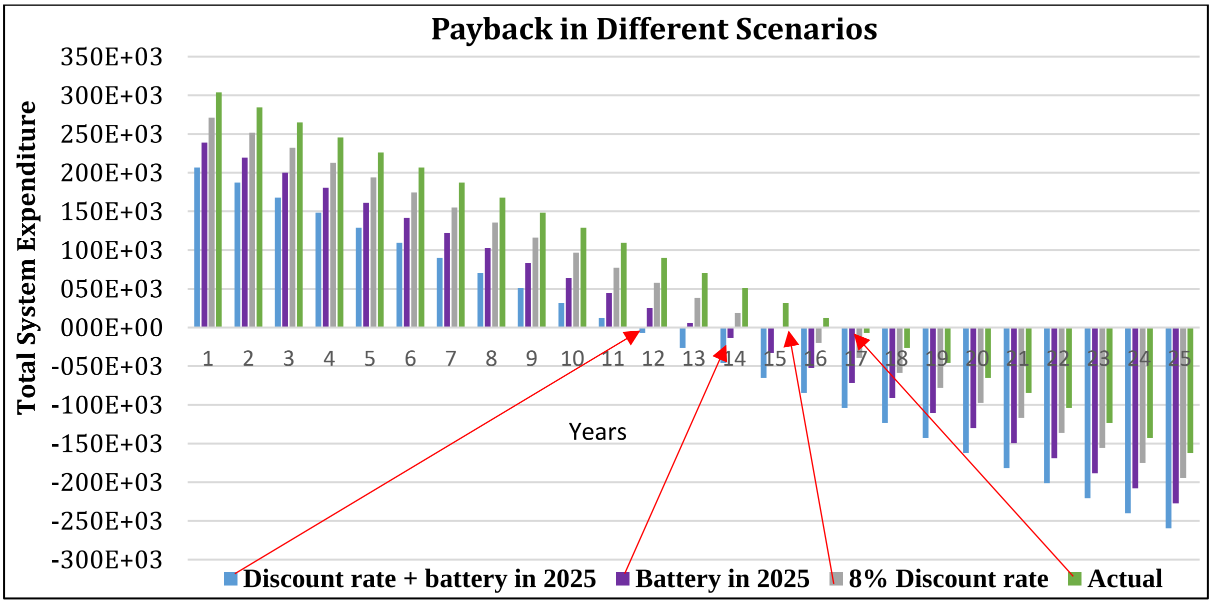

Figure 4.2: The simple payback period for the system with different scenarios. The actual payback (PB) period is 17 years. With 8% discount rate and battery in 2025, PB =11 years.

4.1.4 Attracting Investors (Vans Economics)

This section is to show potential investors a better payback period analysing the possible revenue generation from the vans.

The vans investment cost for 25 years is £153,705, which includes the replacement cost of the cars and operational, and maintenance cost. The vans will consume a total of 1350.5MWh in 25 years. The vans are a source of revenue, but the number of possible revenues that can be generated cannot be determined will 100% accuracy; therefore a detailed analysis is done to see the amount of income that will be generated when moving different number of people.

Figure 4.3. shows the possible electricity pricing with revenue and the number of people with corresponding revenue. This shows that the optimum electricity price for the vans is £0.325/KWh [c] and with this value, the vans will generate a revenue of £432,160 [A] throughout 25 years by transporting approximately 6 people [B] per trip at a fair rate of £0.5/person for five days in a week.

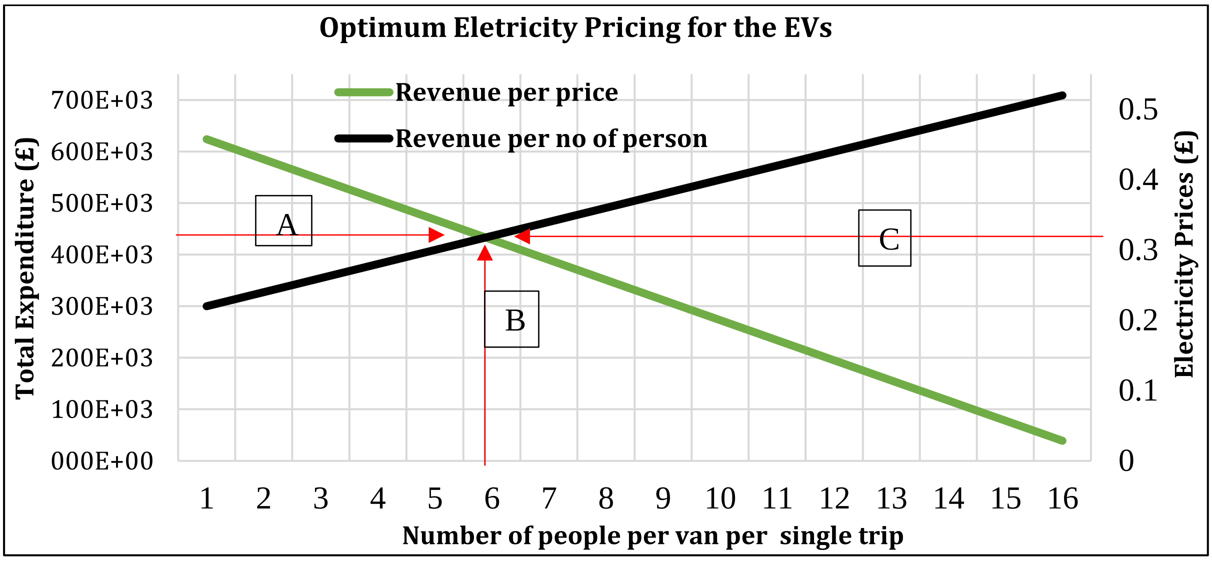

Figure 4.3: Optimum pricing/number of people for the vans. The figure is plotted to determine the possible revenue that can be obtained by the vans as a respect to the number of people transported per full trip (fare = £0.5/trip) with the potential revenue from different electricity pricing for the Vans. (See Appendix I for the formula used).

This shows that these values are achievable and will be used to determine the payback period of the system. The system output has been analysed, and the transportation system will cover part of it; therefore, the remaining portion provides the payback period for the system. Figure 4.4 shows the payback period of 13 years with the lowest electricity price in Nigeria (£0.153/KWh). And also Figure 4.5 shows that the payback period is five years if the Vans are covering the cost.

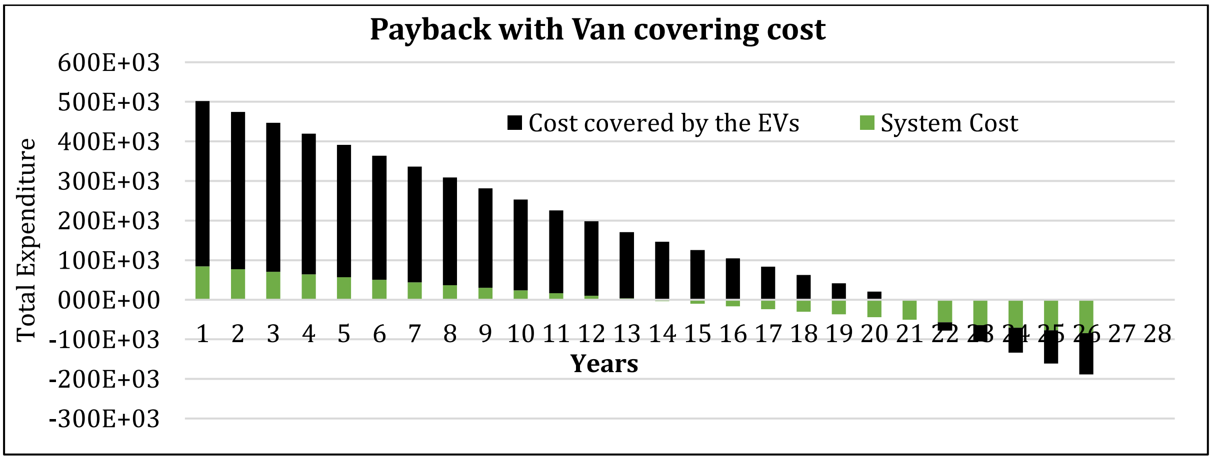

Figure 4.4: The payback period using van's economics analysis. This shows a simple payback of 13 years when the Van is covering parts of the cost.

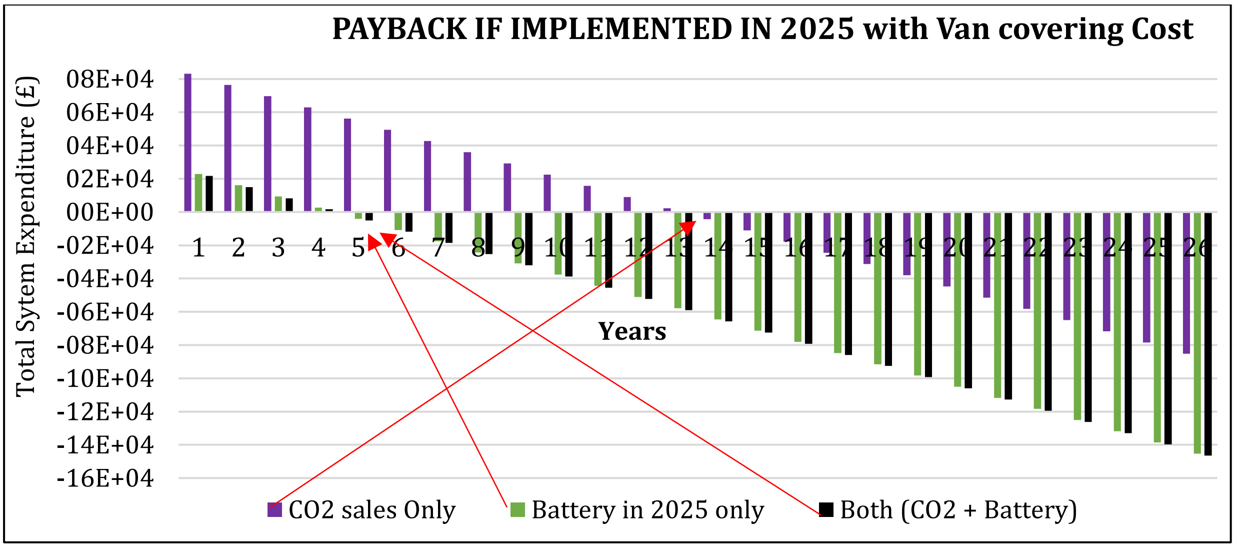

Figure 4.5: Payback Period with Vans covering cost and other scenarios. This shows that the payback of the system will be 5years if implemented in 2025 when the the battery cost has reduced by 31%. This shows a payback of 4 years which will attract investors.

4.2 Feasibility

This section presents some of the constraint and possibly environmental factors to be considered for the project implementation. The last sections state some of the critical assumption made in this study.

4.2.1 Environmental Impact

Renewable energy sources (RES) are known to be clean and emission-free, they are often accepted, but there have been complains when specific RES are installed close to homes. This is one of the debates against the use of wind energy due to visual impact and noise [60]. There has not been a major complaint about the negative visual and noise impact of solar panels [61] instead they have been used to increase the beautiful views of building seen in PV integrated buildings such as zero energy buildings (NZEB) which are widely accepted and currently on the rise [62].

The production of solar panels still result in the emission of toxic chemicals, which are harmful, making solar energy not entirely emission-free, but provides a substantial reduction in the emission caused by fossil fuel [61]. These emissions occur at the site of production and companies have taken different strategies to reduce the emission impact such as carbon capture technologies. Detailed analysis of the percentage reduction in CO_2 emission is carried out in the economics section.

There have been debates on RES taking up significant and cultural landscape of a community [60]; the small-scale solar project has minimal impact on land use as the rooftop is being used for installations. Large-scale installation of PV requires a substantial area of land, which might results in losses of natural landscape and homes for animals if proper policies and monitoring are not put in place. This project will be installed on the roof of the building, and the extension will serve as a parking lot for vehicles; therefore it has no negative impact on land use.

4.2.2 Constraint and Solutions

The roof of the bank will not be enough for the installation of the PV panels; therefore a parking lot will be constructed which must as high as the bank building to prevent shading by the building. This construction will force up the cost of the system.

One of the best exploitable renewable resources exploitable in Nigeria is solar due to its high potential compared to other resources [2][1], but standalone solar systems are relatively expensive compared to other technologies due to the cost of a storage system. Nigeria also has an enormous potential of Biomass but no proper structure and policy for collecting biomass materials [52]. Therefore the project might be a bit expensive than the current diesel engines currently been used; however the EVs will generate income which will be able to cover for any most of the investment cost as shown in the economics section.

There is no regulation against the installation of solar PVs in Nigeria [57]. Nigeria also practices the feed-in-tariff regulation similar to the developed countries, where excess energy by a consumer above the 1MW mark is sold to the nearest distribution network [63]. Connecting to the distribution network at the site location will require lots of investment and will not be needed since the excess energy is not quite much as aimed in the design.

The installation of solar panels on the roof of building results in maintenance difficulty. Special expertise is required for the maintenance of large solar panels installed on the rooftop, these specialities involve the knowledge of the solar system and working with height, which might be relatively scarce in Nigeria; therefore training will have to be given to increase the number of people in this field which will provide employment.

4.2.3 Critical Assumptions

This section presents some of the critical assumption made during the project design.

4.2.3.1 Derating Factor

Derating is the reduction in the maximum capability of system component due to prolong use over a lifetime. Most of the system components will experience derating [64] which is not critically analysed in the system calculation. The weather conditions are not total constant yearly, so there is a possibility for greater production which might bring the system close to the real production.

4.2.3.2 Power VS Energy

The project was designed using the energy approach rather than the power approach. There may be time with peak power demand that will make the energy approach flaw. The diesel generator will be able to guide against any surge in power that may cause system failure.

5 RECOMMENDATION

The number of electric vehicles will increase as the cost of acquiring it becomes cheaper. The aggregate energy requirement will also increase substantially due to the massive energy requirement of charging electric vehicles and shift from fossil fuel powered to electric powered vehicles. The current capacity of the existing grids may not be sufficient to provide this huge energy requirement; therefore, this project/idea proposed in this study can serve as a solution. Industries, schools, building's owner, companies and organisation can adopt this idea and sell the energy generated to their staffs by charging their EVs when they park them at work and can easily deduct their energy usage from their salary. This will reduce the dependences of charging EV from the grid and reduce the effect of large loads on the grids.

Due to the battery cost at this time, the project should be implemented in 2025 or later to allow for better profitability.

This idea can be employed by transport companies and governments providing public transportation but might require different renewable energy resources like the potential for the RES is location dependent.

For further study, detailed analysis into the power and energy consumption of the EVs as a result of an increase in acceleration which is dependent on the nature of the road.

6 CONCLUSION

A solar powered (commercial bank + EVs) has been designed and analysed in this report. This project provides an opportunity to decarbonise both the commercial and transport sector of a developing country, which can be extended to the developed country.

The solar system is designed to be self-sufficient during the dry season and supported by the diesel generators during the raining season to guide against excess energy that cannot be sold, reduce PV panels due to space constraint and lower investment cost.

The technical aspect shows that the project is feasible and will provide 94% of the energy with a carbon saving of 48 tonnes/year. The financial analysis shows that the system is economically feasible and could even be more profitable if implemented later (2025).

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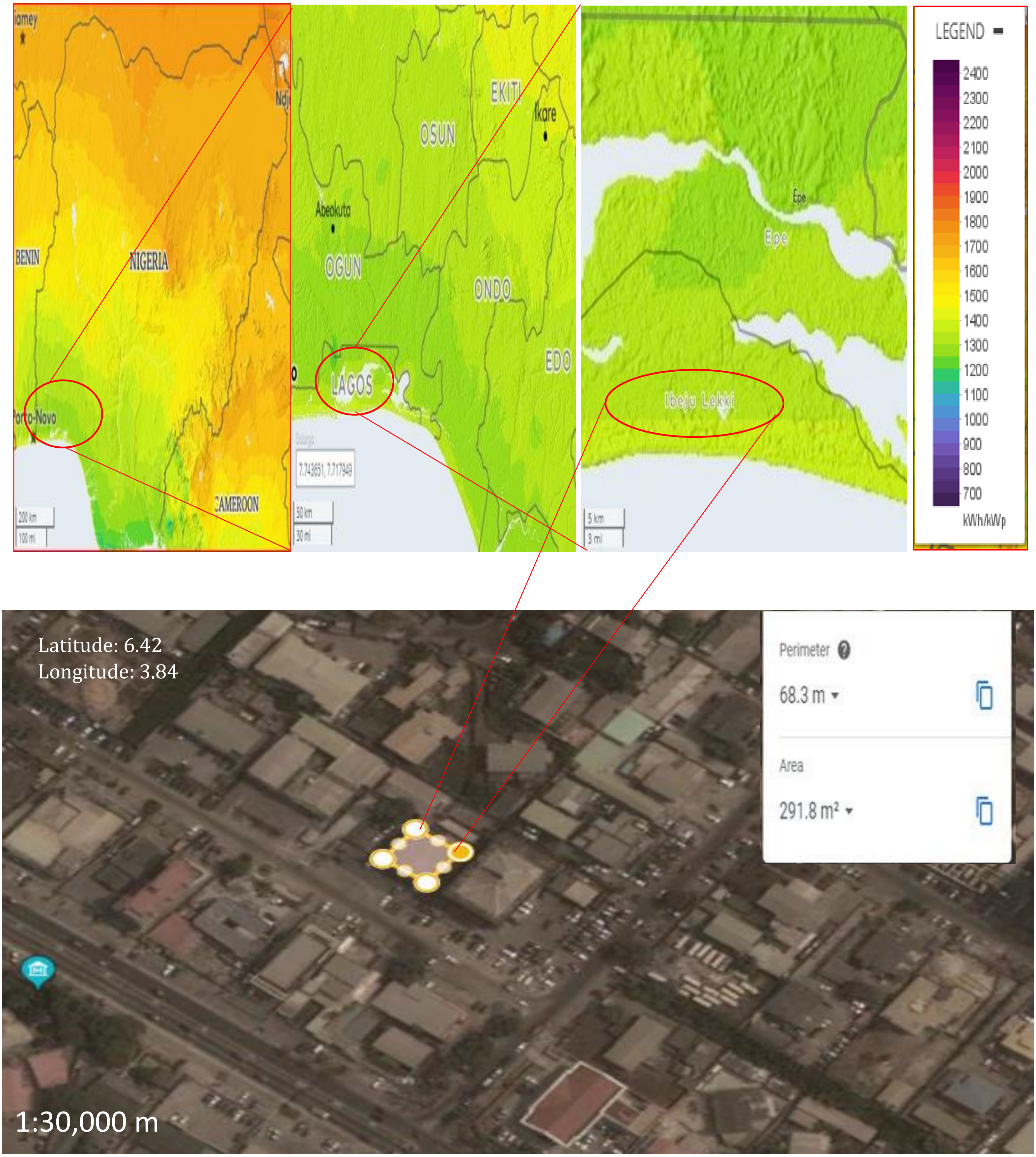
Appendices

Appendix A: (Location Map)



Appendix B: (Bank Devices)

Devices	Rating(W)	Quantity	Avg. runtime (hrs)	Total Rating(W)	Energy/day(KWh)
Compact fluorescent bulbs	14	12	24	0.168	4.032
Air condition (small)	745.7	4	11	2.9828	32.8108
Air condition (Large)	1491.4	2	11	2.9828	32.8108
printers	40	4	2	0.16	0.32
LED monitors	30	3	24	0.09	2.16
computers	100	12	15	1.2	18
router	6	4	24	0.024	0.576
water dispenser	1200	2	1	2.4	2.4
microwave	1200	1	1	1.2	1.2
CCTV cameras	40	6	24	0.24	5.76
electric doors	75	1	10	0.075	0.75
alarm system	2	2	n/a	0.004	1
servers	1200	1	24	1.2	28.8
cordless phones	2	5	2	0.01	0.02
Laptops	90	5	10	0.45	4.5
Security light	30	9	13	0.27	3.51
Digital display board	75	1	24	0.075	1.8
Total				**13.5316**	**140.4496**

Appendix C: (Van's Energy Estimation)

Manufacturer details

Normal charge (KW)	Rapid charge (KW)	Battery Capacity (KWh)
6	50	40

Using a charging efficiency of 90% and a DOD of 80%

Charging time = $\frac{\text{Battery Capacity}}{\text{charging efficiency} * \text{charging type}}$

Normal charging time = $\frac{40}{6.6*0.85} = 7.13hrs$ (for full charge)

Rapid charge time = $\frac{40}{50*0.85} = 0.94hrs$

Energy consumption for full charge = 50 * 0.94 = 6.6 * 7.13 = 47KWh (**which is slightly higher than the prediction from the manufacturer because of the charging efficiency**)

Usable battery capacity = (battery capacity * DOD) = (40*0.8) = 32KWh

Appendix D: (Vans Timetable)

VAN1

Bus stops								
Lagos terminus		07:00	08:30			04:00	05:30	
Iddo		07:03	08:33			04:03	05:33	
Oyingbo		07:09	08:39			04:09	05:39	
Okobaba		07:12	08:42			04:12	05:42	
Osborne		07:16	08:46			04:16	05:46	
GTB Bus Stop		07:22	08:52	Terminus to		04:22	05:52	Full trip
Link Bridge		07:27	08:57	Lekki Phase one		04:27	05:57	
Admiralty		07:35	09:05			04:35	06:05	
Lekki Phase1	06:10	07:40	09:10	Charge for	03:10	04:40	06:10	Charge for
Lekki toll gate	06:15	07:45	09:15	50mins(Rapid)	03:15	04:45	06:15	6 hours
Aboyade	06:20	07:50	09:20	37KWh	03:20	04:50	06:20	37KWh
Ozumba	06:25	07:55	09:25		03:25	04:55	06:25	
Barrack	06:30	08:00	09:30		03:30	05:00	06:30	
CMS	06:43	08:13	09:43		03:43	05:13	06:43	
Marina	06:48	08:18	09:48		03:48	05:18	06:48	
Otto	06:52	08:22	09:52		03:52	05:22	06:52	
Lagos terminus	06:55	08:25	09:55		03:55	05:25	06:55	
DISTANCE(Km)	15	35	35	20	15	35	35	20
Estimated time (mins)	35	80	80	45	35	80	80	45
Consumption(KWh)	4.5	10.5	10.5	6	4.5	10.5	10.5	6
				31.5				31.5
Total Demand/Day (KWh)								63
Total Supply/Day (KWh)								74

VAN2

Bus stops								
Terminus		06:50	08:20			03:50	05:20	
Otto		06:53	08:23			03:53	05:23	
Marina		06:59	08:29			03:59	05:29	
CMS		07:02	08:32			04:02	05:32	
Barrack		07:06	08:36			04:06	05:36	
Ozumba		07:12	08:42	Terminus to		04:12	05:42	Full trip
Aboyade		07:17	08:47	Lekki Phase one		04:17	05:47	
Lekki toll gate		07:25	08:55			04:25	05:55	
Lekki Phase1	06:00	07:30	09:00	Charge for	03:00	04:30	06:00	Charge for
Admiralty	06:05	07:35	09:05	30mins(Rapid)	03:05	04:35	06:05	6hours(Normal)
Link Bridge	06:10	07:40	09:10	37KWh	03:10	04:40	06:10	37KWh
GTB Bus Stop	06:15	07:45	09:15		03:15	04:45	06:15	
Osborne	06:20	07:50	09:20		03:20	04:50	06:20	
Okobaba	06:33	08:03	09:33		03:33	05:03	06:33	
Oyingbo	06:38	08:08	09:38		03:38	05:08	06:38	
Iddo	06:42	08:12	09:42		03:42	05:12	06:42	
Lagos terminus	06:45	08:15	09:45		03:45	05:15	06:45	
DISTANCE(Km)	20	35	35	15	20	35	35	15
Estimated time (mins)	45	80	80	35	45	80	80	35
Consumption(KWh)	6	10.5	10.5	4.5	6	10.5	10.5	4.5
				31.5				31.5
Total Demand/Day (KWh)								63
Total Supply/Day (KWh)								74

Appendix E shows the routes while Appendix D depicts timetable created for the two VANS. 2 min was added to each the travel time was obtained from google and 2 minutes was added at each bus stop to allow for transfer of passengers.

The manufacturer energy consumption per km =0.259 KWh/km

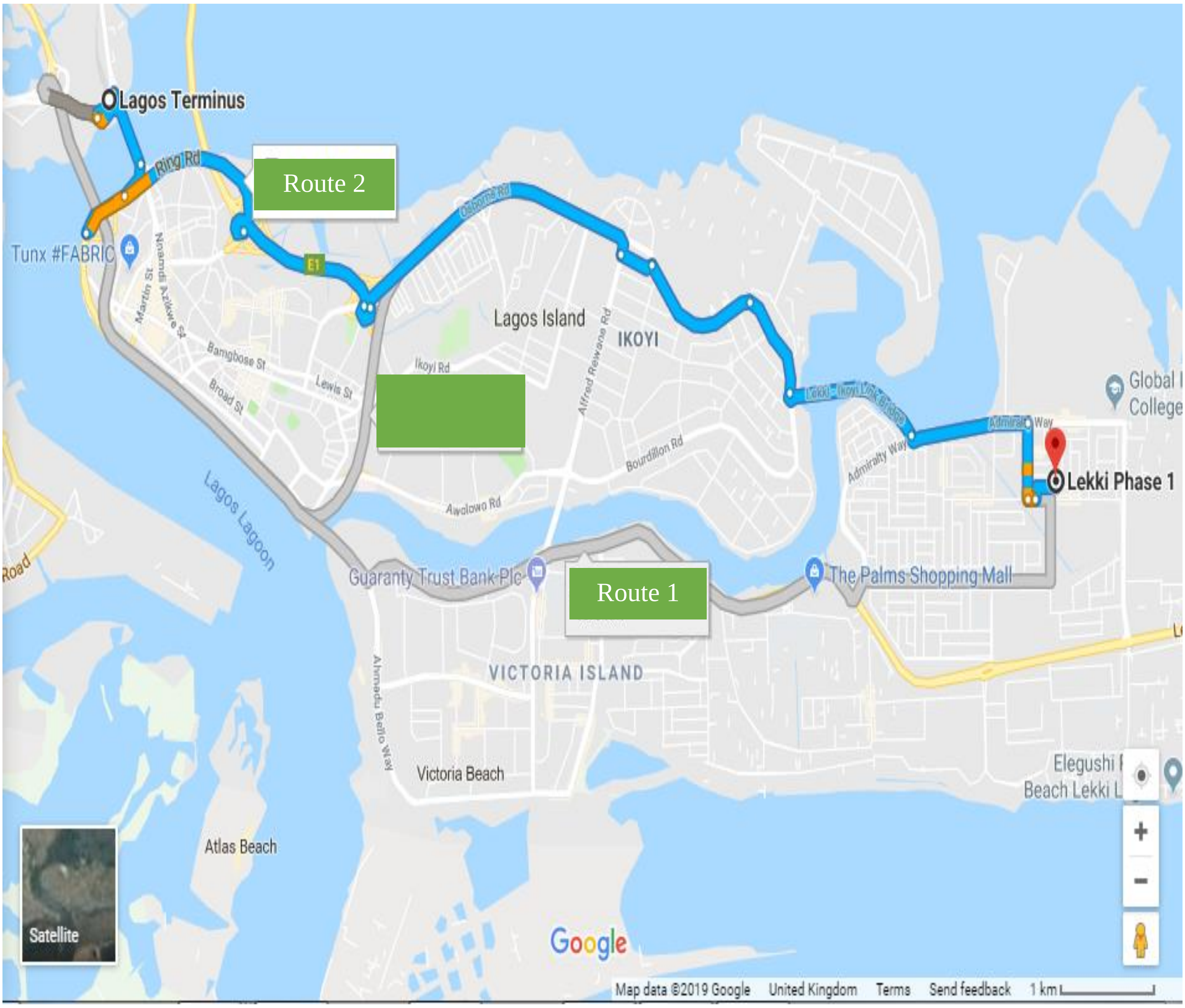
Assuming a round-trip efficiency of 85% to allow for higher consumption during increase in acceleration and climbing of hills.

Actually energy consumption per Km = $\frac{0.259}{0.85} = 0.3KWh/Km$

Total distance per day = 246Km

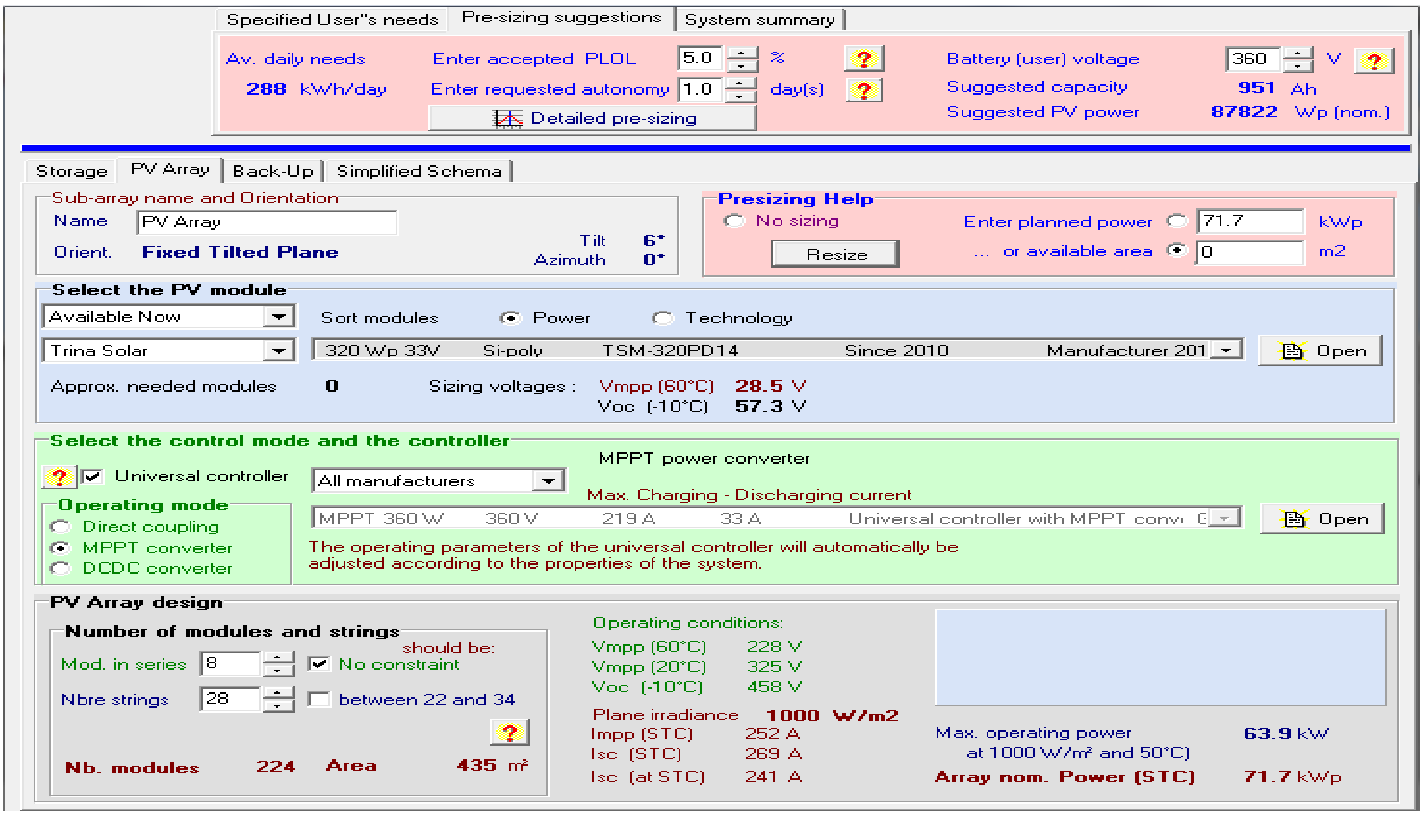
Total energy consumption = 246Km * 0.3KWh/Km = 74KWh

Appendix E: (Vans Route)

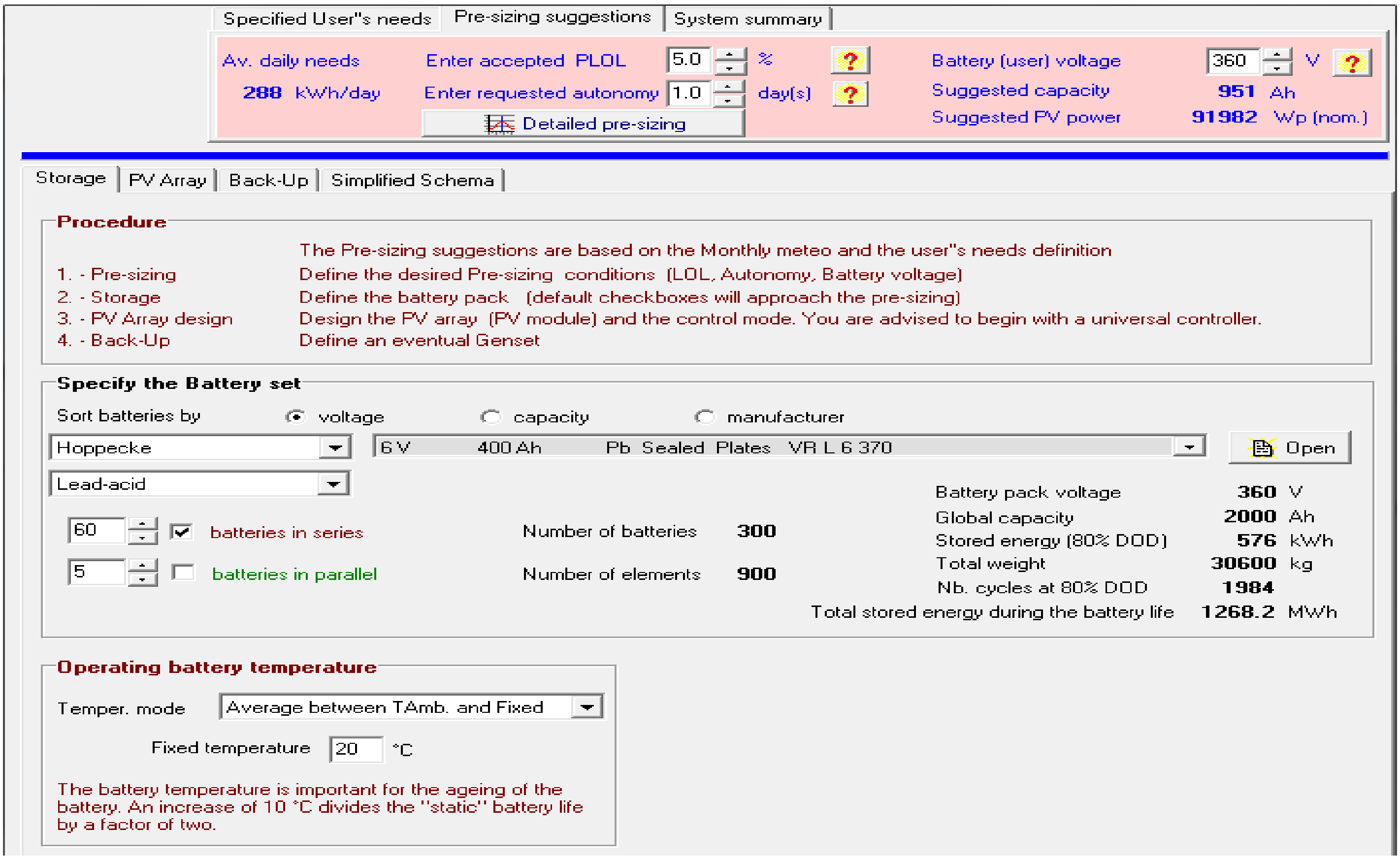


Appendix F: (Simulation Input)

PV INPUT



STORAGE INPUT



Appendix G: (Battery's Calculation)

Using equation 4,
The required battery capacity = 300KWh* 1/0.5*0.85*6 = 120000Ah
Number of batteries = 120000/400 =300 batteries.
The Vans require a charging voltage of 360V; the battery arrangements will be to supply. Therefore 60 batteries will be arranged in series (6*60 = 360V), five stacks of such will be arranged in parallel to give 300 batteries of 360v, 120000Ah.

Appendix H: (Battery Reduction Effect)

The total cost of system = £306,600, total cost of battery = £306,600
% of battery = £306,600/ £306,600 = 81.5%
If battery reduce by 30% in 2025, the total cost will reduce by 81.5% of 30% = 25%
The new total cost = £282,091

Appendix I: (Van's Revenue formula)

Revenue /day = number of vans (2) * fare (0.5) * people/full trip (12) * trip/day (6) = £72/day
Lifetime revenue = revenue /day * days in a week (5) * week in a year (52) * years (25) = £468000.

Appendix J: (Simulation Report)

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Stand alone system: Simulation parameters

Project : Stand-alone Solar PV to power bank and EVs

Geographical Site	**Lekki**		Country	**Nigeria**
Situation	Latitude	6.45° N	Longitude	3.94° E
Time defined as	Legal Time	Time zone UT+1	Altitude	17 m
	Albedo	0.20		
Meteo data:	**Ibeju Lekki**	PVGIS: CMSAF, SARAH or NSRDB - TMY		

Simulation variant : New simulation variant

Simulation date 01/03/19 07h44

Simulation parameters	System type	**Stand alone with back-up generator**		
Collector Plane Orientation	Tilt	6°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Imported
User's needs :	Daily household consumers	Constant over the year		
	average	288 kWh/Day		

PV Array Characteristics

PV module Si-poly	Model	**TSM-320PD14**		
Custom parameters definition	Manufacturer	Trina Solar		
Number of PV modules	In series	8 modules	In parallel	28 strings
Total number of PV modules	Nb. modules	224	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**71.7 kWp**	At operating cond.	63.9 kWp (50°C)
Array operating characteristics (50°C)	U mpp	253 V	I mpp	252 A
Total area	Module area	**435 m²**	Cell area	393 m²

System Parameter	System type	**Stand alone system with back-up generator**		
Battery	Model	**VR L 6 370**		
	Manufacturer	Hoppecke		
Battery Pack Characteristics	Nb. of units	60 in series x 5 in parallel		
	Voltage	360 V	Nominal Capacity	2000 Ah
	Discharging min. SOC	20.0 %	Stored energy	576.0 kWh
	Temperature	Average between fixed (20°C) and External		
Controller	Model	Universal controller with MPPT converter		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	97.0 / 95.0 %		
Battery Management control	Threshold commands as	SOC calculation		
	Charging	SOC = 0.92 / 0.75	i.e. approx.	405.5 / 371.6 V
	Discharging	SOC = 0.20 / 0.45	i.e. approx.	348.9 / 362.0 V
	Back-Up Genset Command	SOC = 0.25/0.45	i.e. approx.	353.5 / 363.7 V
Back-up genset	Model	3 kW		
	Manufacturer	Back-up generator		
	Nominal power	25 kW	Effective power	20 kW

PV Array loss factors

Array Soiling Losses			Loss Fraction	4.0 %
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	14 mOhm	Loss Fraction	1.0 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.2 % at STC
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Stand alone system: Detailed User's needs

Project : **Stand-alone Solar PV to power bank and EVs**

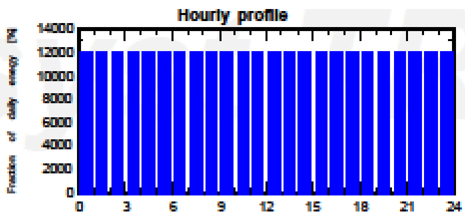
Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone with back-up generator**		
PV Field Orientation	tilt	6°	azimuth	0°
PV modules	Model	TSM-320PD14	Pnom	320 Wp
PV Array	Nb. of modules	224	Pnom total	**71.7 kWp**
Battery	Model	VR L 6 370	Technology	Lead-acid, sealed, plates
Battery Pack	Nb. of units	300	Voltage / Capacity	**360 V / 2000 Ah**
User's needs	Daily household consumers	Constant over the year	Global	105 MWh/year

Daily household consumers, Constant over the year, average = 288 kWh/day

Annual values

	Number	Power	Use	Energy
Demand	1		24 Wh/day	288000 Wh/day
Total daily energy				288000 Wh/day



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Stand alone system: Main results

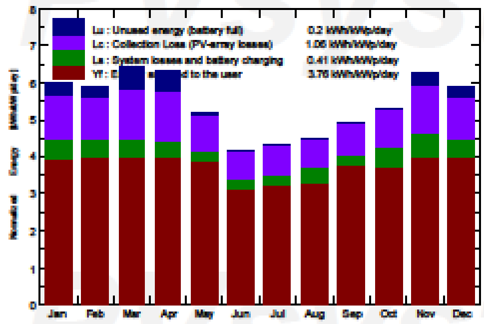
Project : **Stand-alone Solar PV to power bank and EVs**

Simulation variant : **New simulation variant**

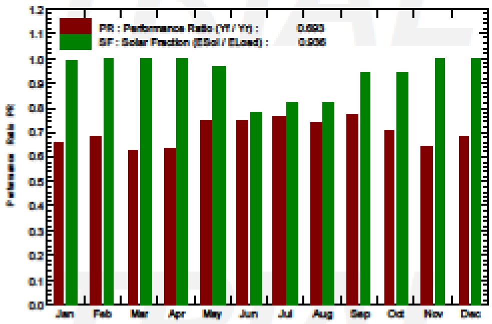
Main system parameters	System type	**Stand alone with back-up generator**		
PV Field Orientation	tilt	6°	azimuth	0°
PV modules	Model	TSM-320PD14	Pnom	320 Wp
PV Array	Nb. of modules	224	Pnom total	**71.7 kWp**
Battery	Model	VR L 6 370	Technology	Lead-acid, sealed, plates
Battery Pack	Nb. of units	300	Voltage / Capacity	**360 V / 2000 Ah**
User's needs	Daily household consumers	Constant over the year	Global	105 MWh/year

Main simulation results				
System Production	**Available Energy**	**107786 kWh/year**	Specific prod.	1504 kWh/kWp/year
	Used Energy	105093 kWh/year	Excess (unused)	5310 kWh/year
	Performance Ratio PR	69.26 %	Solar Fraction SF	93.61 %
Back-Up energy from generator	Back-Up energy	6687 kWh/year	Fuel Consumption	1444/year
Battery ageing (State of Wear)	Cycles SOW	95.8%	Static SOW	94.1%
	Battery lifetime	16.9 years		
Investment	Global incl. taxes	349865.00 GBP	Specific	4.88 GBP/Wp
Yearly cost	Annuities (Loan 0.00%, 20 years)	0.00 GBP/yr	Running Costs	1570.00 GBP/yr
Energy cost		**0.01 GBP/kWh**	Payback period	**undefined**

Normalized productions (per installed kWp): Nominal power 71.7 kWp



Performance Ratio PR and Solar Fraction SF



New simulation variant

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_User kWh	E_Load kWh	SolFrac
January	176.9	173.1	10054	689	8925	8928	0.983
February	160.0	153.7	8885	487	8061	8064	1.000
March	198.0	186.9	10699	1403	8921	8928	0.999
April	191.2	176.7	10139	1172	8634	8640	0.999
May	165.5	149.2	8723	96	8927	8928	0.986
June	129.2	115.8	6932	0	8641	8640	0.778
July	137.2	123.5	7397	0	8929	8928	0.812
August	141.7	129.3	7798	0	8929	8928	0.824
September	147.4	136.8	8198	0	8641	8640	0.944
October	160.8	153.4	8923	67	8928	8928	0.935
November	179.7	175.6	10145	781	8634	8640	0.999
December	172.5	169.6	9898	614	8923	8928	0.999
Year	1960.2	1843.6	107786	5310	105093	105120	0.936

Legends:	GlobHor	Horizontal global irradiation	E_User	Energy supplied to the user
	GlobEff	Effective Global, corr. for IAM and shadings	E_Load	Energy need of the user (Load)
	E_Avail	Available Solar Energy	SolFrac	Solar fraction (EUsed / ELoad)
	EUnused	Unused energy (battery full)		

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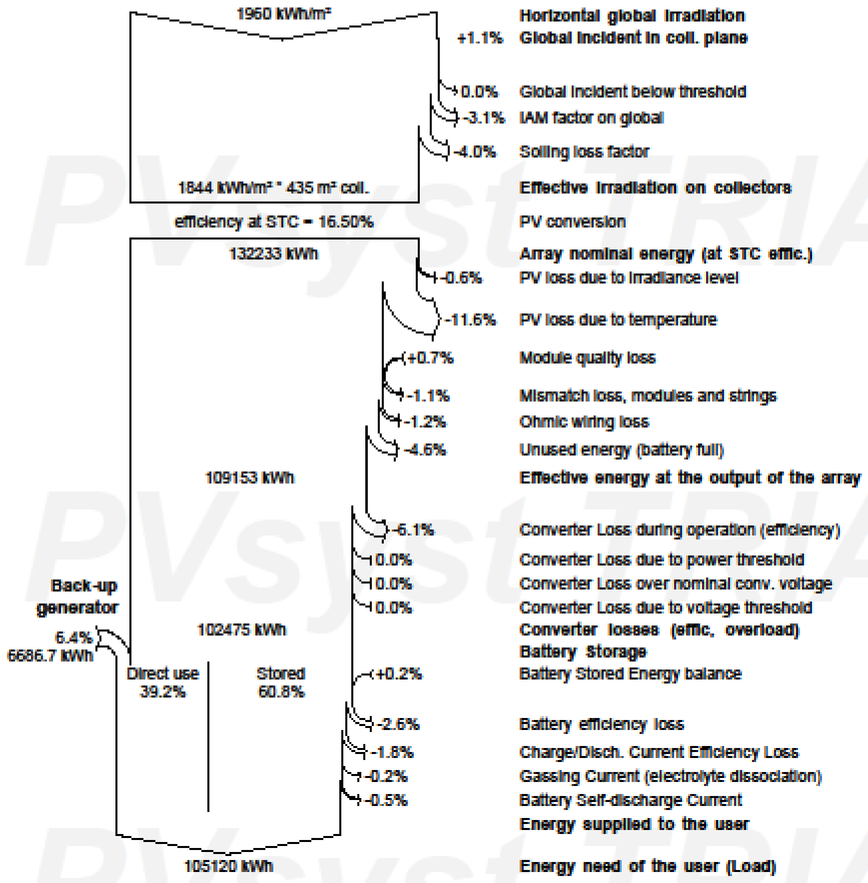
Stand alone system: Loss diagram

Project : **Stand-alone Solar PV to power bank and EVs**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone with back-up generator**		
PV Field Orientation	tilt	6°	azimuth	0°
PV modules	Model	TSM-320PD14	Pnom	320 Wp
PV Array	Nb. of modules	224	Pnom total	**71.7 kWp**
Battery	Model	VR L 6 370	Technology	Lead-acid, sealed, plates
Battery Pack	Nb. of units	300	Voltage / Capacity	**360 V / 2000 Ah**
User's needs	Daily household consumers	Constant over the year	Global	105 MWh/year

Loss diagram over the whole year



Stand alone system: Economic evaluation

Project : **Stand-alone Solar PV to power bank and EVs**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone with back-up generator**		
PV Field Orientation	tilt	6°	azimuth	0°
PV modules	Model	TSM-320PD14	Pnom	320 Wp
PV Array	Nb. of modules	224	Pnom total	**71.7 kWp**
Battery	Model	VR L 6 370	Technology	Lead-acid, sealed, plates
Battery Pack	Nb. of units	300	Voltage / Capacity	**360 V / 2000 Ah**
User's needs	Daily household consumers	Constant over the year	Global	105 MWh/year

Investment

Direct costs			
PV modules	224 units	146.00 GBP / unit	32704.00 GBP
Batteries	300 units	1040.00 GBP / unit	312000.00 GBP
Controllers	300 units	0.87 GBP / unit	261.00 GBP
Installation			
Accessories, fasteners			2100.00 GBP
Wiring			2800.00 GBP
		Net investment (CAPEX)	**349865.00 GBP**

Operating costs

Maintenance		
Salaries		1570.00 GBP / year
	Total (OPEX)	**1570.00 GBP / year**

System summary

Net investment		**349865.00 GBP**
Own funds		349865.00 GBP
Loan	Rate	
Total yearly cost		**1570.00 GBP / year**
Used solar energy		**105 MWh / year**
Excess energy (battery full)		**5.3 MWh / year**
Used energy cost		**0.15 GBP / kWh**
(sum of costs over lifetime / total production over lifetime)		

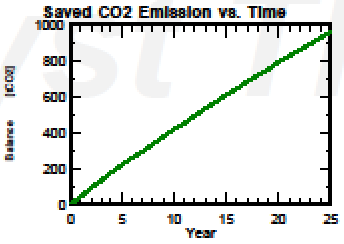
Stand alone system: CO2 Balance

Project : **Stand-alone Solar PV to power bank and EVs**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Stand alone with back-up generator**		
PV Field Orientation	tilt	6°	azimuth	0°
PV modules	Model	TSM-320PD14	Pnom	320 Wp
PV Array	Nb. of modules	224	Pnom total	**71.7 kWp**
Battery	Model	VR L 6 370	Technology	Lead-acid, sealed, plates
Battery Pack	Nb. of units	300	Voltage / Capacity	**360 V / 2000 Ah**
User's needs	Daily household consumers	Constant over the year	Global	105 MWh/year

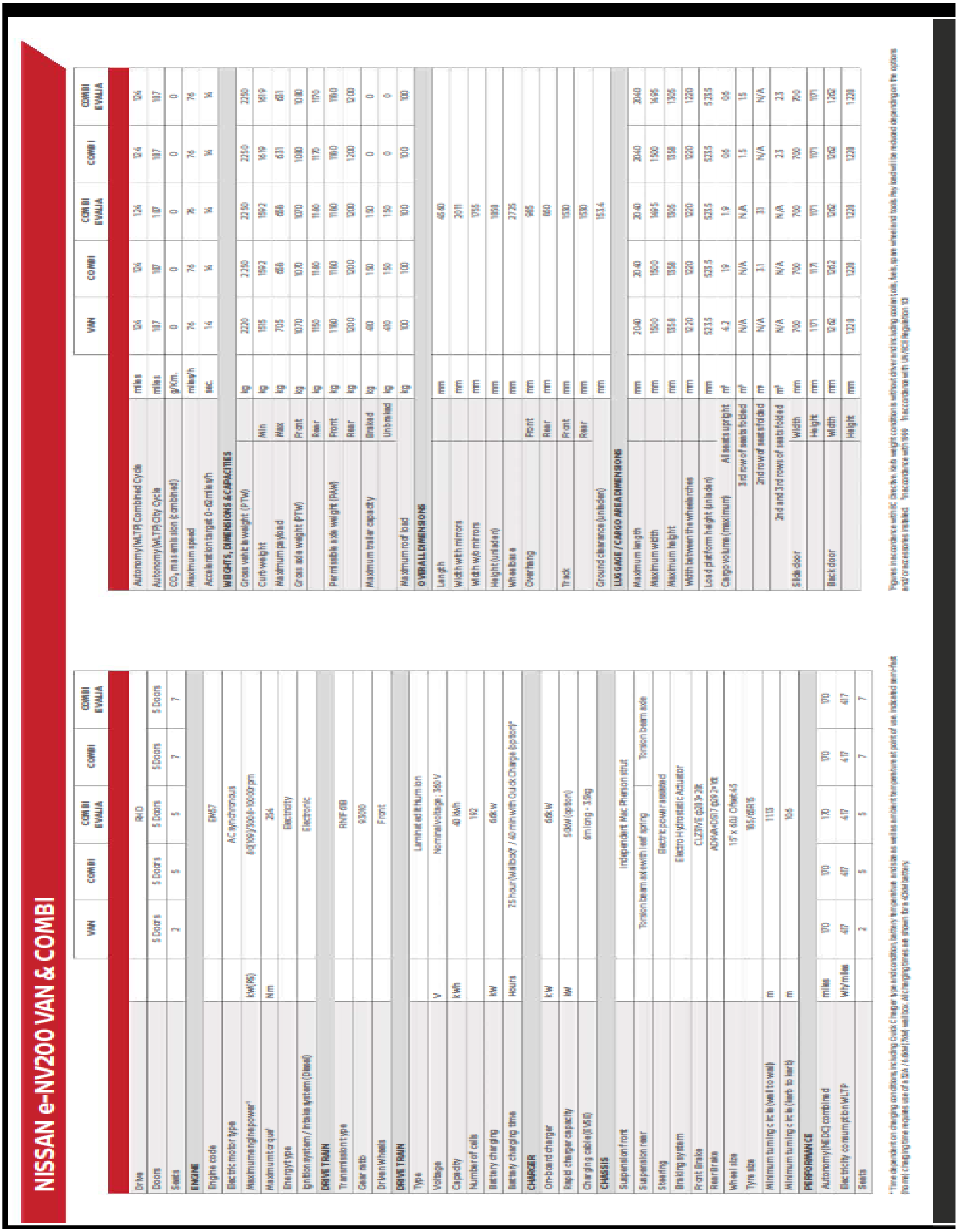
Produced Emissions	**Total:**	**0.00 tCO2**		
	Source:	Custom value supplied by User		
Replaced Emissions	**Total:**	**1083.2 tCO2**		
	System production:	107.79 MWh/yr	Lifetime:	25 years
			Annual Degradation:	1.0 %
	Grid Lifecycle Emissions:	402 gCO2/kWh		
	Source:	IEA List	Country:	Nigeria
CO2 Emission Balance	**Total:**	**962.7 tCO2**		



Appendix K: (Data Sheets)

NB: All data sheets can be opened as Adobe Document Object for clarity.

Nissan e-NV200 data sheet



NISSAN e-NV200 VAN & COMBI

		VAN	COMBI	COMBI EVALIA	COMBI	COMBI EVALIA
Drive		RHD				
Doors		5 Doors	5 Doors	5 Doors	5 Doors	5 Doors
Seats		2	5	5	7	7
ENGINE						
Engine code		EM57				
Electric motor type		AC synchronous				
Maximum engine power¹	kW(PS)	80(109)/3008-10000rpm				
Maximum torque¹	Nm	254				
Energy type		Electricity				
Ignition system / Intake system (Diesel)		Electronic				
DRIVE TRAIN						
Transmission type		RN1F 6B				
Gear ratio		9.3010				
Driven Wheels		Front				
DRIVE TRAIN						
Type		Laminated lithium ion				
Voltage	V	Nominal voltage ; 360 V				
Capacity	kWh	40 kWh				
Number of cells		192				
Battery charging	kW	6.6kW				
Battery charging time	Hours	7.5 hour (Wallbox)* / 40 min with Quick Charge (option)*				
CHARGER						
On-board charger	kW	6.6kW				
Rapid charger capacity	kW	50kW (option)				
Charging cable (EVSE)		6m long - 3.5kg				
CHASSIS						
Suspension front		Independent Mac Pherson strut				
Suspension rear		Torsion beam axle with leaf spring			Torsion beam axle	
Steering		Electric power assisted				
Braking system		Electro Hydrostatic Actuator				
Front Brake		CL25VE ϕ283×28				
Rear Brake		AD9VA+DS17 ϕ292×16				
Wheel size		15" x 6.0J Offset 45				
Tyre size		185/65R15				
Minimum turning circle (wall to wall)	m	11.15				
Minimum turning circle (kerb to kerb)	m	10.6				
PERFORMANCE						
Autonomy (NEDC) combined	miles	170	170	170	170	170
Electricity consumption WLTP	Wh/miles	417	417	417	417	417
Seats		2	5	5	7	7

* Time dependent on charging conditions, including Quick Charger type and condition, battery temperature and size as well as ambient temperature at point of use. Indicated semi-fast (home) charging time requires use of a 32A / 6.6kW (7kW) wall box. All charging times are shown for a 40kWh battery.

			VAN	COMBI	COMBI EVALIA	COMBI	COMBI EVALIA
Autonomy (WLTP) Combined Cycle		miles	124	124	124	124	124
Autonomy (WLTP) City Cycle		miles	187	187	187	187	187
CO_2 mass emission (combined)		g/Km.	0	0	0	0	0
Maximum speed		miles/h	76	76	76	76	76
Acceleration target 0-62 miles/h		sec.	14	14	14	14	14
WEIGHTS, DIMENSIONS & CAPACITIES							
Gross vehicle weight (PTW)		kg	2220	2250	2250	2250	2250
Curb weight	Min	kg	1515	1592	1592	1619	1619
Maximum payload	Max	kg	705	658	658	631	631
Gross axle weight (PTW)	Front	kg	1070	1070	1070	1080	1080
	Rear	kg	1150	1180	1180	1170	1170
Permissible axle weight (PAW)	Front	kg	1160	1160	1160	1160	1160
	Rear	kg	1200	1200	1200	1200	1200
Maximum trailer capacity	Braked	kg	430	150	150	0	0
	Unbraked	kg	430	150	150	0	0
Maximum roof load		kg	100	100	100	100	100
OVERALL DIMENSIONS							
Length		mm	4560				
Width with mirrors		mm	2011				
Width w/o mirrors		mm	1755				
Height (unladen)		mm	1858				
Wheelbase		mm	2725				
Overhang	Front	mm	985				
	Rear	mm	850				
Track	Front	mm	1530				
	Rear	mm	1530				
Ground clearance (unladen)		mm	153.4				
LUGGAGE / CARGO AREA DIMENSIONS							
Maximum length		mm	2040	2040	2040	2040	2040
Maximum width		mm	1500	1500	1495	1500	1495
Maximum height		mm	1358	1358	1305	1358	1305
Width between the wheelarches		mm	1220	1220	1220	1220	1220
Load platform height (unladen)		mm	523.5	523.5	523.5	523.5	523.5
Cargo volume (maximum)	All seats upright	m^3	4.2	1.9	1.9	0.6	0.6
	3rd row of seats folded	m^3	N/A	N/A	N/A	1.5	1.5
	2nd row of seats folded	m^3	N/A	3.1	3.1	N/A	N/A
	2nd and 3rd rows of seats folded	m^3	N/A	N/A	N/A	2.3	2.3
Slide door	Width	mm	700	700	700	700	700
	Height	mm	1171	1171	1171	1171	1171
Back door	Width	mm	1262	1262	1262	1262	1262
	Height	mm	1228	1228	1228	1228	1228

Figures in accordance with EC Directive. Kerb weight condition is without driver and including coolant, oils, fuels, spare wheel and tools. Pay load will be reduced depending on the options and/or accessories installed. ¹In accordance with 1999 ²In accordance with UN/ECE Regulation 101

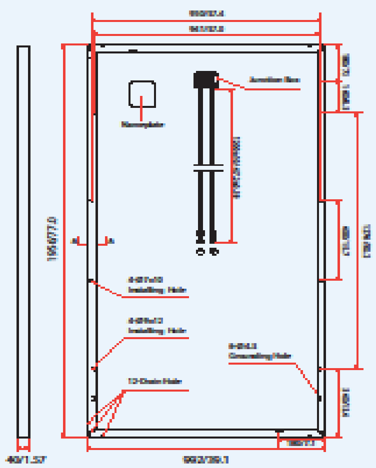
Solar PV data sheet

TALLMAX

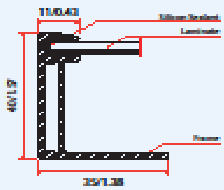
FRAMED 72-CELL MODULE

PRODUCTS	POWER RANGE
TSM-PD14	320-335W

DIMENSIONS OF PV MODULE (mm/inch)

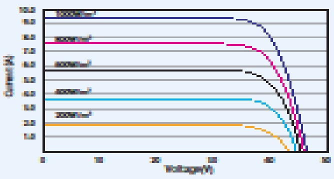


Back View

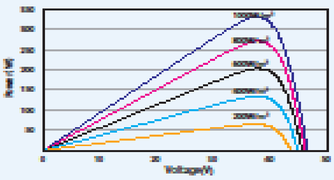


(A-A)

I-V CURVES OF PV MODULE(335W)



P-V CURVES OF PV MODULE(335W)



ELECTRICAL DATA (STC)

Peak Power Watts-P_{MAX} (Wp)*	320	325	330	335
Power Output Tolerance-P_{MAX} (W)		0 ~ +5		
Maximum Power Voltage-V_{MPP} (V)	37.1	37.2	37.3	37.6
Maximum Power Current-I_{MPP} (A)	8.63	8.76	8.87	8.91
Open Circuit Voltage-V_{OC} (V)	45.8	45.9	46.1	46.3
Short Circuit Current-I_{SC} (A)	9.10	9.25	9.38	9.39
Module Efficiency η_m (%)	16.5	16.8	17.0	17.3

STC: Irradiance 1000W/m², Cell Temperature 25°C, Air Mass AM1.5.
*Measuring tolerance: ±3%.

ELECTRICAL DATA (NOCT)

Maximum Power-P_{MAX} (Wp)	238	242	246	249
Maximum Power Voltage-V_{MPP} (V)	34.4	34.5	34.6	34.9
Maximum Power Current-I_{MPP} (A)	6.91	7.02	7.11	7.14
Open Circuit Voltage-V_{OC} (V)	42.5	42.6	42.7	42.9
Short Circuit Current-I_{SC} (A)	7.35	7.47	7.57	7.58

NOCT: Irradiance at 800W/m², Ambient Temperature 20°C, Wind Speed 1m/s.

MECHANICAL DATA

Solar Cells	Multicrystalline 156.75 × 156.75 mm (6 inches)
Cell Orientation	72 cells (6 × 12)
Module Dimensions	1956 × 992 × 40 mm (77.0 × 39.1 × 1.57 inches)
Weight	22.5 kg (49.6 lb)
Glass	3.2 mm (0.13 inches), High Transmission, AR Coated Tempered Glass
Backsheet	White
Frame	Silver Anodized Aluminium Alloy
J-Box	IP 67 or IP 68 rated
Cables	Photovoltaic Technology Cable 4.0mm² (0.006 inches²), 1200 mm (47.2 inches)
Connector	MC4 or Amphenol H4/UTX
Fire Type	Type 1 or Type 2

TEMPERATURE RATINGS

NOCT (Nominal operating cell temperature)	44°C (±2°C)
Temperature Coefficient of P_{MAX}	- 0.41%/°C
Temperature Coefficient of V_{OC}	- 0.32%/°C
Temperature Coefficient of I_{SC}	0.05%/°C

MAXIMUM RATINGS

Operational Temperature	-40~+85°C
Maximum System Voltage	1000V DC (IEC) 1000V DC (UL)
Max Series Fuse Rating	15A

(DO NOT connect Fuse in Combiner Box with two or more strings in parallel connection)

WARRANTY

10 year Product Workmanship Warranty

25 year Linear Power Warranty

(Please refer to product warranty for details)

PACKAGING CONFIGURATION

Modules per box: 27 pieces

Modules per 40' container: 648 pieces

Trinasolar

CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.

Version number: TSM_EN_2017_A www.trinasolar.com

Battery data sheet

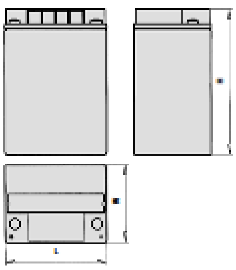
Capacities, dimensions and weights

Series OPzV bloc		Nominal voltage V	C_{100}/1.85 V Ah	C_{50}/1.85V Ah	C_{24}/1.83V Ah	C_{10}/1.80V Ah	C_{5}/1.77V Ah	ca. Weight kg	max.* Length L mm	max.* Width W mm	max.* Height H mm	Fig.
sun | power VR L	12-70	12	70	65	58	51	45	40.0	272	205	383	A
sun | power VR L	12-120	12	130	125	118	103	91	52.5	272	205	383	A
sun | power VR L	12-180	12	200	190	175	154	136	75.5	380	205	383	A
sun | power VR L	6-250	6	270	250	235	205	181	51.0	272	205	383	B
sun | power VR L	6-300	6	330	315	293	250	226	66.0	380	205	383	B
sun | power VR L	6-370	6	400	375	350	308	272	73.0	380	205	383	B
Series OPzV												
sun | power VR L	2-250	2	287	264	243	204	189	18.3	105	208	420	C
sun | power VR L	2-310	2	359	329	304	255	236	22.3	126	208	420	C
sun | power VR L	2-370	2	430	395	365	306	283	26.5	147	208	420	C
sun | power VR L	2-420	2	478	453	428	391	346	29.9	126	208	535	C
sun | power VR L	2-520	2	574	543	513	470	415	35.1	147	208	535	C
sun | power VR L	2-620	2	670	634	599	548	485	42.1	168	208	535	C
sun | power VR L	2-750	2	847	802	762	682	595	48.7	147	208	710	C
sun | power VR L	2-875	2	990	935	888	796	694	61.3	215	193	710	D
sun | power VR L	2-1000	2	1130	1070	1016	909	793	65.9	215	193	710	D
sun | power VR L	2-1125	2	1271	1203	1143	1023	893	75.6	215	235	710	D
sun | power VR L	2-1250	2	1412	1337	1270	1137	992	80.5	215	235	710	D
sun | power VR L	2-1375	2	1553	1471	1397	1250	1091	89.3	215	277	710	D
sun | power VR L	2-1500	2	1695	1604	1524	1364	1190	94.6	215	277	710	D
sun | power VR L	2-1700	2	1955	1870	1785	1545	1372	110.0	215	277	855	D
sun | power VR L	2-2000	2	2281	2182	2082	1802	1601	136.5	215	400	815	E
sun | power VR L	2-2300	2	2607	2493	2380	2060	1829	152.9	215	400	815	E
sun | power VR L	2-2600	2	2933	2805	2677	2317	2058	173.0	215	490	815	F
sun | power VR L	2-2900	2	3258	3117	2975	2574	2287	186.5	215	490	815	F
sun | power VR L	2-3200	2	3584	3428	3272	2832	2515	214.7	215	580	815	F
sun | power VR L	2-3500	2	3910	3740	3570	3089	2744	222.3	215	580	815	F

C_{10} and C_{100} = Capacity at 10 h and 100 h discharge

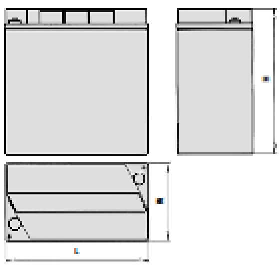
*according to DIN 40742 data to be understood as maximum values

Fig. A Series OPzV bloc



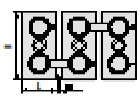
sun | power VR L 12-70 –
sun | power VR L 12-180

Fig. B Series OPzV bloc



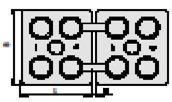
sun | power VR L 6-250 –
sun | power VR L 6-370

Fig. C Series OPzV



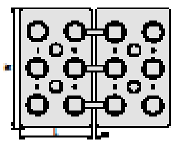
sun | power VR L 2-250 –
sun | power VR L 2-750

Fig. D Series OPzV



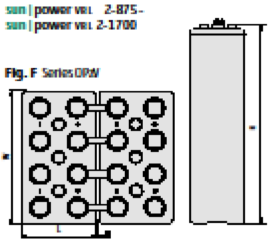
sun | power VR L 2-875 –
sun | power VR L 2-1700

Fig. E Series OPzV



sun | power VR L 2-2000 –
sun | power VR L 2-2300

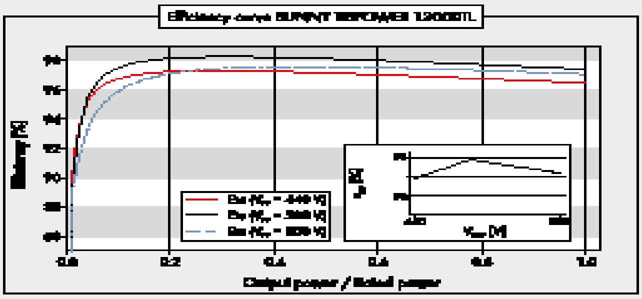
Fig. F Series OPzV



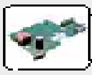
sun | power VR L 2-2600 –
sun | power VR L 2-3500

Optimal environmental compatibility –
closed loop for recovery of materials in an accredited recycling system
IEC 60896-21 · IEC 61427

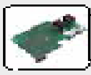
Inverter data sheet



Accessories



Power Controle Module
PWCBRD-10



RS485 interface
485BRD-10

[1] Does not apply to all national appendices of EN 50438
[2] Only STP 9000TL-20
[3] Only with external NS protection
[4] AS 4777, SI4777 available as of September 1, 2014
[5] Available as of October 2014

● Standard feature ○ Optional feature — Not available
Last updated: August 2014
Data at nominal conditions

Sunny Tripower 10000TL	Sunny Tripower 12000TL[5]	
10250 W	12275 W	
1000 V	1000 V	
370 V ... 800 V / 580 V	440 V ... 800 V / 580 V	
150 V / 188 V	150 V / 188 V	
18 A / 10 A	18 A / 10 A	
18 A / 10 A	18 A / 10 A	
2 / A:2; B:2	2 / A:2; B:2	
10000 W	12000 W	
10000 VA	12000 VA	
3 / N / PE; 220 / 380 V 3 / N / PE; 230 / 400 V 3 / N / PE; 240 / 415 V	3 / N / PE; 220 / 380 V 3 / N / PE; 230 / 400 V 3 / N / PE; 240 / 415 V	
160 V ... 280 V	160 V ... 280 V	
50 Hz, 60 Hz / -5 Hz ... +5 Hz	50 Hz, 60 Hz / -5 Hz ... +5 Hz	
50 Hz / 230 V	50 Hz / 230 V	
14.5 A	17.4 A	
1	1	
0.8 overexcited ... 0.8 underexcited	0.8 overexcited ... 0.8 underexcited	
3 / 3	3 / 3	
98 % / 97.6 %	98.3 % / 97.9 %	
●	●	
● / ●	● / ●	
● / ● / —	● / ● / —	
●	●	
I / III	I / III	
470 / 730 / 240 mm (18.5 / 28.7 / 9.5 inches)	470 / 730 / 240 mm (18.5 / 28.7 / 9.5 inch)	
37 kg (81.6 lb)	38 kg / 84 lbs	
-25 °C ... +60 °C (-13 °F ... +140 °F)	-25 °C ... +60 °C (-13 °F ... +140 °F)	
40 dB(A)	40 dB(A)	
1 W	1 W	
Transformerless / Opticool	Transformerless / Opticool	
IP65	IP65	
4K4H	4K4H	
100 %	100 %	
SUNCLIX / spring-cage terminal	SUNCLIX / spring-cage terminal	
Graphic	Graphic	
○ / ● / ●	○ / ● / ●	
● / ○	● / ○	
● / ○ / ○ / ○ / ○	● / ○ / ○ / ○ / ○	
AS 4777[4], CE, CEI 0-21[3], C10/11:2012, DIN EN 62109-1, EN 50438[1], G59/3, G83/2, IEC 61727/MEA[2], IEC 61727/PEA[2], IEC 62109-2, NEN EN 50438, NRS 097-2-1, PPC, PPDS, RD 661/2007, RD 1699:2011, SI 4777[4], UTE C15-712-1, VDE0126-1-1, VDE AR-N 4105, VFR 2013, VFR 2014		
STP 10000TL-20	STP 12000TL-20	