Lappeenranta University of Technology
LUT School of Energy Systems
M.Sc. Electrical Engineering

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INCREASING AGRICULTURAL LAND USE EFFICIENCY AND GENERATING ELECTRICITY USING SOLAR MODULES.

Case study: Santa Agro-Ecological Village Republic of Cameroon

Master's Thesis, 2018

Examiners: Professor Jero Ahola

Associate professor Antti Kosonen

Abstract

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The continuous rise in electricity demand across the globe has been a major source of carbon dioxide (CO_2) emissions and other gases such as greenhouse gases (GHGs) resulting from the excessive use of crude oil and fossil fuels by energy sectors for many decades. Because of the environmental and ecological problems that burning fossil fuels to generate electricity have caused rapidly, most governments through the United Nations Organization efforts to ensure sustainable communities, nature preservation, CO_2 mitigation and the reduction of global warming also led to the adoption of a goal to ensure affordable and clean energy for all.

However, a renewable energy resource such as solar has vast global potentials to support the future needs of energy through sustainable conversion technology like photovoltaic systems. Solar energy optimization is a reliable and efficient step towards increasing the share of renewable energy in the energy mix of most nations, especially in regions with high solar irradiation due to favorable climatic conditions and adequate annual sunshine hours. However, solar energy has some disadvantages such as difficulties in balancing production and consumption, which then requires batteries for energy storage. In addition, some regions may periodically have poor solar irradiation due to changes in weather conditions.

In this thesis, a solar powered system for a farmer in the Santa village in northwest region Cameroon was, studied and designed to meet his socio-economic goals. With the aim to increase his agricultural land use efficiency by providing enough shading using solar panels, on a piece of dry and hot crop land often affected by excess sunshine, and to generate electricity for daily farm use including the keeping of poultry and to power agricultural machinery. In addition to sell electricity to surrounding residents as an alternative source of income generated from his solar farm in which the crops, fruits and vegetables are cultivated beneath the solar panels in a system called agro-photovoltaics (APV). The APV also aims to create jobs, improving the socio-economic standard of living for people in this region and to boost up annual food production to meet the financial needs of the farmer.

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Abbreviations and symbols

Acronyms

PV	Photovoltaic
APV	Agrophotovoltaics
NREAP	National Renewable Energy Action Plan
NASA	National Aeronautics and Space Administration
AC	Alternating Current
DC	Direct Current
HOMER	Hybrid Optimization for Electric Renewables
LCC	Life Cycle Cost
NOCT	Nominal Operating Cell Temperature
NREL	National Renewable Energy Laboratory
STC	Standard Test Conditions
UNDP	United Nations Development Program
ENEO	Energy of Cameroon
SD	Sustainable Development
DOD	Depth of Discharge
IPP	Independent Power Producer
MPP	Maximum Power Point
IEA	International Energy Agency

1. **Introduction**

The needs for sustainable communities, green environments and clean energy for all, has influenced many governments and institutions, to join the trend towards improving the standard of living of people, and the protection of nature. This include the entire biodiversity (a variety of all forms of life, from genes to species, through the broad scale of ecosystems) by engaging and setting up renewable energy targets. Researchers, governments, environmental pressure groups, energy agencies and other organizations, have clearly confirmed that the continuous consumption of fossil fuels account for the huge production of greenhouse gas emissions, which have greatly resulted to the gradual increase in the overall temperature of the earth's atmosphere, generally attributed to the greenhouse effect due to increased levels of carbon dioxide emissions.

The depletion of the ozone layer and some major environmental damages can be, linked to the excessive burning of fossil fuels in order to produce electricity in particular as required for our daily use in living homes, offices and industries and for other purposes where electricity is, needed as a form of energy. Other factors such as increasing population across the globe have triggered the need for more energy alternatives in order to satisfy the steadily increasing demands for energy. To this effect, the shift to renewable energy resources is highly important as a means to lower significantly the effect that energy consumptions through the burning of fossil fuels have caused to the environment in the past.

Through the United Nations initiative for sustainable development, one of its goals is to ensure affordable and clean energy for all. This has empowered many governments and institutions to develop policies that emphasize the use of green energy, by gradually diverting the focus of consumers from conventional energy sources such as fossil fuels and ensuring that the use of renewable energy is, promoted entirely. Providing energy subsidies for both producers and consumers of energy is one very effective way by which most governments have managed to implement action plans that have seen the use of renewable energy gradually replacing fossil fuels in most developed countries, where the renewable energy targets set within a specified timeframe are almost reached (UNDP, 2018).

This research work therefore outlines clearly the possibility to combine solar PV panels and crops on the same field, in a system whereby farmers harvest radiant light (sunlight) in order to produce both electric power and crops in a solar power plant. In this setup, the crops are cultivated beneath the solar PV panels. This thesis provides in more details economic, social and environmental impacts of agro photovoltaics as a solution, which satisfies farmer's needs to produce both electricity and agricultural products. Moreover, the APV is as well a system whereby the solar panels help in reducing the quantity of water required for dry farmland irrigation by providing enough shading on the crops preventing the agricultural products from very hot and excessive sunshine.

This practice is more beneficial in regions with absolutely higher solar potential and great amount of annual sunshine, good access by roads to farmlands but a complete lack of access to electricity grid. Hence the electricity generated from an APV power plant, can be a great source of income for the plant owner. However, the excess electricity generated can be, distributed to local inhabitants who demand electrical energy for domestic applications, and some used for poultry farming, (keeping of animals). In addition, powering farm tools, machinery and other equipment used by the farmers, and most especially for the storage of perishable crops in refrigerators such as tomatoes, carrots, potatoes and vegetables before their arrival at the markets or consumers location.

The Agro photovoltaics project is capable to satisfy the demand for electricity by households, and the vast possibility to provide electric power needed for intensive farming activity in very sunny regions with relatively higher temperature and dry farmlands that require sufficient water irrigation. By engaging in this practice, farmers do not only aim to afford electricity, but also emphasizing the shift towards a 100% use of renewable energy in the future irrespective of the demand sectors. Considering the fact that sunshine is periodic and some hours of the day can present very poor solar irradiation, batteries storage with larger capacities are utilized for the APV power plant project to store the required energy that can be used during night hours as discussed in this research work. Battery storage is a great means to reserve the excess energy generated by the APV plant and intended for use during evening and night times when the electricity generation falls drastically due to little or no sunshine (irradiation).

1.1 **Background**

As far back as in 1981, Professor Goetzberger serving as the head of the Fraunhofer Institute for solar energy systems, published his stunning article which focused mainly on the possibility whereby solar panels can be installed on agricultural land especially in those regions with very hot and dry climate of the world. He predicted that the shading presented by the panels on the soil will make it to bloom and by this effect, will reduce the quantity of water needed to irrigate the land for agricultural produces. He added that around the year 1981, photovoltaics technology was still very expensive and therefore researchers were looking for ways to make extra profit from the same piece land used in installing solar panels other than just generating electricity and leaving part of the lands completely vacant (PV Europe, 2017).

Therefore the desire for efficient land use, led to the progress and development of the Agro-photovoltaics project carried out by building the first pilot installation near Lake Constance in Germany in the year 2016. However, the Agro-photovoltaics would equally be a great opportunity for jobs and will raise the standard of living for the surrounding community where the farmers or power plant owners have the vast potential to harvest crops and same time generate electricity from the solar power plant installed above agricultural products. Furthermore, this practice will certainly require some extra cost such as raising the solar panels (modules) much more above the soil level in order to create space for the free movement of farm tools beneath the panels where agricultural activities are, performed.

At this early stage, the need for funding delayed the implementation of the first pilot installation of the Agro-photovoltaics project. This initiative then took until autumn 2016 following the repeated submission of project proposals by the Fraunhofer Institute to raise funds and then engage in the implementation of the practical phase of the project as was ideally predicted by the researcher, Professor Goetzberger. Agro-photovoltaics has the potential to generate about 50GW of power for Germany alone and will continue to grow as long as the demand increase significantly over the years, and especially in the southern countries where solar irradiation is often too strong.

1.2 **Research limitation**

Even though it’s, a clear fact that the shading on crops by the solar panels help to limit the quantity of water needed to irrigate the dry lands throughout the farming process, yet it‘s assumed expensive to realize the entire Agro-photovoltaics project. When taking into consideration the heights recommended for the panels to be above the soil level, means the panels should be at certain heights in order to allow the free movement of farming tools and persons under the modules during crop cultivation and harvesting when they are ready. Despite of the high demand for electricity as a source of income from the APV power plant, the combination of PV panels and crops on same field will lead to some reduction in the crop yields annually. The pilot project near Lake Constance, actually realized a drop of about 5.3% for clover grass planted under the PV array when compared to growing it in an opened field where there is no shading from panels (Fraunhofer, 2017).

The variations in solar conditions of any region chosen for such activity (Agro-photovoltaics) emphasize the need to utilize batteries with large storage capacities. This has been an important factor to consider. Though usually presents some major challenges depending on the quantity of electrical energy needed in periods when the solar irradiation drops significantly and only storage systems can provide the amount of electrical energy needed for mainly lighting, refrigeration and heating of homes of the local population in the community. Considering that an APV plant is also intended to supply sustainable and clean energy to local subscribers and help to boost the standard of living and as well an important source of income for the farmer or plant owner throughout the power plant life span and should fulfill sustainability criteria.

In the case study area for this research work, there have been frequent problems between the farmers and grazers of the Santa ecological village, continuous cases of farmers, and grazer crisis and reported incidence whereby the grazers are unable to prevent their cattle from trespassing on the farmlands. This could be a major constraint to the success and realization of the APV project if proper restrictions are not made to safeguard the farmers and their lands from the threats presented by pastoral nomadism where the needs for greener pastures by the grazers from one place to another during seasons when they are faced with scarcity is in place.

Additionally, the share of solar energy in the Cameroonian energy mix is very low and almost negligible and this to some extend may present the impossibility for the government to adopt flexible laws, rules and regulations that will grant investors the freedom to invest in the solar energy systems in the nation. Government policies in Cameroon can greatly affect the growth and transition to renewable energy and sustainable development entirely. Currently hydropower accounts for about 75% of total electricity consumption in Cameroon and the remaining consumption is mainly from oil, natural gas, biofuels and waste.

Energy Monopoly

Another limitation of this study is the fact that there is very strict monopoly system in the Cameroonian energy sector whereby just one company ENEO (The Energy of Cameroon) carries out energy related projects, distribution of local energy to end users, sales and accountability. However, to implement a private power plant that would require the sales of electricity to local population needs to take into consideration the possibility to obtain the relevant license, permits and fulfilling all taxation requirements. The strict implementation of monopoly in the energy sector in Cameroon has not given way for competitions whereby competing investors might have considered utilizing RES and leading the way towards a more sustainable, greener and carbon dioxide free energy systems in Cameroon. Finally, one limiting factor for this thesis work by taking into consideration the case study area may be insufficient skilled workers and lack of human resources due to the fact that the solar energy has not been fully utilized or harnessed to the extend, that everyone has become aware of its major role.

The inability to strengthen private efforts and utilize the vast solar potential that is able to produce enough energy across Cameroon if properly managed, and investing in large-scale solar plants through government funding, more education and training of solar engineers to specialize in the realization of major projects in the country has been a setback. It is a clear fact that the possibility for consistence solar energy production depends on weather conditions from time to time. Moreover, during the rainy seasons when the sunlight is not sufficient to produce the required amount of energy needed, usually present some challenges in carrying out farming activities (such as powering farm tools), keeping of animals which require the generation of electricity as stipulated for an APV activity where crops are grown beneath the solar PV panels.

1.3 **Objectives**

The aim of this work is to study a solar system whereby farmers can increase land use efficiency by generating both electricity and growing crops on the same piece of a given land (APV). This practice takes place particularly in regions with high solar potentials where the solar panels provide adequate shading on the hot and dry farmland to make it more useful, productive and suitable for growing crops beneath the modules (solar panels). This solution is suitable for farmers in the Northwest Region of Cameroon, where intensive vegetable and fruits farming is a common practice around the Santa village but lack access to electricity for storage and irrigation. This work also aims to integrate communities into the National Renewable Energy Action Plan (NREAP) target and focusing consumer's attentions on green technologies and sustainable energy systems such as solar power for both commercial and domestic applications.

- Providing a sustainable innovation and solution to farmers seeking to create an alternative source of income other than producing just crops, but also generate electricity for sale to surrounding communities as an auxiliary commodity.

- Raising the share of renewables in the overall national and annual energy consumption by households, commercial, private and public sectors of a country that has clearly stated its needs and pursuit of renewable energy and setting goals to mitigate CO_2 emissions caused by burning fossil fuels and other gases when producing electricity.

- Improving standard of living for persons and protection of nature, ecosystem and biodiversity by implementing energy systems with little or no negative environmental impacts such as high deposition of GHGs and CO_2 emissions and other gases.

Raising consumer's awareness on the importance of switching to renewable energy, promoting sustainability, and making sustainable innovation and system transition from conventional energy sources such as fossil fuels into new energy alternatives as a common initiative for the Cameroonian governments, NGOs, energy stakeholders and environmental pressure groups.

1.4 **Research Methodology**

The HOMER software designed by the National Renewable Energy Laboratory (NREL) was, used entirely in this study to design the power system, simulating different results for the solar irradiations and annual temperature conditions of chosen region for this research work. Input data such as daily electric load profiles, equipment costs are, fed into the HOMER software and the results are, then simulated based on the economic and technical expectations and analysis, which then yielded the different output results showing clearly the variations for particular period of a year. Taking into account all the different constraints, the HOMER software seeks to find the most appropriate solution for the solar power system design based on technical specifications and cost efficiency.

The economic aspect of this solar power system, is based on life cycle cost (LCC) of the entire system which includes the initial capital costs, installations costs, system operational costs and maintenance costs throughout its life span estimated between 25–30 years. However, the results of the simulations are purposely to satisfy the desired demand for power when using the resources and the various technological specifications available whereas the most suitable design configurations is vital for this study and implemented accordingly. In this study, a comprehensive observation and connection between the following parts and elements relating to the PV conversion technologies for power generation are considered.

- Solar Photovoltaics (PV) system
- Battery (energy storage) system
- Inverters specifications for the APV project
- By choosing the relevant degree of protection for the solar system
- By defining and selecting the right components to make up an APV system.

This research in addition required, visits to installation sites, where similar solar projects have been realized and clearly outlining the possibility that an APV solar system can satisfy farmer’s needs and therefore, able to meet the specified sustainability requirements such as environmental protection and as a means to increase land use efficiency for farmers in hot climatic regions.

HOMER software simulation layout.

The HOMER software takes into consideration all the different constraints and sensitivities in obtaining the optimal solution for the design of the energy system to satisfy any particular demand such as electricity for lighting or powering farming appliances.

The economic analysis is, based on life-cycle cost (LCC) of the system, which made up of the initial capital cost, installation costs, operational and maintenance costs of the solar power system during its entire lifetime. The diagram in Figure 1 shows the different elements making up the HOMER configuration that was, used to achieve these results and goals. The main components include- a solar PV system, a battery storage, a converter, a primary load showing the energy demand by the farm on-site equipment and households fed by the APV plant.

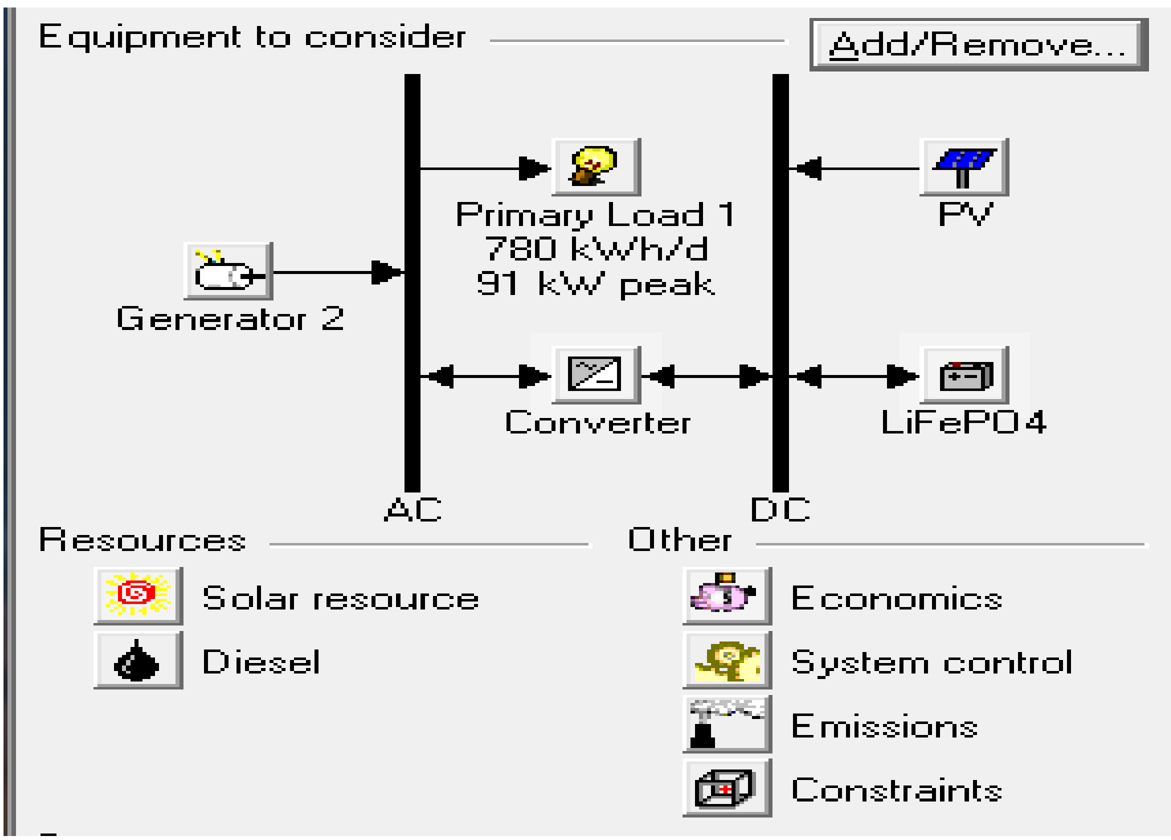


Figure 1. HOMER software simulation layout for the APV project

1.5 **Organization of the thesis**

This thesis comprises mainly the main ideas as expected, which makes it more simplified and easy for reading and understanding by people. The focus being the elaborate description of a solar farm, a system whereby solar PV are, installed above crops on same field to generate electric power for crop cultivation and storage. Major part of the work being the sizing of the solar PV system where some calculations are, made for the power and energy required to meet up the demand for electricity. Moreover, sizing the batteries to meet up the storage demand of electricity intended for flexible use. An overview of the main features of the methodology being presented and in addition, some key points taken into account include-; the following topics and sub topics listed below which are discussed in this thesis work.

- Introduction
- Limitations, research objectives, methodology
- Resources analysis and site description
- Conversion technology (PV systems)
- Simulation results
- Life Cycle Cost (LCC) analysis
- Economic and social impacts
- Sizing the PV system
- Battery (storage) dimensioning
- Conclusions
- References.

The thesis work takes into account the diversity and backgrounds of different readers and makes understanding of the main subjects easier and clear enough. Avoidance of complex issues by focusing mainly on the goal of the thesis, which is to design an APV system for farmers where they intend to harvest crops and then generate electric power on same field. However stating clearly the possibility to analyze relevant results by entering input data into the HOMER software, which satisfies the actual design synthesis that will make the APV plant a sustainable solution for farmers in hot climatic regions. Carefully choosing the right irrigation pumps considering the soil is too dry for crops cultivation, implies shading is technically and environmentally confirmed as a major solution using PV panels above crops to make the soil blooms and suitable for farming.

2. Solar resource availability

The global solar atlas contains some details of global solar irradiation condition for different countries and presents the following solar resource map in the case of Cameroon showing clearly the scaled annual average irradiation value of the country (Solaratlas, 2016).

2.1 Solar resource maps of region.

This solar resource map presents a summary of the estimated solar energy potential available for power generation and other energy applications for Cameroon. It represents the average daily/yearly sum of global horizontal irradiation (GHI) within the period of 22 years (1994 –2015). The map in Figure 2 below, represent the solar condition in Cameroon from all ten regions with the southern part of the country having much stronger irradiation due to relatively higher sun hours per year when compared to other regions in Cameroon.

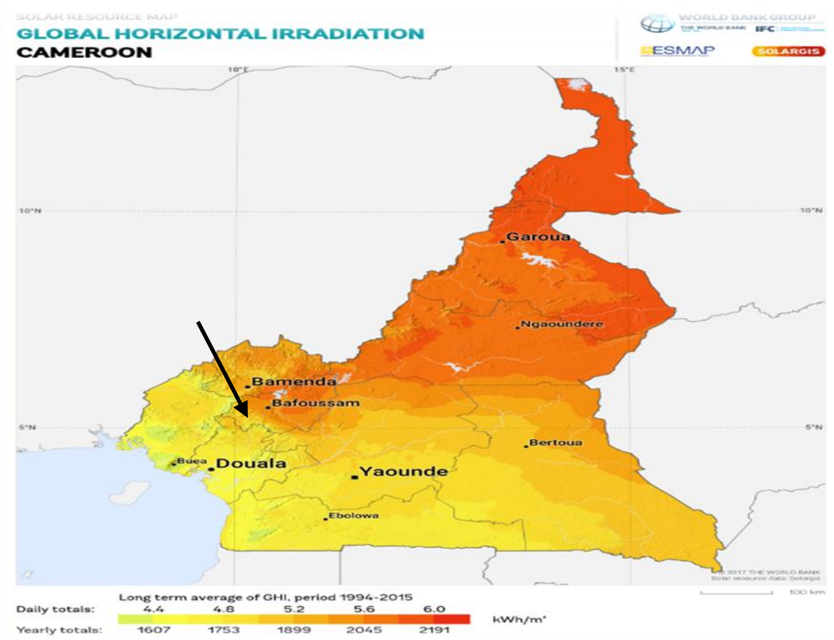


Figure 2. Global Horizontal Irradiation Map of Cameroon (Solargis, 2016)

The lack of measurement data for the high ground quality, might have posed some uncertainties in the yearly GHI estimate due to limited regional solar potential in different seasons as estimated to vary regionally from 5–8%. However, GHI is the most important data for energy yield calculation and the performance assessment of flat-plate Photovoltaics (PV) technologies in any given region where solar electricity is generated (Solargis, 2016).

Being a central-west African country with relatively higher sunshine, Cameroon presents very strong solar irradiation yearly that is capable to generate sufficient electricity using PV system for different application models such as domestic, commercial and industrial electrification. This is due to great access to an estimated annual average sunshine hours varying between 2600–2900 hours (Koundja, 2016).

2.2 Average monthly hours of sunshine in region.

- On average, December is the most sunny month
- On average, August has the lowest amount of annual sunshine value

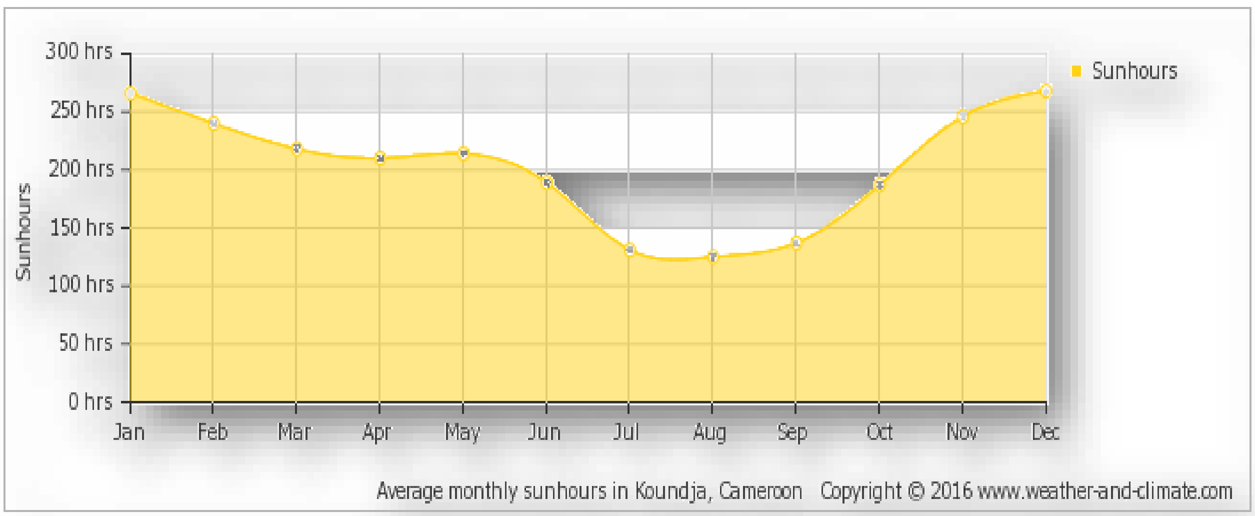


Figure 3: Average monthly sunshine hours Bamenda Cameroon (Koundja, 2016).

The statistics of annual sunshine in Cameroon is such that the month of December for each year, experiences the strongest radiant light (sunshine) due to the dry season across the country. January and February also follow respectively but as the rainy season start approaching in the beginning of March, the climate condition begins to change and giving way for the rainy season, which slowly leads to lower daily sunshine. The month of August, is therefore the period with lowest amount of sunshine. Usually during this time, solar condition is poor and the estimated amount of energy generated is lower when compared to the production capacity and solar potential during the dry season; that is between the month of November and February for any given year in Cameroon (Koundja 2016).

2.3 Solar resource inputs

By introducing the latitude and longitude's coordinate values in the HOMER configuration window as seen in Figure 4, generated the following chart showing the solar resource condition of the project location in Bamenda Cameroon. The daily solar radiation measured in kWh/m^2/day changes as the sunshine also changes with different month. Between the months of November and March, the peak production occurs for most part of Cameroon including the northwest regions. The sunshine drops more between the month of May and October with July and August having the lowest daily solar radiation (insolation values). The scaled annual average for the APV project location in northwest region of Cameroon is still about 5.01 kWh/m^2/day as seen on figure 4 below. This means that Cameroon has a higher average annual solar insolation compared to most of EU countries whose daily average insolation range between 2.26kWh/m^2/day–5.61 kWh/m^2/day. Finland's annual average insolation varies between the following values as follows: Annual average insolation 2.73 kWh/m^2/day–3.32 kWh/m^2/day (Leidi, 2000).

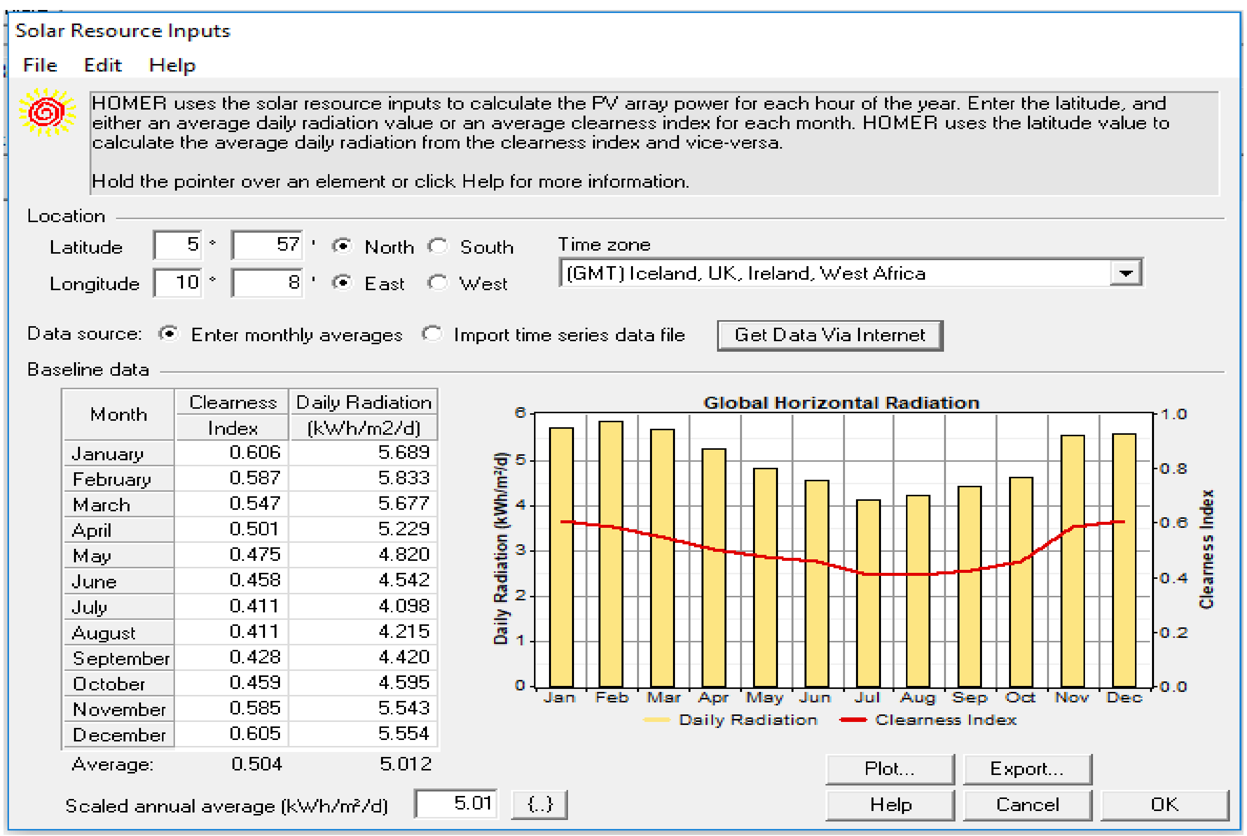


Figure 4: Global horizontal radiation for Bamenda Cameroon

2.4 Optimum tilt angle

In this study, the solar energy production depends strongly on few factors such as solar condition of installation sites, shading condition, weather changes and most importantly the tilt angle for which the panels are placed on the fixed axis above the crops in an APV project. In order to get the most from the solar system, we point the panels to the direction that allows them with the high possibility to capture the most of sunshine falling on the area. However, there are some variables (factors) in figuring out the best directions of sunshine. In most cases, the tilt angles are kept at a value equivalent to the latitude, plus 15° (degrees) in winter periods and then the latitude minus 15° (degrees) in the summer periods.

It is quite profitable and simple to mount solar panels at a fixed tilt angle in regions with almost same weather condition throughout the entire year where there is relative little variation in solar condition. In order to obtain the proper tilt angles suitable for PV panels in regions where the latitude is below 25°, one needs to multiply the latitude with a constant of 0.87.In addition, if the latitude is between 25° and 50°, then it is recommended to multiply the value by 0.76 plus 3.1 degrees (Solartilt 2017). All these refers to situation whereby a fixed tilt is used where there is neither any winter nor summer variations in insolation level. In the Santa agro-ecological village where this APV project is to support, a farmer's needs of electricity for agricultural activities and for distribution to local consumers, the latitude and longitudes are as follows:

Latitude: 5°57'34.9" N, Longitude: 10°8'45.5" E

This implies that for the case of the Santa agro-ecological village in Bamenda Cameroon, the tilt angle is as follows:

Tilt angle (α) = $5^\circ * 0.87 = 4.35^\circ$. However, at least 10° is desirable to ensure efficient performance of the solar panels.

Additionally, in order to ensure proper cleaning of the modules, a minimum tilt angle of 10° is more desirable and capable to allow the solar modules to capture sunshine more effectively. Therefore, at this angle the panels are placed on the fixed axis in the APV farm) and this stays same throughout the year as the weather condition is periodically not very affected by any winter or summer changes in insolation. Nevertheless, with only constraint being the little changes that may occur during the rainy season and particular in August which have the lowest solar insolation level in Cameroon. However, the panels can be nearly horizontally on the axis for the case of northwest region in Cameroon (Solartilt, 2017).

The table 1 gives some examples of different latitudes and tilt angles of some regions that can be, considered for solar panels installations. It also shows the average insolation on the panel for each region over the year (in $kWh/m^2/day$), and the amount of energy received compared to the best possible tracker. All these satisfies one of the equation discussed above which are:

For latitude below 25°, the tilt angle is, given by the relationship below

Tilt angle α = latitude * 0.87 (2.1)

Moreover, for latitude between 25° and 50°, the tilt angle given by the relationship below

Tilt angle α = (latitude * 0.76) + 3.1°.

Table 1. Fixed tilt angles and average insolation of selected regions (Solartilt.com).

Latitude	Full year angle	Average insolation on panels	% of optimum tilt
0° (Quito)	0.0	6.5	72
5° (Bogota)	4.4	6.5	72
10° (Caracas)	8.7	6.5	72
15° (Dakar)	13.1	6.4	72
20° (Merida)	17.4	6.3	72
25° (Key West)	22.1	6.2	72
30° (Houston, Cairo)	25.9	6.1	71
35° (Tokyo)	29.7	6.0	71
40° (Madrid)	33.5	5.7	71
45° (Milano)	37.3	5.4	71
50° (Prague)	41.1	5.1	70

These refers to fixed tilted panels without any tracking systems needed for the energy production in these regions throughout the year. A good example is the case of Santa agro-ecological village in Cameroon with no winter obstacles such as snow, where the use of fixed tilted system for solar panels installation is simpler and at very small tilt angles falling below 10°. As an advantage, fixed tilt also ensures costs efficiency of installations and time saving for installers of photovoltaics systems in regions with almost constant solar irradiation

2.5 Photovoltaics electricity output of region

The map in Figure 5 below, describes in details the daily and annual photovoltaics electricity yields of the case study region of Santa village Bamenda, Republic of Cameroon. The solar condition changes by regions due to some environmental factors such as vegetation, mountains, solar elevation or inclinations of the solar rays to the horizon, water vapor. But in average, the estimated value of photovoltaic electricity output (PVout) for the Santa sub region in Bamenda Cameroon varies between 1546 kWh / kWp per year –1936 kWh/ kWp per year at optimum module orientation and tilt angle, which in this case falls between 4° and 10° tilt.

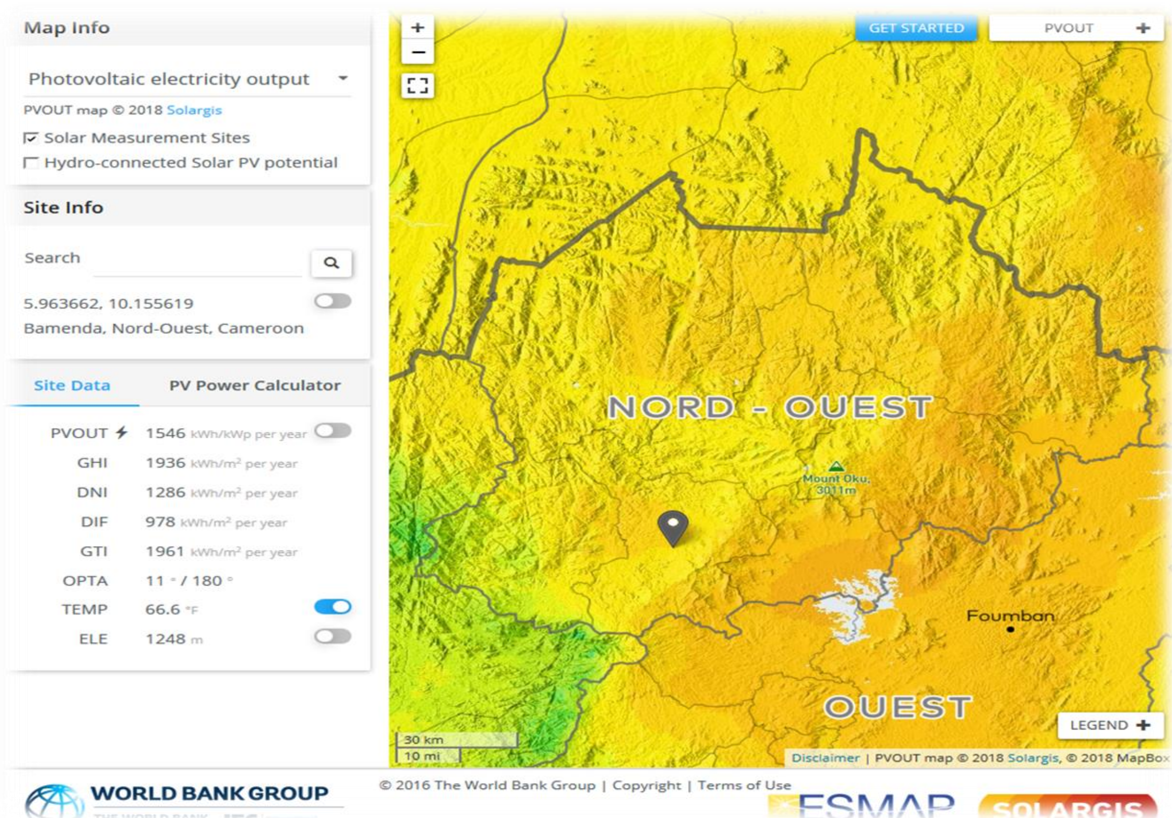


Figure 5: Photovoltaics electricity output of Bamenda Cameroon (Global solar atlas, 2016)

Figure 5 presents the various solar parameters of the Santa region in Bamenda Cameroon such as the GHI of 1936 kWh/m^2 per year. Also one very important data seen from the available parameters include the Global tilted irradiation (GTI) of 1961 kWh/m^2 per year, with an elevation of 1248m and an optimum angle of PV modules of 11° / 180°. The temperature of the region measured at 66.6 $^{\circ}$F (19.2 $^{\circ}$C) on average annually (Solargis, 2018)

2.6 Solar measurement of site.

Table 2 presents the results of the various solar potential and measurements developed for the region where the APV project is suitable for farmers. Considering this is an outstanding agricultural village in northwest region of Cameroon, where farmers have sufficient solar potentials to produce electricity as an alternative source of income, provided they incorporate their agricultural activities, with solar PV panels in order to generate electricity for sale and then boost up their annual turnover. These values have been almost same from years to years, even though in some periods such as August, the solar condition becomes weaker due to heavy rainfall and only starts to rise again in the beginning of November and then continues through to February (Global solar atlas, 2018).

Table 2. Solar measurement of site (Solargis, 2018).

Parameter	Daily yields (kWh/m^2 per day)	Annual yields (kWh/m^2 per year)
GHI	5.315	1936
DNI	3.748	1286
DIF	2.542	978
GTI	5.384	1961
Parameter	Daily yields	Annual yields
OPTA	11° / 180°	11° / 180°
TEMP	62.1 $^{\circ}$F	66.6 $^{\circ}$F
ELE	1248m	1248m
Parameter	Daily yields (kWh/kWp per day)	Annual yields (kWh/kWp per year)
PV out	4.236	1546

3. Energy distribution

Cameroon has approximately 24 million people and a GDP per capita of about 1250 USD. However the nationwide access of electricity in 2015 amounted to just 55%, with rural regions as low as 20% of access to electricity distribution. Cameroon is second with the most abundant hydroelectric power potential on the African continent. Hydropower contributes more than two-thirds of its total energy production. Due to regular water level fluctuations especially during the dry seasons as one major disadvantage of hydropower in Cameroon, energy officials managed to develop a policy that would make solar energy as a backup for hydro allowing both renewable energy resources to, greatly accelerate excess annual production of electricity. By combining hydro and solar resources together, Cameroon energy and utility company ENEO aims to increase the share of national renewable energy that would satisfy the electricity demands of households and commercial sectors across the nation by making sure different homes are energy self- sufficient irrespective of regions (Solar Plaza, 2016, 24).

Cameroon has very favorable solar conditions for PV system especially in the northern regions where the irradiation can reach up to 5.8 kWh/m^2/day. Electricity consumption per capital in 2015 stood around 278 kWh, which implies approximately 24.000.000 * 278 kWh (6,672TWh) with renewable electricity representing about 73.4% of total electricity output being sourced from the countries four main hydro power plants. However, due to the country's high dependence on hydro energy whereas the hydro stations face regular problem of water level variations, makes the nation electricity demand to be affected severely especially during the dry seasons when the water levels are not sufficient enough to deliver the expected electricity output needed by all sectors nationwide. The variation in water levels being a major challenging factor posed by hydropower plants across Cameroon, has gradually pushed the ministry of energy, rural electrification agencies, and other energy stakeholders to start considering the vast potential of solar resources. Considering solar resource is able to generate sufficient amount of energy annually in Cameroon most especially in the northern regions where irradiation is quite stronger. The shift to solar photovoltaics has been an important topic for the Cameroonian energy sectors as a way to also uphold the value and safety of the environment, and to mitigate the effects that burning fossil fuels has caused the nations that is by influencing different health challenges and leading to high cost of compensation and adaptation.

After hydro, oil represents about 19.1% of the total electricity production in Cameroon. However, some continuous efforts are underway to decarbonize the energy sectors, which mean trying to replace all conventional energy sources with completely renewables and so far hydro and solar are the most cost efficient alternatives when compared to wind turbines. Local residence and small-scale businesses are able to afford energy from solar resources by using rooftop solar panels or depending on medium sized solar systems like the case of an APV plant in order to have good access to clean and sustainable electricity with constant flow and cost efficient when compared to the national grid electricity tariffs.

3.1 Share of total annual electricity production

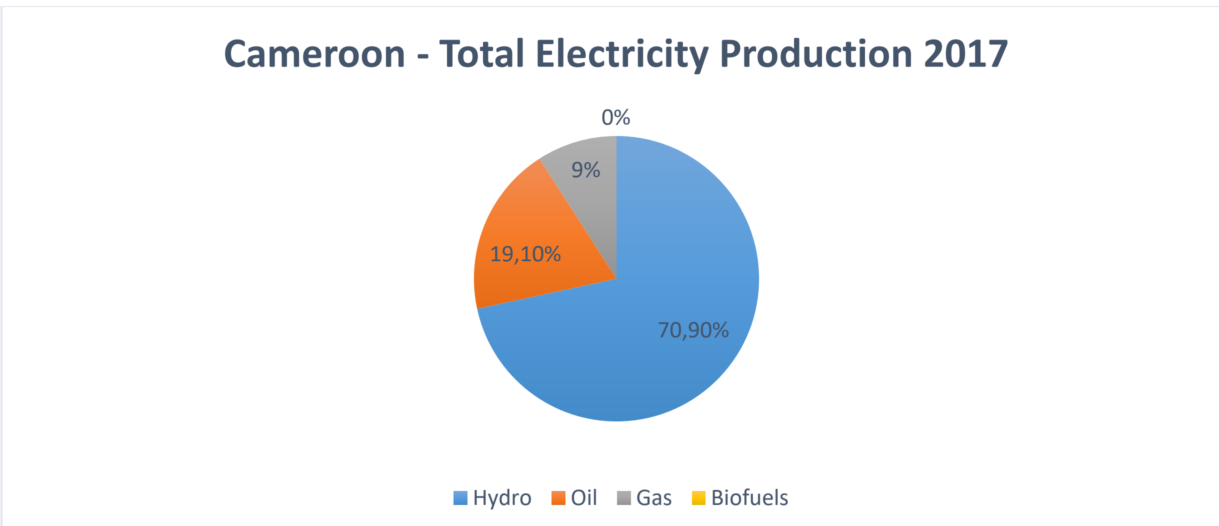


Figure 6: Cameroon total electricity production 2017 (Solar plaza, 2018, 25)

Though Cameroon is rich in forest and biofuel residues, it has not properly utilized the biomass resources to generate electricity. The share of biofuels in Cameroon's total electricity production, as seen in Figure 6 was approximately 0% by the year 2017, even though unprocessed wood in large quantity for cooking and traditional heating in homes. This was due to lack of adequate managerial skills and insufficient conversion technology to integrate biomass residues into the overall annual energy production in Cameroon. In addition, no specifications for the share of wind power production mentioned in the national renewable energy action plan or strategy to reach a one hundred percent use of renewable energy in the country. Gas represented about 9% of total electricity production in Cameroon in the year 2017 to contribute in reaching the expected electricity demands (Solar plaza, 2016, 25).

3.2 Share of total annual electricity consumption

The industrial sectors draw more than half of the total annual energy consumption in Cameroon and the economic capital (the city of Douala) of Cameroon has the greatest demand of electricity and energy due to very high concentration of more than 75% of industrial and commercial activities carried out in this region alone. Other commercial sectors also consume more energy in Cameroon and this rate has not been able to satisfy the demands they require annually due to frequent power failures and other major constraint in the electricity sectors in Cameroon. Most large companies still use diesel generators as alternative sources of energy production during power cut-off to support their increasing energy needs.

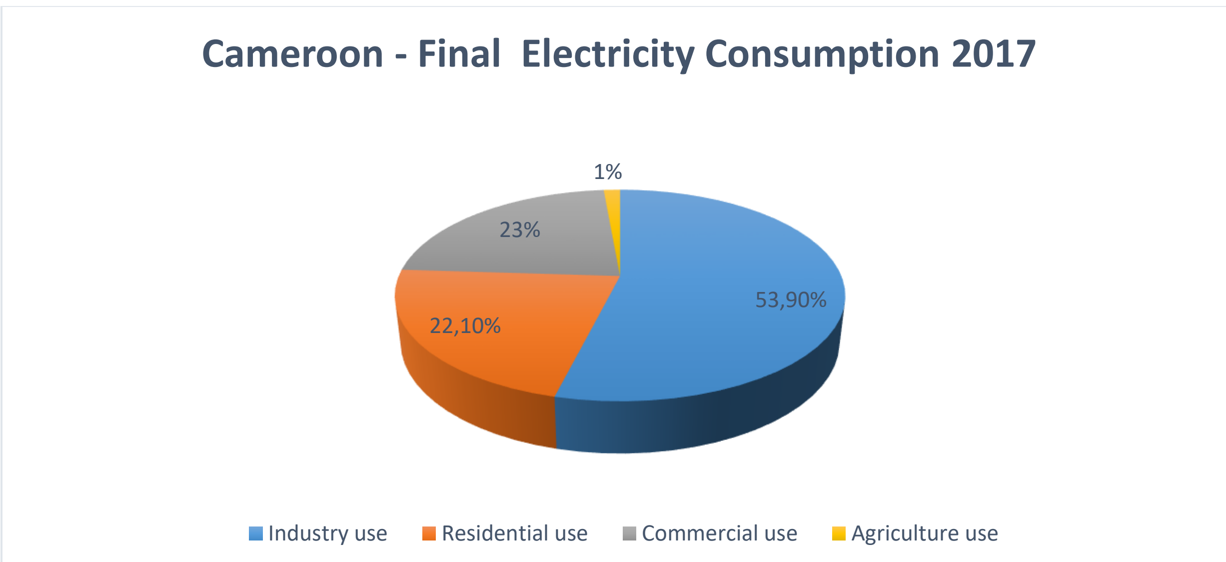


Figure 7: Cameroon final electricity consumption 2017 (Solar plaza, 2018, 25).

To satisfy these demands and ensures sustainable energy consumption by major industrial firms and companies in Cameroon, solar photovoltaics systems stand out to enable some savings on the amount of money spent on electricity bills. In addition, this will also lower dependence on burning diesel fuels as a means to reduce emission concentration on the atmosphere, toxic chemicals and pollution that burning diesel may cause to the environment, plants and animals. Though about 46% of Cameroon's economy is, based on agricultural activities, only about 1% of energy is, used by this sector across the nation. Most farming activities are, done locally and this has led to very low electricity demand by the sector, which employs many Cameroonians and have supported the high food demand.

3.3 Energy efficiency

This is the goal to reduce the amount of energy required to satisfy a particular demand by consumers in various energy sectors. This study takes into consideration the provision of lighting systems for areas such as poultry, and most residential units using LEDs and fluorescent lamps which are still capable to produce the required amount of illumination needed even though with relatively low consumption rate. By laying, more emphasis on the reduction of energy used by on-site APV farming equipment and households will lead to the reduction in total monthly electricity bills. By limiting total energy consumption, is an effective way to ensure energy efficiency and lowering emissions. In addition, the case where the energy conversion process is by means of solar photovoltaics, main goal is not on emission reduction but on energy savings such as unwanted high consumption costs, and energy losses, which usually occur due to consumer's inability to operate some of their appliances only during particular periods of a day.

Some energy saving terminology includes:

- Requires changes in energy conversion system
- Requires changes in consumer's habits and behavior
- Time shifting of certain home appliances for use only at particular periods
- Phase-out of inefficient lighting systems
- Net-zero energy buildings (total production slickly equal to total demand)

The international energy agency examines that by ensuring improved energy efficiency systems in buildings, industrial processes and transportation could drop the world's energy needs in 2050 by one third, and help control the recurring effects of global emissions of greenhouse gases. One important solution is to eliminate government-led energy subsidies the enable over production and high energy consumption (inefficient) energy use in more than half of the countries in the world where there have been increasing energy demand but affordable through some subsidies. Therefore, energy efficiency and renewable energy such as solar are to be the main pillars of sustainable energy policy. By efficiently using energy, most countries will lower their level of energy imports from foreign countries and will slow down the depletion of domestic energy resources as consumer's habits on energy demand has changed positively (IEA, 2011).

4. Solar PV system sizing and PV solutions

In order to size a solar system for any kind of application, the first thing to consider is the energy demand (electricity needed) by the consumer. By identifying the total number of household equipment such as lighting points, refrigerators, electric iron, heating elements, electric fans, basic electronic appliances such as televisions, computers and more. In addition, taking into account the total daily consumption time for each of these units, makes it more realistic and easier to determine very precise energy estimation for the consumer (household) where energy is required. This estimation is, based on energy demand for an average household in Cameroon and particularly in the case study region for this APV power plant.

The electricity consumption may vary between different homes depending on the types of equipment and the operating duration in used by the subscribers, and then based on the electrical equipment rated values (power, current and voltage). However, based on research purpose, the calculation of total energy consumption of a household as it is the case in this exercise, takes into consideration the situation for an average home with just the most commonly used electrical appliances listed in Table 3. During the peak sun hours of a day, about 60--80 % of these appliances are not consuming any power from the solar system because most energy users are out of homes during day times for work or to carry out some other daily activities and less energy is being used between 10.00am and about 4.00pm

However, storage systems by the use of batteries are then utilized properly to store the relevant amount of energy that can be needed later during the nights when production capacity from the solar power plant drops significantly, and not able to generate the required amount of electricity that would satisfy consumer needs by powering their various appliances. In Cameroon, electricity for lighting is often between 5.00pm and 11.00pm when most people stay awake to use lights for various purposes. Due to high electricity bills from national grid, most highly rated equipment such as electric irons, vacuum cleaners, blenders, and more are used only occasionally with the aim to save energy cost and keep electricity bill lower. This practice in return, also ensure energy efficiency of systems and present little stress and loses on the power plant or main grid; a process generally described as demand response which mean balancing consumption and production to keep power systems more efficient and resilient.

4.1 Estimated yearly average energy consumption of a household

Household equipment and their operating modes based on annual energy consumption as used in determining the actual size for the APV solar system project size and total energy demands based on peak production month only and time when water irrigation is highly needed by the farmers. This estimation based on a typical household where the consumer demands energy as follows:

Table 3: Estimated yearly average energy consumption of a household in Cameroon

Appliances	Rated power (W)	Operating time daily (hours)	Length of use (yearly)	Number of appliances	Annual Energy consumption (kWh)
Fluorescent lamps	32	7	365 days	5	408.8
LEDs lamp	24	6	365 days	3	157.7
Electric iron	1000	1	Weekly	1	52
Electric fan	75	6	~ 5 months	1	67.5
Television	150	8	365 days	1	438
Blender	600	0.25	3 days weekly	1	23.4
Refrigerator	120	12	365 days continuously	1	525.6
Freezer	150	12	365 days continuously	1	657
Microwave	1200	0.25	365 days	1	109.5
Vacuum cleaner	1400	0.5	365 days	1	225.5
Computer	100	12	365 days	1	438
Phone charger	5	10	365 days	2	36.5
Electric Shaver	15	0.5	weekly	2	0.78
Miscellaneous units	300	5	weekly	2	156
Total	-	-	-	-	**3295**

Table 3 simply presents the estimated annual energy consumption by a household in Cameroon with approximately 5–6 persons per home. About eight lighting points, refrigerator, freezer, and other electrical and electronic equipment in regular use. From this estimation, the monthly energy consumption of a household can be, calculated as follows:

- Estimated annual energy consumption per household = 3295 kWh
- Estimated monthly average energy consumption per household = 275 kWh
- Estimated daily average energy consumption per household = 9 kWh

4.2 Estimated yearly energy consumption by farm equipment

A piece land measuring about 52.9m * 40m is used for growing crops, beneath the PV arrays, where the farmer intends to grow mainly vegetables such as carrots, tomatoes, cabbage, potatoes and also the keep poultry and other animals on same field. Considering the plot is isolated from main grid, and following his intention to engage in a renewable energy project. He then considers solar to be of great advantage due to high solar irradiation. By identifying, the various equipment for his farm and their rated power enabled the actual sizing of the solar system based on total, energy demand per equipment per year such as water pumps, refrigerators and LEDs lighting.

Table 4: Estimated yearly energy consumption by APV farm equipment in region

Appliances	Rated power (w)	Operating time daily (hours)	Length of use (yearly)	Number of appliances	Annual Energy consumption (kWh)
Irrigation pumps	1492	2	~ 5 months	4	1790.4
Commercial refrigerator	672	18	~ 4 months	1300L x 8	11612.2
LED Poultry Lighting	10	24	365 days	30	2628
LED Horse barn lighting	80	18	365 days	10	5256
Miscellaneous	100	10	~ 6 months	3	540
Total	-	-	-	-	**21826**

Table 4 clearly states details of energy consumption by different on-site farming equipment that make up an APV system with reference to the chosen region in Cameroon. Estimating the amount of energy for large commercial refrigerators, pumping system for water irrigation, estimated energy for LEDs lighting to power the poultry room and lighting for other animals, also taking into account unforeseen (miscellaneous) estimated energy which could be reserved for other daily operations, within the farm, makes the sizing of the PV system easier.

The table presents values for suitable equipment needed to reach the sustainability requirement of an APV project. Considering the APV project is strictly, recommended in hot and dry regions, the need to irrigate water into the farmland is an important factor to keep the soil fertile and productive for agricultural yields throughout the farming season.

To ensure efficient farming where the sustainability issues will be met and capable to support the farmers and customer needs, all important aspect of the APV plant must be taken into consideration such as using the right equipment with the actual standard. This mean rated power of refrigerators, water pump calibration for irrigation purposes, LED lighting types and their recommended properties for poultry farming are as well major issues to consider in order to, prevent any hazard that can be, caused by poor illumination of the poultry rooms (Sinoled, 2010).

Therefore, the estimated monthly average consumption by the plant's on-site equipment during peak demand of energy is as follows:

Estimated annual energy consumption by on-site farming equipment = 21826 kWh

Estimated monthly average energy consumption by on-site farming equipment = 1818 kWh

Estimated daily average energy consumption by on-site farming appliances = 60 kWh.

The monthly energy consumption is an average values based on peak production and peak demand periods only. The energy demand changes from seasons to seasons due to less energy needed for irrigation pumps in the rainy seasons. Similarly, less energy is required for storage refrigerators when the weather condition is cold compared to the dry seasons. However, in this case each season presents slightly different electricity demands. Due to technical reasons, these calculations are, based on the season when energy is, needed the most.

Based on these estimations, the consumption ratio between a single household and the farm which include equipment such as commercial refrigerators, LEDs lights, irrigation pumps operated within the farm to either consume energy for storage of vegetables, or lighting of poultry units, or for pumping of water (irrigation) to the farmland is approximately in the order of 1:6. This implies the on-site farming appliances consume electrical energy about six times more compared to an average household in the region.

These calculations are, based on standard values and rating of various electrical equipment deemed suitable for these applications, based on their energy efficient settings, sustainability regulations and considered extremely convenient for use to form an APV system for farmers. An average household consumes about 9 kWh of energy per day. Meanwhile for the on-site farming equipment, it is, estimated that total energy consumption is around 60 kWh per day that the APV plant is capable to provide to meet the stated demands.

However, to size the PV system mean taking into account total number of neighboring households requiring electric power daily to be fed by the APV plant. After determining the total number of homes for which each is, assumed to consume about 9 kWh of energy per day, it is hence possible to do the actual sizing of the APV solar power plant based on total number of homes and total daily energy demand by all these households and then the on-site appliances.

Assuming that about eighty households nearby the APV project demands electrical energy from the power plant on a regular monthly subscription deal and tariff that means total daily consumption by 80 homes is around: 9 kWh/day per home * 80 homes = 720 kWh per day. This covers just the household appliances for about 80 homes around the solar plant.

Total daily consumption by all households plus on-site farming appliances is therefore, calculated as follows: 720 kWh per day + 60 kWh per day = 780 kWh per day.

Combined (farm + homes) Annual average energy consumption is, given by

AE= 780 kWh/day * 365 days/year = 284700 kWh/year

4.3.1 Battery specification and sizing

Energy storage is strictly required in most stand-alone solar systems, as energy production and consumption do not often match. Solar power generated during the day is usually not required until evening when most household equipment start to run, and therefore has to be temporarily stored for usage during peak demand periods. Most stand-alone solar systems have batteries. An exception may be solar water pumping systems where the water can be, pumped even during the daytime when the solar power is available due to sufficient sunlight. For water pumping systems, batteries are not very much required to store the solar power generated, since the water can be, pumped at same time into the required areas when the solar power is being produced (DGS LV 2013, 149). The type of battery used in this solar PV systems, is the rechargeable Lithium ion batteries. These are sustainable, effective and can handle large and small charging currents with high efficiency and high depth of discharge.

Table 5: Temperature Multiplier Coefficient (Sunelco.com).

Fahrenheit (˚F)	Celsius (˚C)	Multiplier Coefficient
80	26.0	1.00
70	21.2	1.04
60	15.6	1.11
50	**10.0**	**1.19**
40	4.4	1.30
30	-1.1	1.40
20	-6.7	1.59

In this study, the 12V 300Ah deep cycle Lithium ion battery is use, as it appears to be safer than lead acid battery even though lead acid batteries are cost efficient compared to Lithium ion. The Lithium ion batteries are lighter in weight and more compact than lead acid batteries. They also have a slightly higher depth of discharge (DoD) and longer lifespan when compared to lead acid batteries. Lithium ion batteries are green and non-hazardous, with about 30% more energy density in the small size cases. This are about 99.9% efficient, capable to provide over 100% usable energy of the rated capacity, also lose only less than 1% per month self-discharge (Lithiumion, 2018).

The temperature multiplier selected to determine the actual size for the battery in Ah, is 1.19 at the temperature of 10.0 °C as seen in Table 5. In this study, we consider a depth of discharge (DoD) for the lithium ion battery of 80% and a DC system voltage of 48V. Also the days of autonomy (DOA) which is defined as the amount of days the system can operate on battery power alone without any input power from the APV solar plant is considered to be 2 days. Average daily energy consumption for both on-site farming equipment and the total number of households requiring energy from the APV solar system stand at 780 kWh per day. If the energy demand drops, then the battery storage shouldn't be affected due to the fact that the rate of discharge, shouldn't hinder performance which is expected to work even at full load when all the system equipment become operational according to the design requirements of the solar system.

From these specifications, the battery storage capacity can, be evaluated based on the given parameters as seen above. In order not to exhaust the batteries by fully discharging it, the storage capacity can, be doubled in order to support the total energy demand of the consumers, which depends on how much the solar system can produce at any given time also considering that depth of discharge is around 80% only.

$$\text{Battery Size (Ah)} = \frac{\text{Total daily energy(Wh)} * \text{days of autonomy} * \text{multiplier effect}}{\text{depth of discharge} * \text{DC system voltage}} \tag{4.1}$$

Battery system capacity: 48343 Ah

Single bank: Two parallel set of four serial batteries in each set that forms a synergy of total voltage of 48v, and 600Ah is capacity per bank. This implies, about 24 banks of eight batteries per bank is needed to satisfy the energy storage for this APV solar system. The HOMER software is however capable to model the battery based on the amount of electricity that can be stored and hence showing the cost and quantity curve needed to satisfy the demands by consumers. The batteries are however considered to function normally through their life cycles, provided the discharge rate is not, altered as the specification stipulates. Main properties of the battery are the nominal capacity, life span, capacity curve and DoD and its efficiency.

4.3.2 Battery storage inputs

The equation (4.2) below explains the approach used in determining the battery size by taking into consideration the following variables. Knowing the total daily energy demand, number of autonomous days, temperature multiplier coefficient, depth of discharge and the DC system voltage led to the realization of the battery size suitable for use in the APV solar system. In this study, the Lithium ion battery fulfills the sustainability and technical needs that that makes the battery a perfect choice to store the energy produced daily on the solar farm intended for use during evening and nights when the solar condition has dropped on a typical sunny day. The HOMER software was able to generate the costs curve after the battery systems costs was introduced to the software and the replacement costs as well

$$\text{Battery Size (Ah)} = \frac{\text{Total daily energy(Wh)} * \text{days of autonomy} * \text{multiplier effect}}{\text{depth of discharge} * \text{DC system voltage}} \quad (4.2)$$

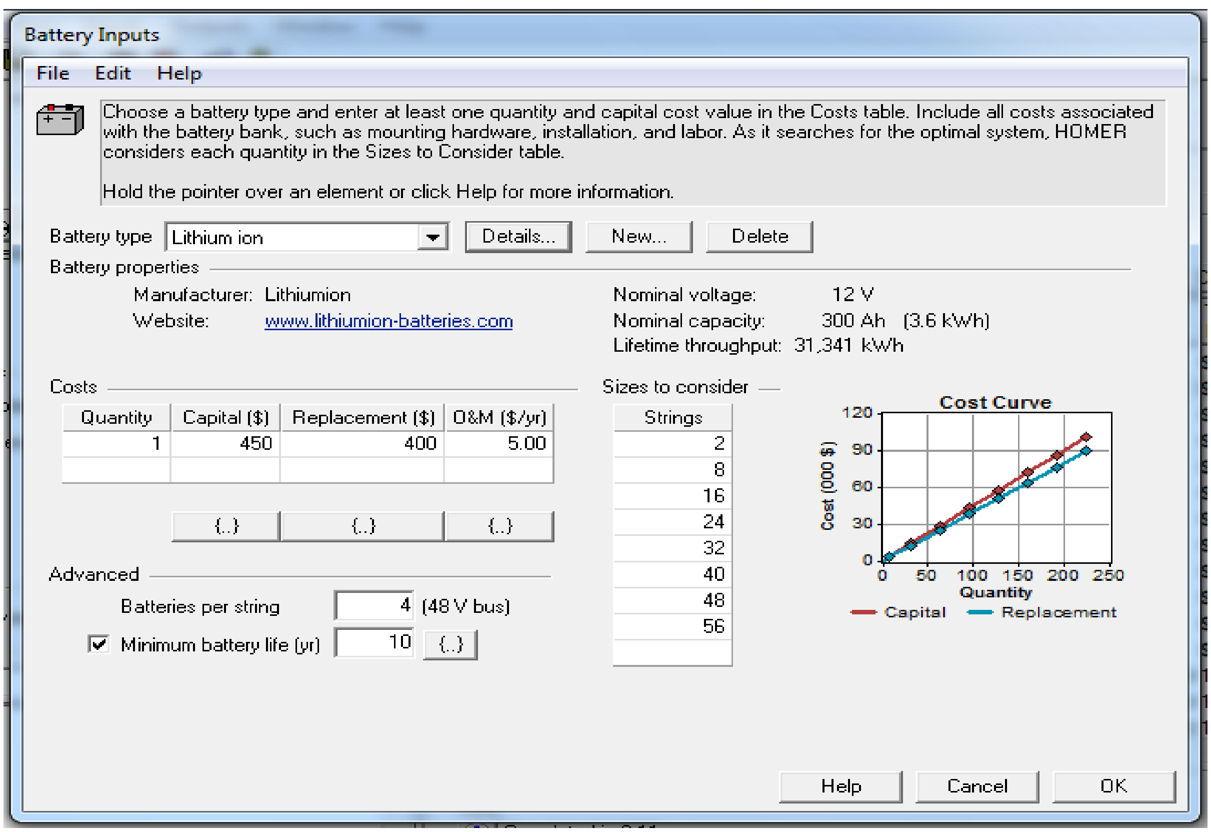


Figure 8: Battery input and costs curve

The battery details for a Lithium ion battery storage are, generated and shown in Figure 9 such as the curves variation between the battery capacity in (Ah) and the discharge current in (A). The curves show the maximum capacity that a single battery is able to support during any charging cycle when the solar energy produced is sufficiently higher during a sunny day. However, the more the battery depth of discharge is increased, the shorter its lifespan becomes. Therefore, for the Lithium battery, a convenient discharge rate of 60–80% is, considered safer for the battery with a round trip efficiency of about 99.9%. The battery lifespan is, estimated between 10–15 years if the discharge rate is, strictly respected and not allowing the battery to be, drained completely by any load after it has been, fully charged.

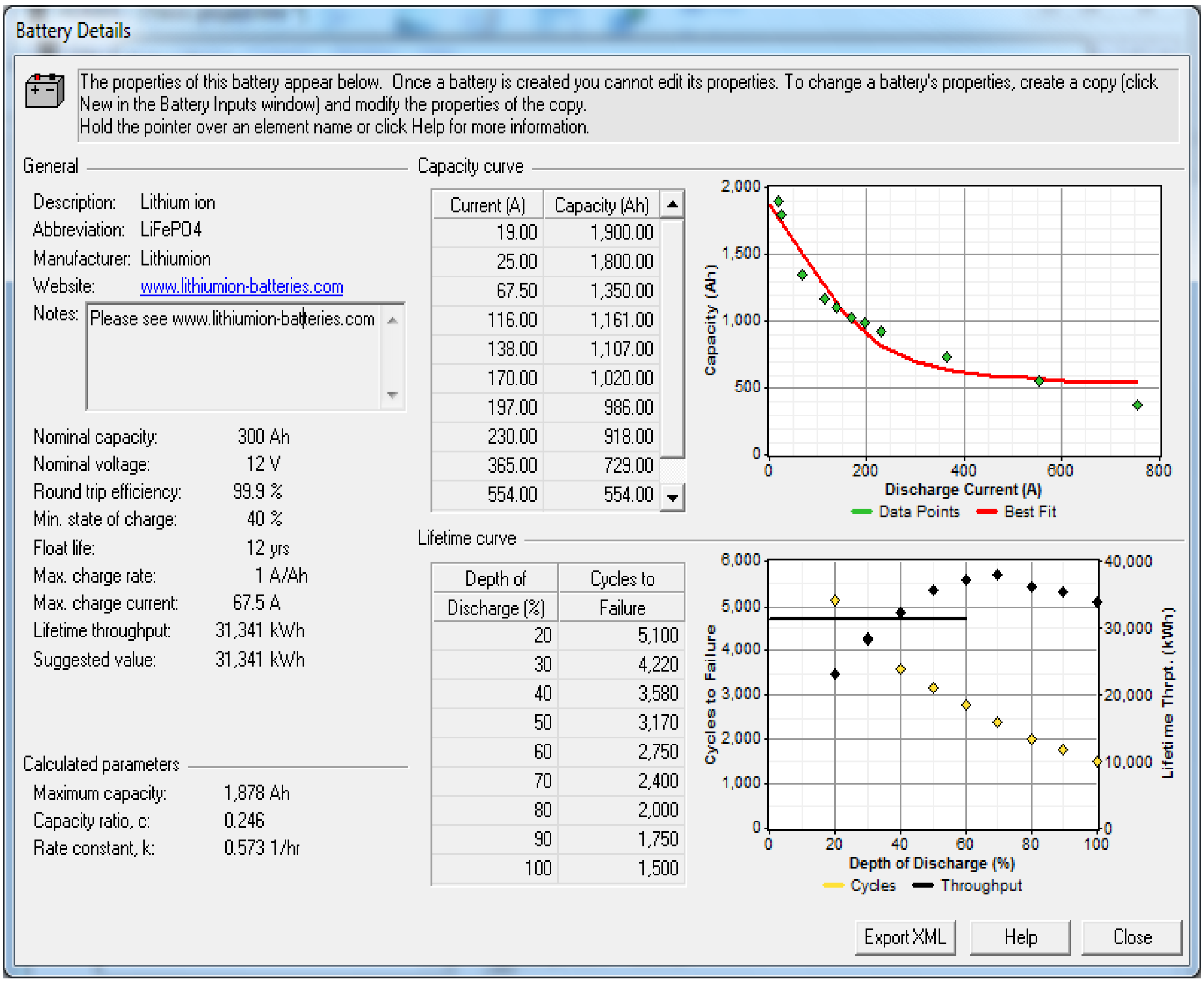


Figure 9: Capacity curve and lifetime curve of the modelled battery

4.3.3 Battery Simulation

The battery simulation results for the 156 kW PV system as deduced by the HOMER software is, described in Figure 10. The battery state of charge lies between 40–100% and seen on the frequency histogram of the battery banks. The levelized cost of energy (LCOE) as utilized by the battery storage system is around $0.068/kWh, annual operating cost of $10,397/year. This system requires about 160kW inverter and rectifier each to ensure the smooth operation of the solar APV project. The average energy cost for storage is as low as $0.009/kWh, which makes this system really cost efficient.

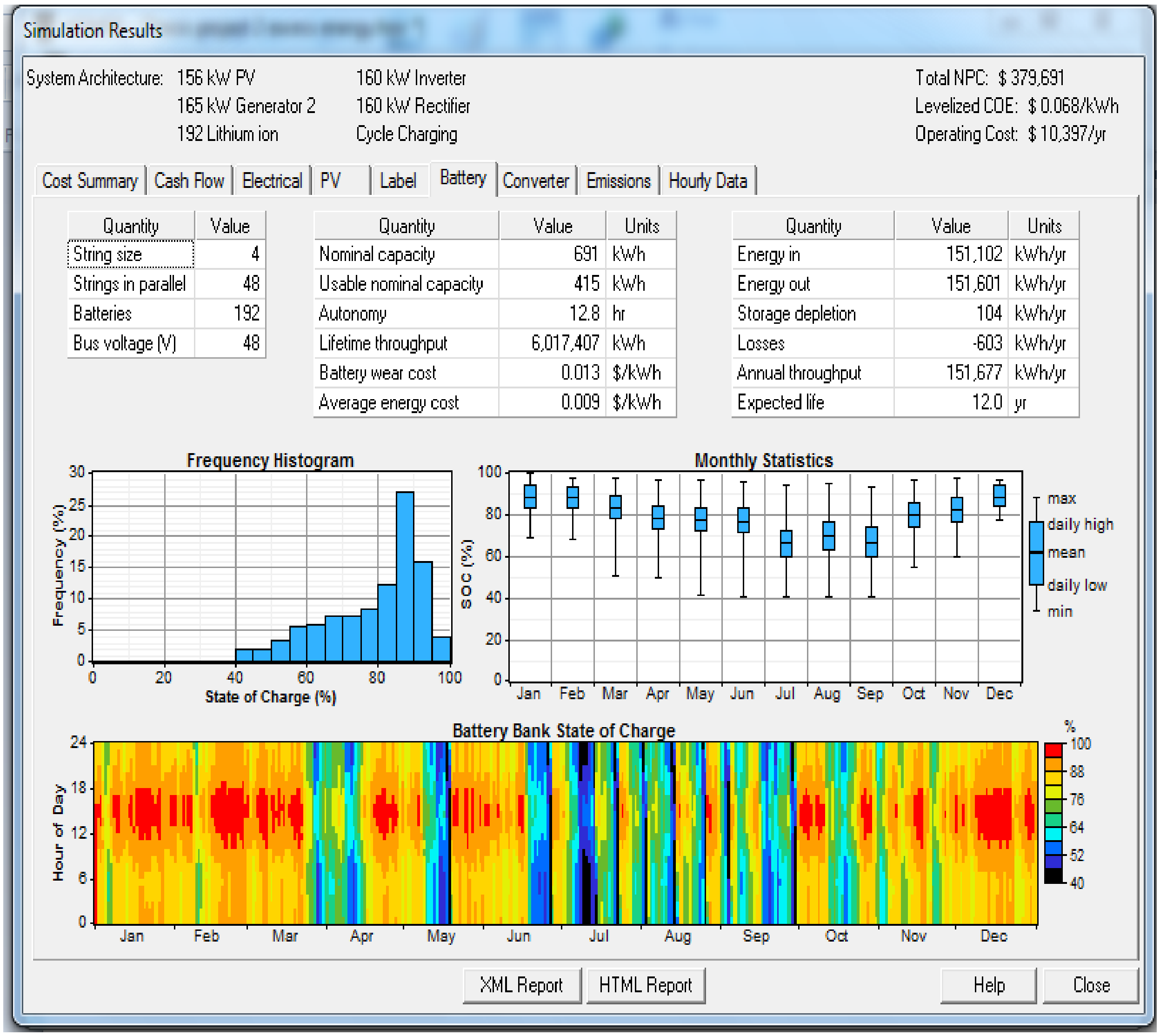


Figure 10: Battery simulation results

4.5 Polycrystalline silicon solar cell (p-Si)

The polycrystalline solar cell, for the production of solar modules is a low cost manufacturing product that has been distributed in recent times and capable of supporting the increasing solar energy demands of diverse customers across the globe. This product presents some important characteristics as seen in Table 6 and with this features, these solar panels are able to generate the required solar power under normal operating conditions. Suitable for application in multiple domain including solar farming. In this study, the polycrystalline silicon solar cell is, deemed very suitable for an APV plant as it is, characterized by some properties among which include the following points:

- Low cost (US $0.32–0.36 / watt) ~ $360 / kW of solar panels
- Large annual production capacity
- Wastes from silicon is less, compared to monocrystalline.
- Solid and light weighted product

Table 6: Polycrystalline silicon solar panels characteristics (Solar reviews 2018).

Parameters	**Values**
Maximum power at STC	250 W
Maximum power current (I_{mpp})	8.20 A
Maximum power voltage (V_{mp})	30.8 V
Short circuit current (I_{sc})	8.85 A
Open circuit voltage (V_{oc})	37.7 V
Cell efficiency	17.40%
Module efficiency	15.74%
Power tolerance	0 ~ + 3%
Dimension (A*B*C)	1640 * 990 * 40 mm
Polycrystalline Silicon	Si
Number of cells (6 * 10)	60 pcs
Junction box	IP67

The raw material polysilicon is, melted in quartz crucible, doped with boron and poured into a rectangular shape to form the cells. By means of controlled heating and cooling, the cast blocks cools evenly in one direction. The purpose of this directed solidification is to form large numbers of largest possible homogeneous silicon crystals, with grain sizes from a few millimeters to several centimeters. Usual sizes in centimeters are as follows: 10 * 10; 12.5*12.5; 15*15; 15.6*15.6 and then 21*21 (4 inch, 5 inch; 6 inch, 6+ inch; and 8 inch). However, the block casting process forms crystals with different orientations because the light is reflected differently (DGS LV 2013, 33).

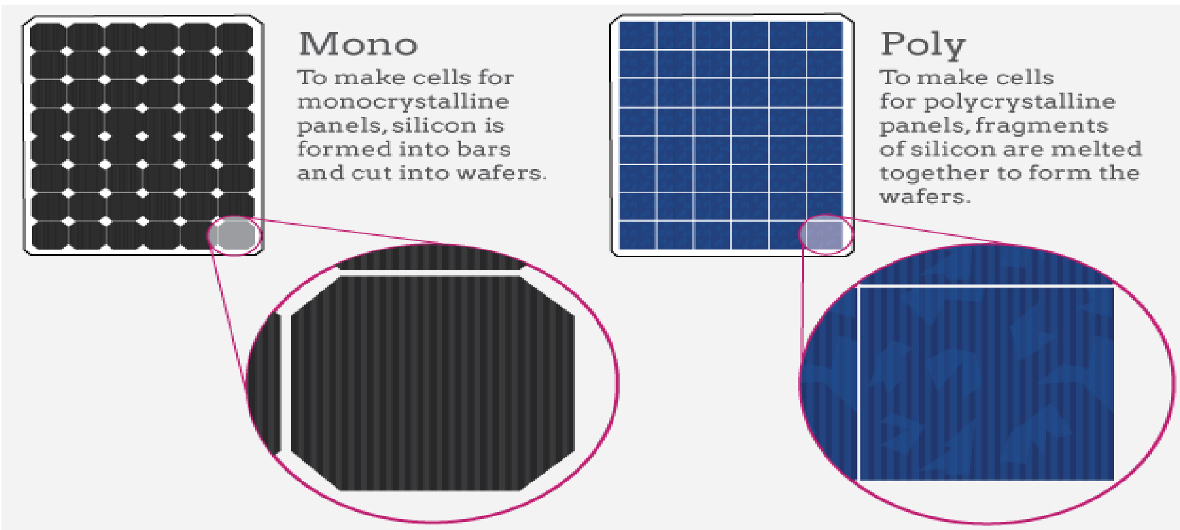


Figure 11: Comparing mono and poly crystal silicon cells (DGS LV 2013, 33)

The monocrystalline silicon has slickly higher efficiency than polycrystalline cells, but due to high production costs, it is profitable for economic reasons to use the polycrystalline cells, which also requires a simpler manufacturing process and have lower costs. Mass production is simple and requires less time to achieve them. Flexible in nature and opens up many new potential applications in the solar energy markets. With this solar panel type, it is clearly profitable to use it in large solar systems, which require higher capital or investment costs such that the payback time can be, reduced as much as possible due to low investment cost than in monocrystalline solar panels designated for the same purpose to generate power.

4.6 Solar PV inputs

The HOMER configuration window illustrated in Figure 12 is, used to indicate the selected PV panels for this study and project with its specifications such as the panel efficiency, normal operating cell temperature (NOCT), and the temperature coefficient of the power. Moreover, the directions and the orientation of the PV panels/arrays are, specified using the slope and azimuth properties. In this project, the orientation of the PV panels defined by the slope was, kept at 10.98° obtained by considering the latitude and longitude coordinates of the chosen project location in Cameroon. The direction where the panels are facing is specified by the azimuth angle and due south is 0°, due east is -90°, due west is 90° and due north is 180°.

HOMER also performs both technical and economic simulations which searches for the optimal system and in this window, is also defined the cost curve of the PV panels, replacement costs, as well as the O&M costs for the solar photovoltaics panel. For this project, the initial capital cost of the PV panel is given by $360, replacement costs at $320 and an estimated annual operating and maintenance costs of PV panels is given by $5 (Solar panels, 2018).

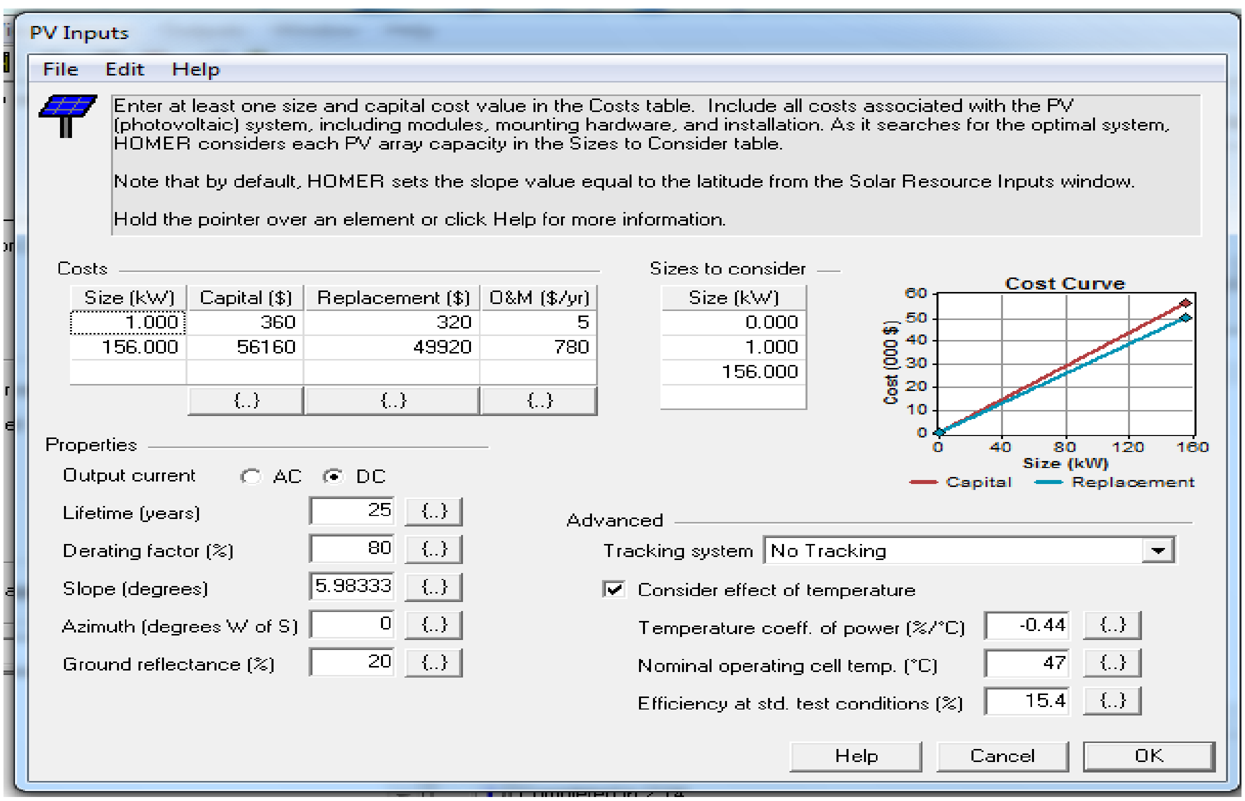


Figure 12: PV inputs window and costs curve.

4.7. Inverter specification

The solar inverter is the link between the PV array and the AC grid or AC loads. However, the inverter's main task is to convert the solar DC (direct current) electricity generated by the PV array into AC (alternating current) electricity and ensuring that this is up to the frequency and voltage level of the building's electrical system. In this study, the main application area is the stand-alone system where the electric power produced, by the solar PV arrays is, instantly converted and fed into the load or stored in batteries for use at the relevant time of demand. This off-grid solar system main components are; solar PV modules, Battery storage, inverters, generator arranged in a way that the inverter acts as the grid ensuring that the battery is charged accordingly to fulfill the needs. The off grid solar inverter's operations include the following:

- Charges the batteries and transforms the DC from the battery to AC that powers the electronic devices (loads).
- Adjustment of the inverter's operating point to the MPP of the PV modules (MPP tracking)
- Recording of the operating data and signaling (display, data storage and data transfer)
- Establishment of DC and AC protective devices (ensuring incorrect polarity protection, overvoltage and overloading protection)

One important requirement for inverters is that the voltage must match the battery bank for which the inverter is, designed to work on. The inverter is the central equipment in any solar PV system and expected to have very high reliability to ensure smooth link between the arrays and the battery systems for which it is, designed to handle. In this study, the pure sine wave inverter is, recommended due its high reliability and efficiency. However, solar inverters require a charge controller in-built system, which helps to keep the batteries from overcharging. This unit regulates the voltage and current coming from the solar panels going to the battery. The main purpose for this is to keep the battery safe and extending its lifespan as it turns to work less due to the charge controller unit usually built in the inverter circuit. Approximately 16–18 pieces of the inverters as specified in Table 7 are, needed to satisfy a solar power system with 156 kW capacity, considering a situation whereby the rated power per inverter is, around 10 kW for the solar system designed to satisfy the energy demands of the end users.

4.7.1 SMA Sunny Island.

The sunny island 4548 US provides efficient, safe and consistent electricity supply in commercial applications such as in agricultural sectors, hotels, supermarkets and schools. However, the inverter drives the efficiency of a solar panel system, since inverters convert direct current into alternating current. This solar PV inverter operates optimally within a predetermined operational window. When the power input to the inverter from the solar panels goes up and down, the inverter's the ability to efficiently convert it from DC electricity to AC electricity differs. Expected lifetime vary between 10–15 years and equipped with monitoring protective devices to instantly signal any abnormal behavior, however maintaining a safe operating mode for all other associated equipment in the solar system topology (SMA, 2018).

Table 7: SMA Sunny island solar PV inverter (SMA, 2018)

Rated power	3kW – 8 kW
Output current	26A
Input voltage	48V
Lifespan	10–15 years
Output waveform	Pure sine wave output
Output frequency	50Hz
Degree of protection	IP65
Display	LCD
Efficiency	96%
Output voltage	0–264.5 V
Type	DC/AC inverter
Output type	Multiple
Application	Solar power system

This inverter has suitable properties for diverse application, including APV project whereby the power precision and sustainability standards are highly expected to ensure proper social and economic fulfilment of the power plant. This product has the ability for higher power yields with efficiency of about 96%, extremely quiet during operation with just about 15 dB of noise. Optimal integrated Ethernet and Wi-Fi communication system. Operated with remote controllers and light weighted, compact design with IP65 casing for outdoor application such as in APV systems.

4.7.2 Inverter inputs

Unlike the battery and solar PV inputs, the inverter configuration window of the HOMER software simply displays the inverters output results when some data such as costs, lifetime and efficiency are, inserted into the software. The cost varies linearly with the size of the inverter, which is, determined by its rated power (kW). In this study, the initial capital cost for inverter vary between $85 and $100 per kW of power of the inverter selected to satisfy the solar system power requirement. And the output must be scaled enough to match the battery capacity for which it is intended to convert DC power from the PV panels to AC power for the load system. Lifetime of 15 years and efficiency of 96% are some important properties of the inverter selected for this solar PV energy scenario in an APV project plant.

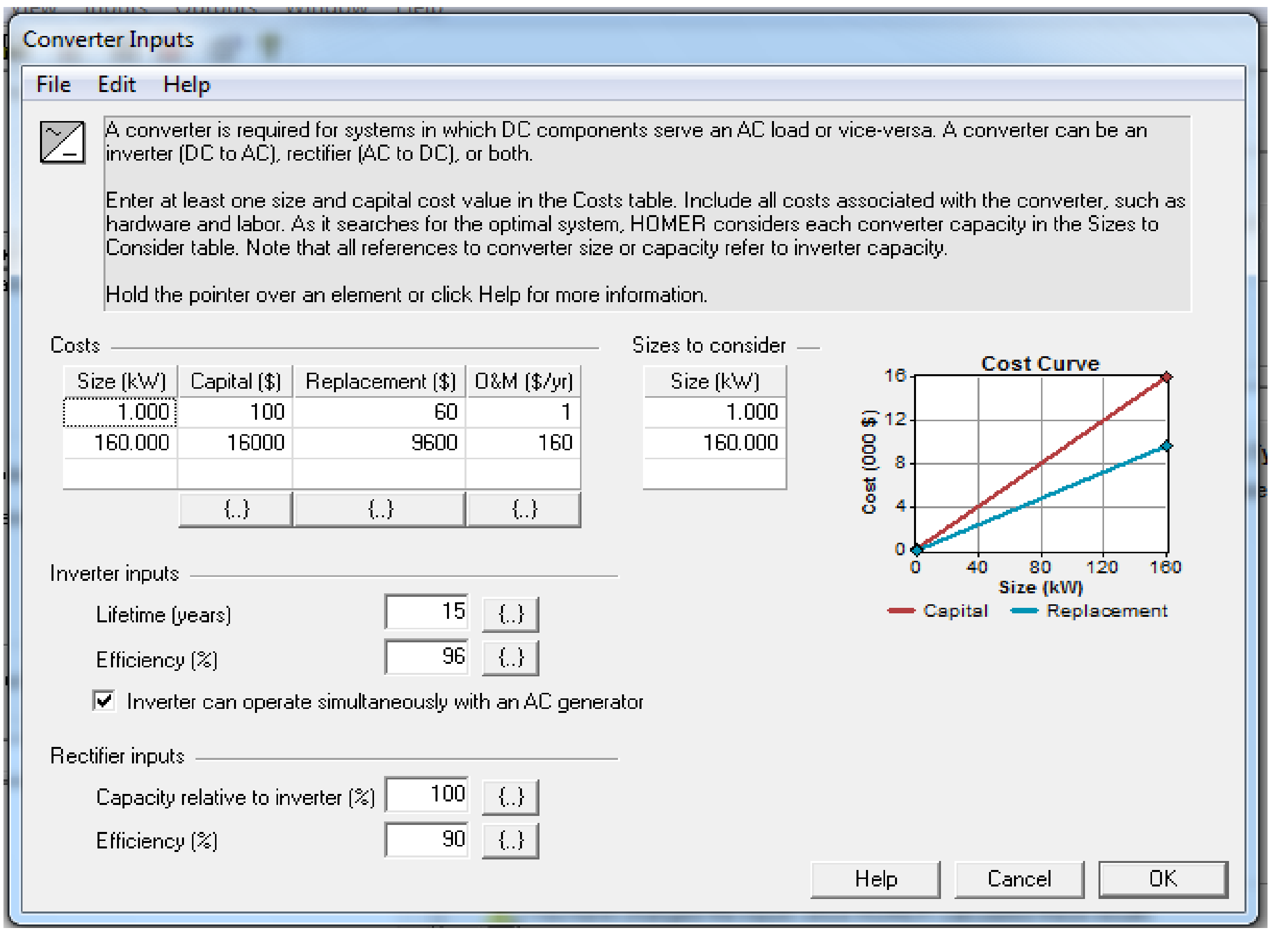


Figure 13: Inverter input and cost curve

4.7.3 Generator Input

The HOMER input window in Figure 14 represents the diesel generator input window of the HOMER software, which simply displays the generators estimated output power rating cost curve respectively. By choosing a generator rated slightly above the size of the solar system makes it possible to obtain a precise result or excess electricity required for the APV solar system. This is required in the system as standby power source with the aim to generate a greater amount of electric power alongside the solar system especially in periods when the insolation is poor (little or no sunshine). In the case study area, the solar system alone is not capable to deliver the total energy needed to satisfy the farmer's needs, energy consumers in the rainy season particularly between the month of June and September when the solar irradiation is falls drastically. The solar system size for this project is 156 kW and due to losses in the generator, the relevant rated power is above the solar system size in order to maintain the smooth operation of the system and ensuring consistency.

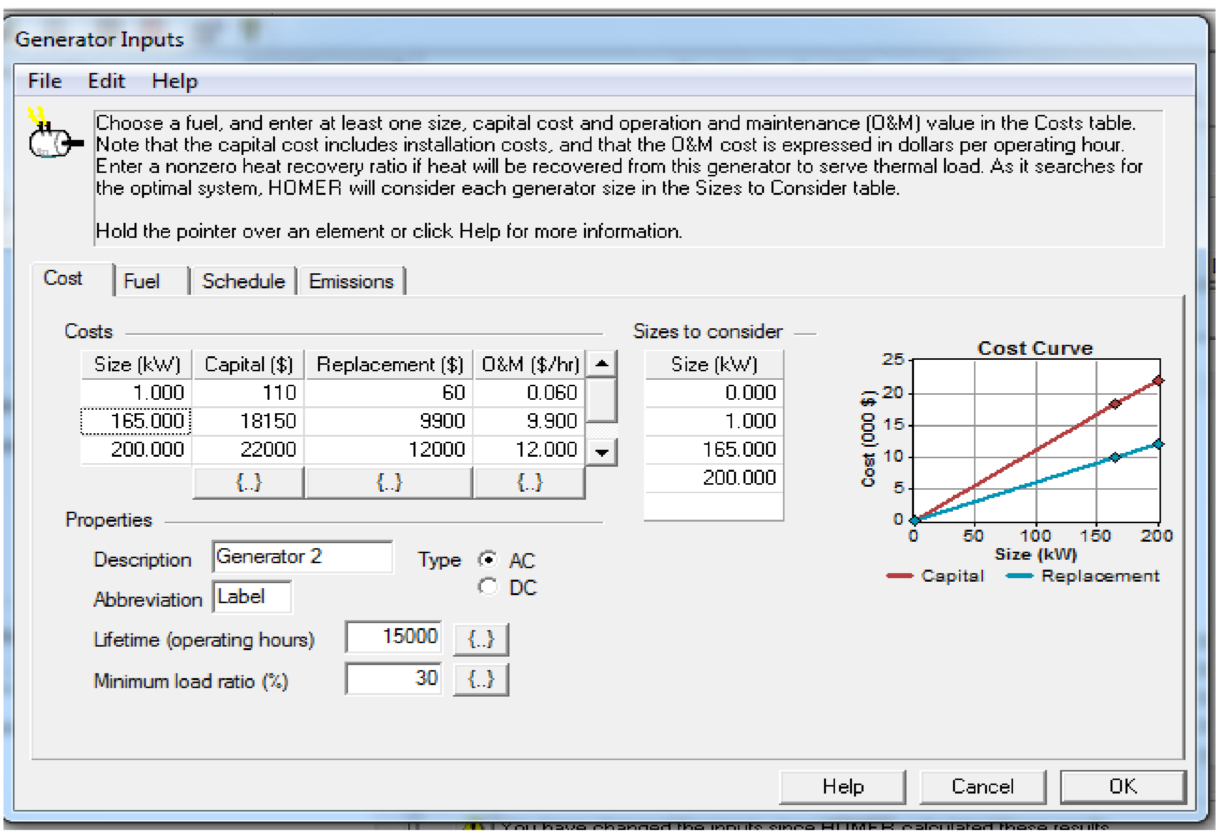


Figure 14: Generator input and cost curve

5. Simulation of daily load profile

In the load's input window, the daily load profile is simulated by the HOMER based on the actual daily power distribution entered into the software. This makes up the total energy demand of a particular day. The consumption scenario varies between different hours of a day from 00.00 am to 11.59 pm. However, the baseline data was obtained from the load profile created for the energy consumption periods of a typical households in Cameroon showing peak consumption period between 6.00pm and 8.00pm, when most residents are back from work and schools and more to start using electricity for different applications most especially lighting, television and cooking. However, in this case HOMER uses the same daily consumption profile for the whole year. Some changes may occur during periods of low insolation but this simulation covers mainly December and January months, which both have higher solar irradiation compared to other months of a particular year or season in Cameroon.

5.1 Primary load inputs

The simulation result in Figure 15 describes the daily load profile of a typical sunny and hot day in the month of January or December with the highest insolation during that year. During different hours of this day, the electricity consumption changes depending on demand by consumers. Between 5.00pm – 8.00pm peak consumption occurs since many consumers turn on their equipment such as lighting appliances and electric cookers.

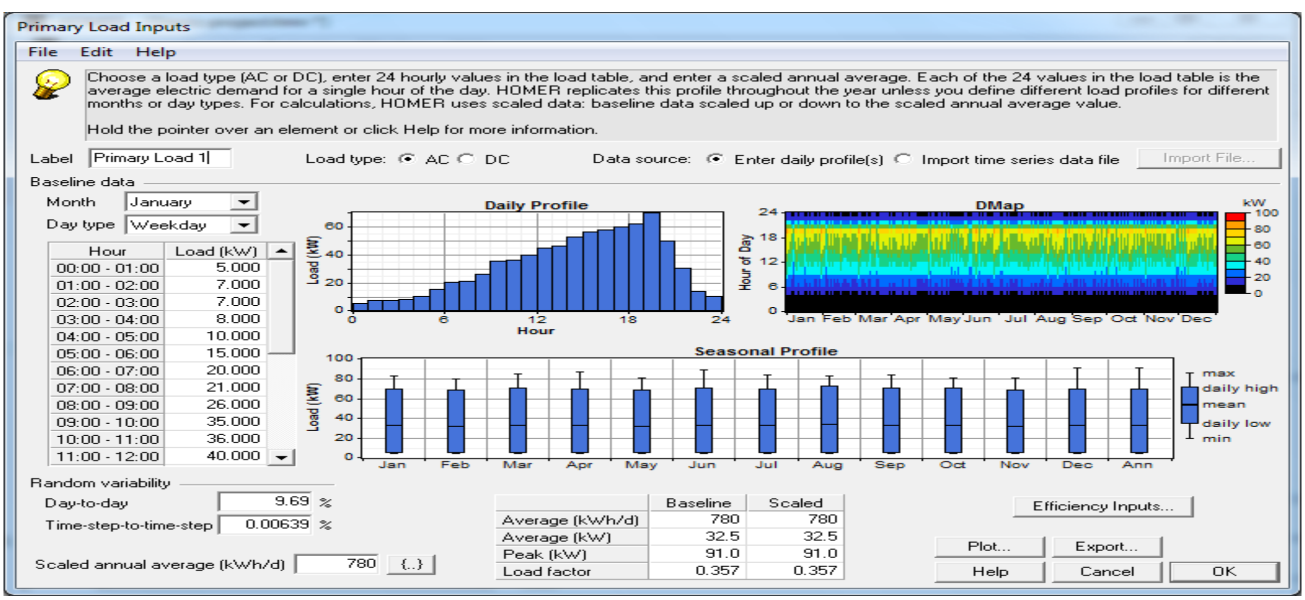


Figure 15: Primary load input and daily load profile

5.1.1 PV Electricity production

The solar PV system size of 156 kW was, inserted as input value into the HOMER in order to calculate the annual PV production in the project location in Cameroon based on the solar irradiation data as earlier calculated by the software. The simulation results are, seen in Figure 16. The simulation results shows that the estimated annual AC primary load consumption is 284,701 kWh/year. The results as illustrated in Figure 16 shows that the PV production for the entire year is 296,156 kWh and clearly states that it is not sufficient to meet the total energy demand by the farm and residential homes requiring electricity for daily use. Therefore, in this situation the generator helps to match the demand in providing extra electric power to the solar system with peak production in January and August with weaker insolation.

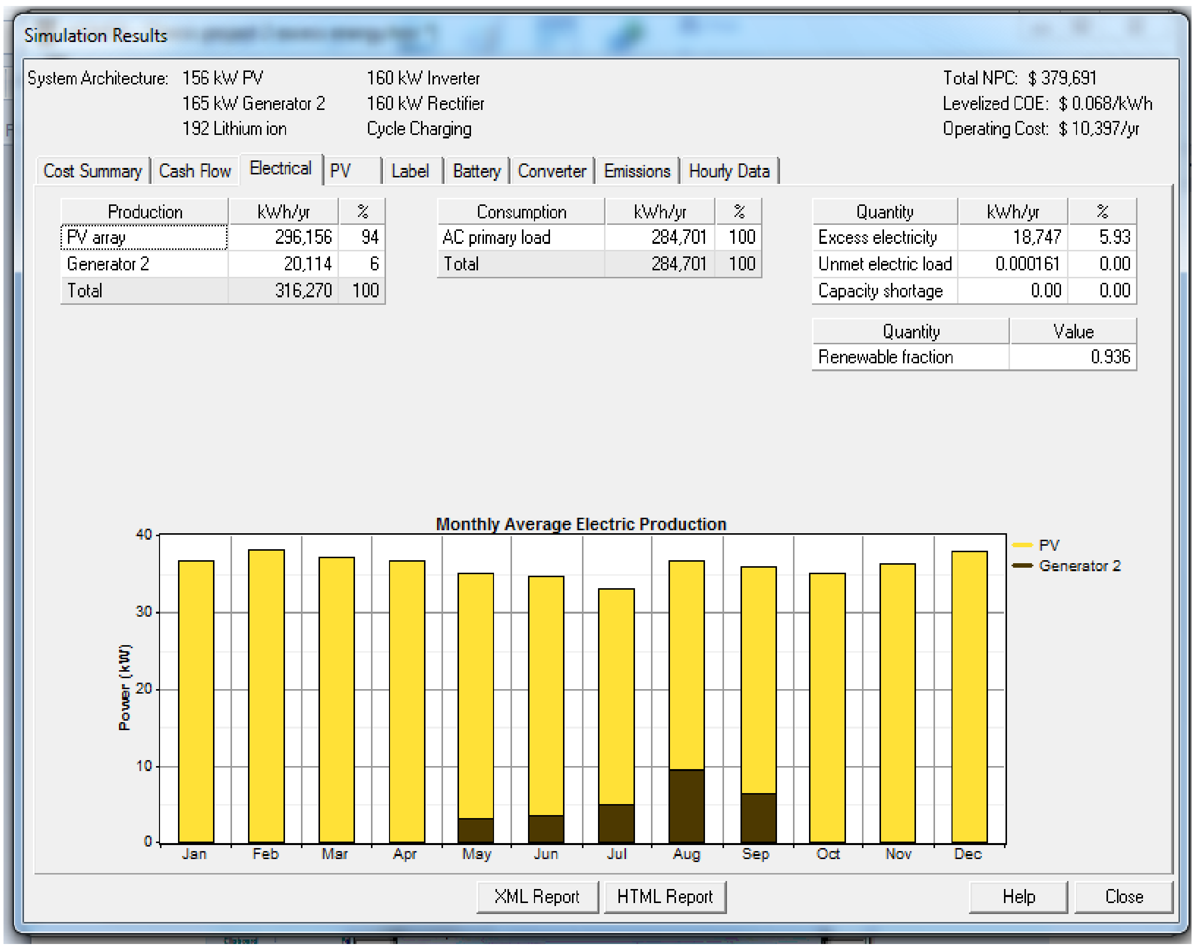


Figure 16: Monthly average electricity production northwest Cameroon

The simulation results in Figure 17 shows the variation between the PV power and AC primary load. This indicates clearly how the consumption varies with the production during the month of January, which has the highest value of solar energy production (higher insolation) throughout the year. By properly utilizing the battery systems, makes it easier to store the extra electricity produced and purposely for use in the night time when the irradiation drops. When solar PV system is not able to generate enough power, as it is the case in the rainy season, then the generator is, used as a booster to increase the power of the system and to match the energy demand of consumers during that particular period of the year.

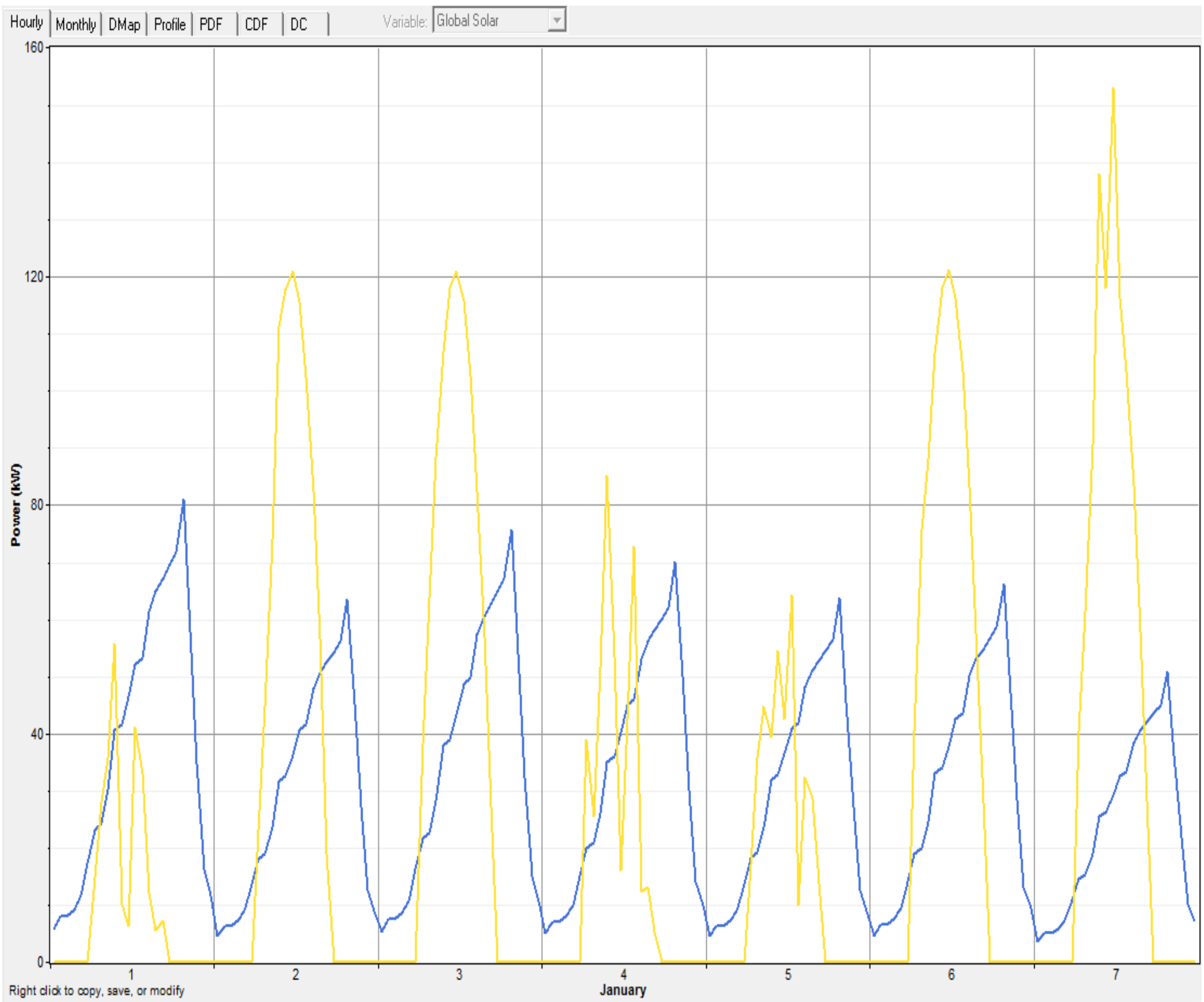


Figure 17: AC primary load and PV power curves

The simulation results as shown in Figure 18 describes the solar PV production for each month throughout a particular year which covers mainly two seasons in Cameroon. In January month in particular, when the solar radiation is quite strong when compared to other months, the solar system is capable to generate the required amount of power needed to satisfy consumer's demands. In cases when the solar energy produced cannot match the electricity demand of consumers, the generator is, slightly utilized to support the energy needs of consumers.

The solar condition is almost same for every year, though some minor variations may occur based on other factor. However, the average value of global horizontal solar radiation for each month changes symmetrically such that January remains the month with highest level of insolation whereas August constantly experiences the lowest value as seen on figure below.

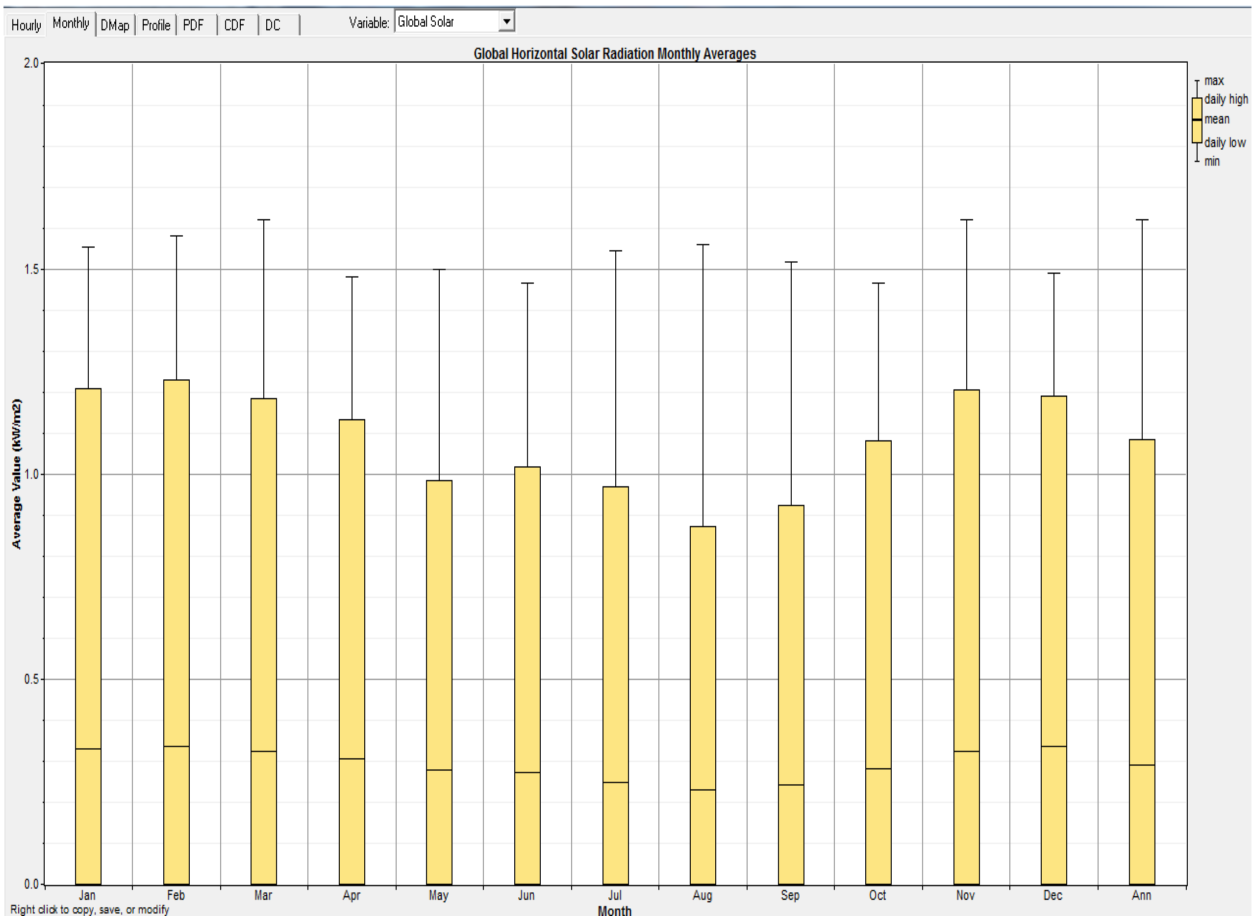


Figure 18: Global horizontal solar radiation monthly average

5.1.2 PV power output

The simulation results shown in Figure 19 explains clearly the solar PV production and primary load pattern. In general, the main production months for the case of Cameroon has approximately similar values (variations) of the solar PV produced for a given season of the year. Solar PV plays a great role towards reducing the energy needs of consumers who could depend solely on the grids and other sources of power. The situation changes for other periods of the year such as in the rainy season when the insolation level is very low and farmers usually require alternative sources of power, which in this case is a diesel generator.

The solar potential of Cameroon is, estimated around same level to that of Almeria in Spain where the scaled annual average values are 5.05 kWh/m^2/day, and 5.06 kWh/m^2/d respectively. As mentioned earlier, Cameroon has abundance solar resources throughout the year but with peak solar radiation occurring in January. The recorded lowest annual average is around 4.03 kWh/m2/day and the highest annual average is about 6.8 kWh/m2/day.

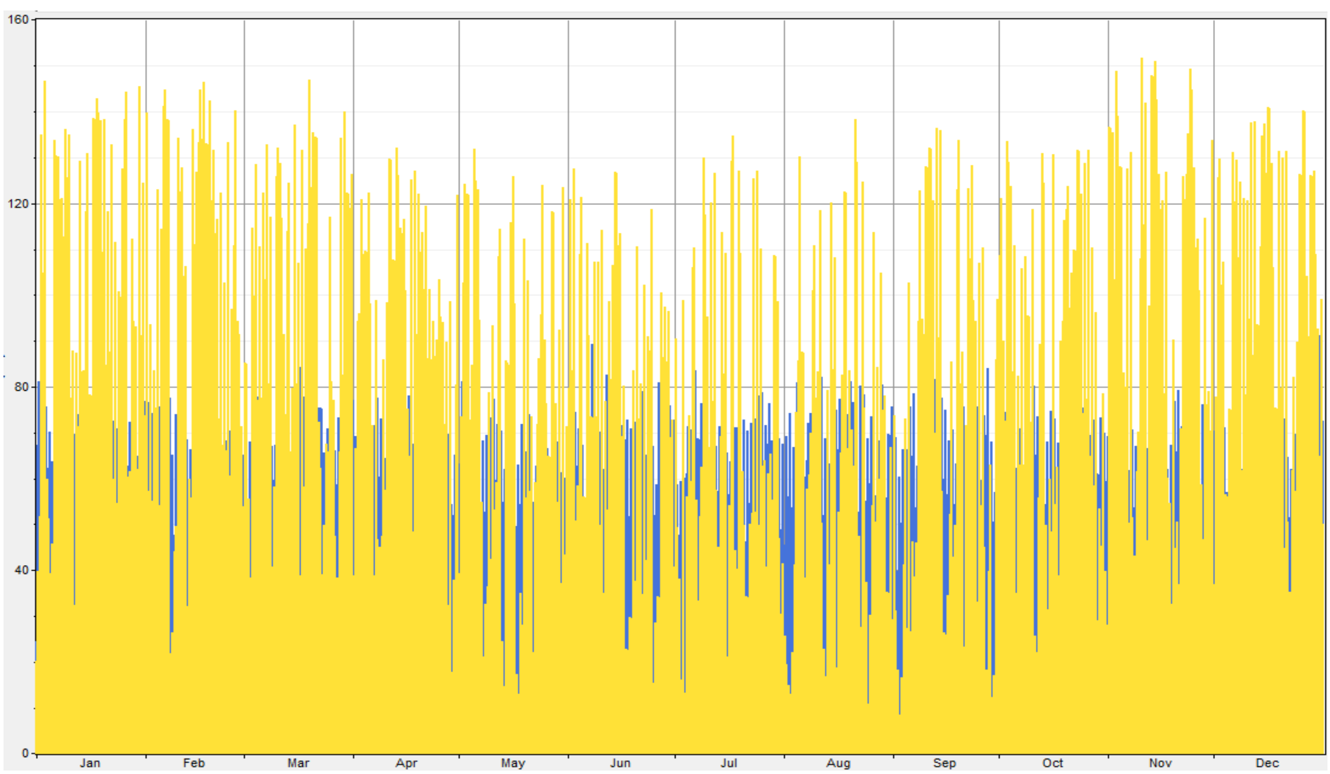


Figure 19: HOMER simulation of PV power output in Cameroon (156kW system)

5.2 Peak sun-hours for system sizing

This is the time when the intensity of sunlight is about 1000 watts per square meter. This unit helps to determine what a solar panel is capable to generate in a given locality and used in determining the size of the solar system when the daily energy demand of a customer is, known or calculated. Peak sun hours occur at solar noon; a time when the sunshine is highest in the sky. In summer, the value is much higher due to the sun's higher position in the sky. However, solar energy increases as the solar system is near the equator and decreases as the system is, moved away from the equator.

So if the installation site for the solar PV system is nearby large body of water, more cloud and snow covers, then it would decrease the amount of peak sun-hours in that particular region. In the state of Oregon USA, peak sun hours vary between 3–5 hours per day (Renogy, 2013). In the northwest region of Cameroon, the peak sun hours vary between 4–6 hours with an average value of 5 hours. Other factors that affect peak sun-hour value include tall trees, tall buildings, and other physical conditions of the region where the solar system is, installed. Therefore, in these calculations, the peak sun-hour of 5 hours is, selected in the sizing of the solar system needed for the APV project in Santa village Cameroon.

This implies if the total estimated daily energy consumption by the farm and surrounding consumers is, given by 891.82kWh, then we divide this value by the peak sun hours to obtain the solar system size in kilowatts unit.

$$\text{Power (kW)} = \frac{780\text{ kWh}}{5\text{ h}} = 156\text{ kW} \tag{5.1}$$

A solar system of 156 kW is suitable for an APV project by assuming that the total losses are, ignored for technical reasons. Assuming the project requires solar panels rated at 250 w each. This mean a total of panels for the installation of the system is, calculated as follows:

$$\text{Number of panels } (N_P) = \frac{156\text{ kW} * 1000}{250\text{ W}} = 624. \tag{5.2}$$

A total of about 624 solar panels would be needed to realize the APV project in the specified region in Cameroon in order to meet up with the electricity demands for the on-site farming equipment and the surrounding residential customers requiring electricity for mainly lighting purpose, cooking and storage facilities.

5.3 Load profile with zero energy for pumps

In order to save energy and using it efficiently, we shutdown equipment such as irrigation pumps during rainfall since the farm does not really require any water from pumps. During this period, the farm gets water naturally from rainfall and the amount of energy that could be, drawn by the pumps is being stored for lighting purposes.

Total energy demand by onsite farm equipment during dry season is 21826 kWh. During the dry season, irrigation pumps consume about 1790 kWh. Total energy demands for refrigerators during dry season is approximately 11612 kWh. Assuming the energy needed for refrigeration is, dropped by half in rainy season when compared to dry season, implies for the period between April and October of any farming year, we have as follows:

$\frac{11612 \text{ kWh}}{2}$ = 5806 kWh (energy needed by refrigerators drops by half in the rainy season)

Approximately no energy (0 kWh) is, needed for irrigation pumps during rainy season (April-October). Implies energy drawn by onsite farming equipment during rainy season is, given by:

21826 kWh – (5806 kWh + 1790 kWh) = 14230 kWh

During the rainy season, total daily energy consumption drawn by on-site farming equipment dropped from 60 kWh/day to about 39 kWh/day (a drop of about 1/3). From this difference in energy consumption by on-site farming equipment, we can deduce that new daily energy consumption by all household appliances and farming equipment is, given by:

9kWh * 80 homes = 720 kWh. Therefore, 720 kWh + 39 kWh = 759 kWh.

From these calculations, we can notice that throughout the period from April to October for any given agricultural season. The amount of energy needed for the farm's equipment is same for lighting, but changing for irrigation pumps and also for refrigerator equipment. In this case, the total daily energy consumption is less when compared to a typical hot and sunny day in the dry season. However extra energy generated by the solar system can be used to increase lighting capacity then being used to power irrigation pumps and some refrigerators which do not really require power considering the weather condition at the time is quite favorable for harvested crops even if not stored as the case in other seasons.

The simulation results seen in Figure 20 represents the daily load profile for a day in the month of August when during rainfall, the energy demand for refrigeration is dropped by half and then no energy needed for irrigation pumps. During this period April and October, the amount of energy drawn by the farm is about 1/3 less compared to the dry season. This is because the farmland draws water naturally from rainfall and does not require any irrigation into the farm. The energy demand for poultry lighting and other animal facilities remains unchanged since apparently the same amount of electricity for lighting purposes is, needed throughout the year irrespective of the season.

Energy for domestic heating is irrelevant due to a normal weather condition at standard temperature in Cameroon so no amount for heating energy was, specified in this study. Peak consumption period remain same as in previous scenario varying between 5.00pm and 8.00pm when most energy users have returned to their homes from job places and other daily activities to start using electricity around the evening for cooking and lighting in particular. The rainy season lasts about seven months in the northwest region of Cameroon and then about five months of total dry season for every farming year.

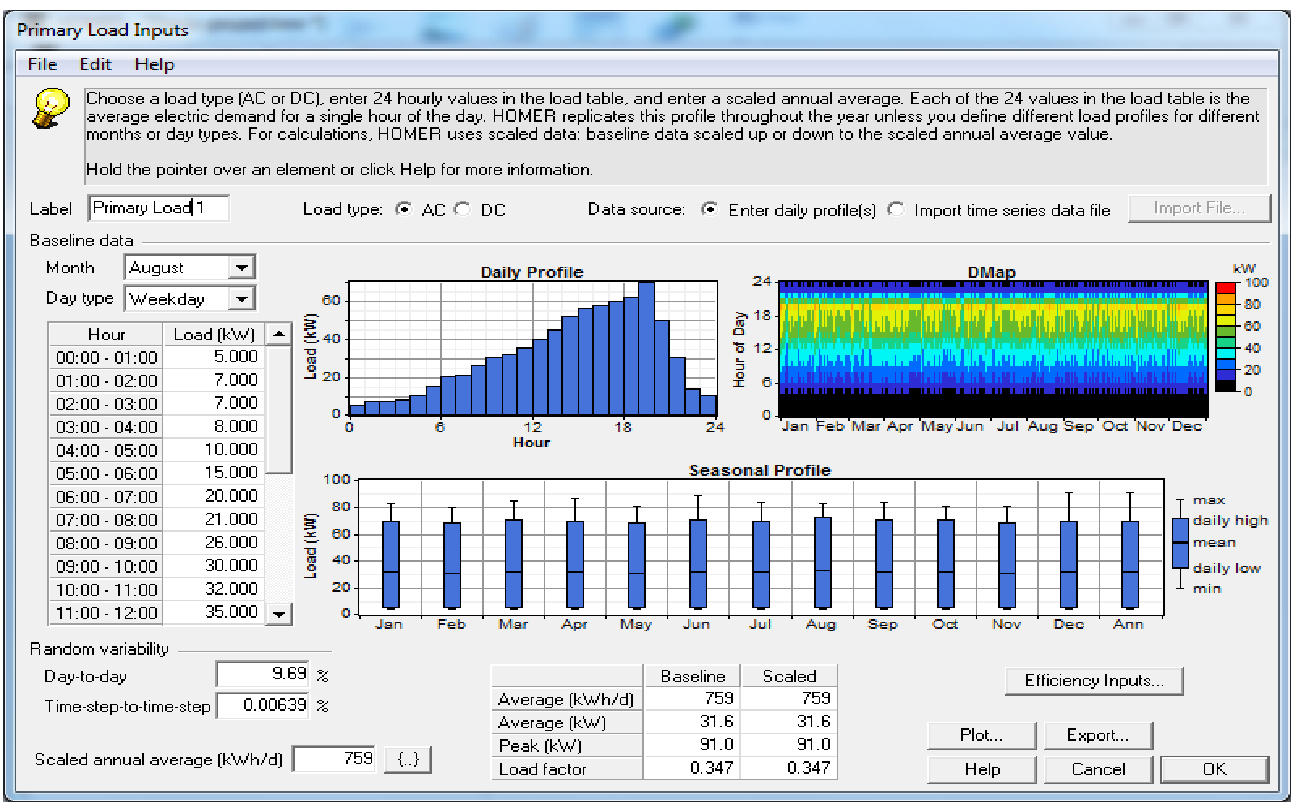


Figure 20: *Primary load input and daily load profile with zero energy for pumps*

5.3.1 Electricity production with zero energy for pumps.

The new value estimated for the solar PV system size with approximately zero energy consumed by the water irrigation pumps is 151 kW. By inserting this new value into the HOMER software made it possible to calculate the annual PV production in the project location in Cameroon based on the solar irradiation data. However, the simulation results are, seen in Figure 21 whereby the amount of power contributed by the generator is capable to boost up the solar system energy required by consumers.

The simulation results show that the estimated annual AC primary load consumption is 277,035 kWh/year. The results as illustrated on the figure below also shows that the PV production for the entire year is 276,629 kWh and clearly states that it is not sufficient to meet the total energy demand by the farm and residential homes requiring electricity for daily use.

Therefore, in this situation the generator helps to match the demand in providing extra electric power to the solar system with peak production in January while August experiences weaker insolation.

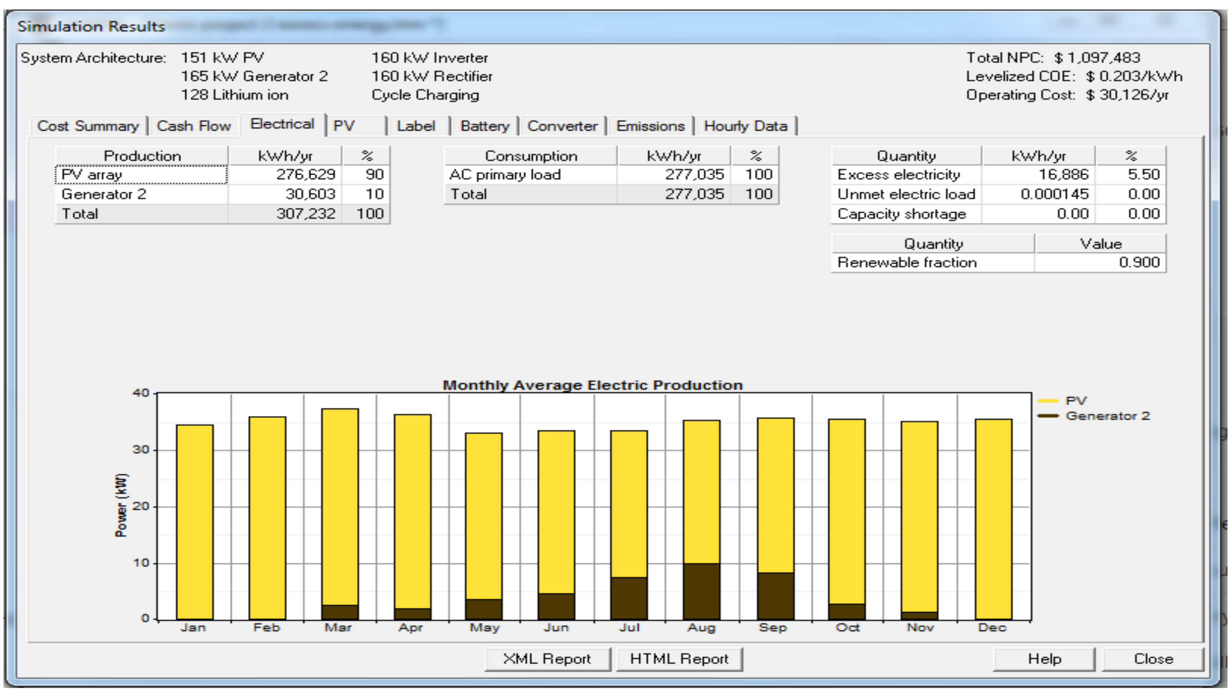


Figure 21: Monthly average electricity production northwest Cameroon

The simulation result seen in Figure 22 shows the variation between the PV power and AC primary load. This indicates clearly how the consumption varies with the production during the month with highest production, value of solar energy (higher insolation) throughout the year. In this simulation result, we can conclude that the curves has not changed compared to previous simulation. The differences can be seen on Figure 15 where the quantity of batteries have changed from 192 to 128 due to the drop in about 5 kW of power when compared to the previous solar PV system size of 156 kW. This is, designed purposely for the month of August when the pumps do not consume any energy for irrigation purposes. Despite of poor solar radiation at that time, the generator is capable to provide the extra electricity needed by the farm and other consumers demanding power from the solar system. Other power electronics remain the same for both cases of the system simulation.

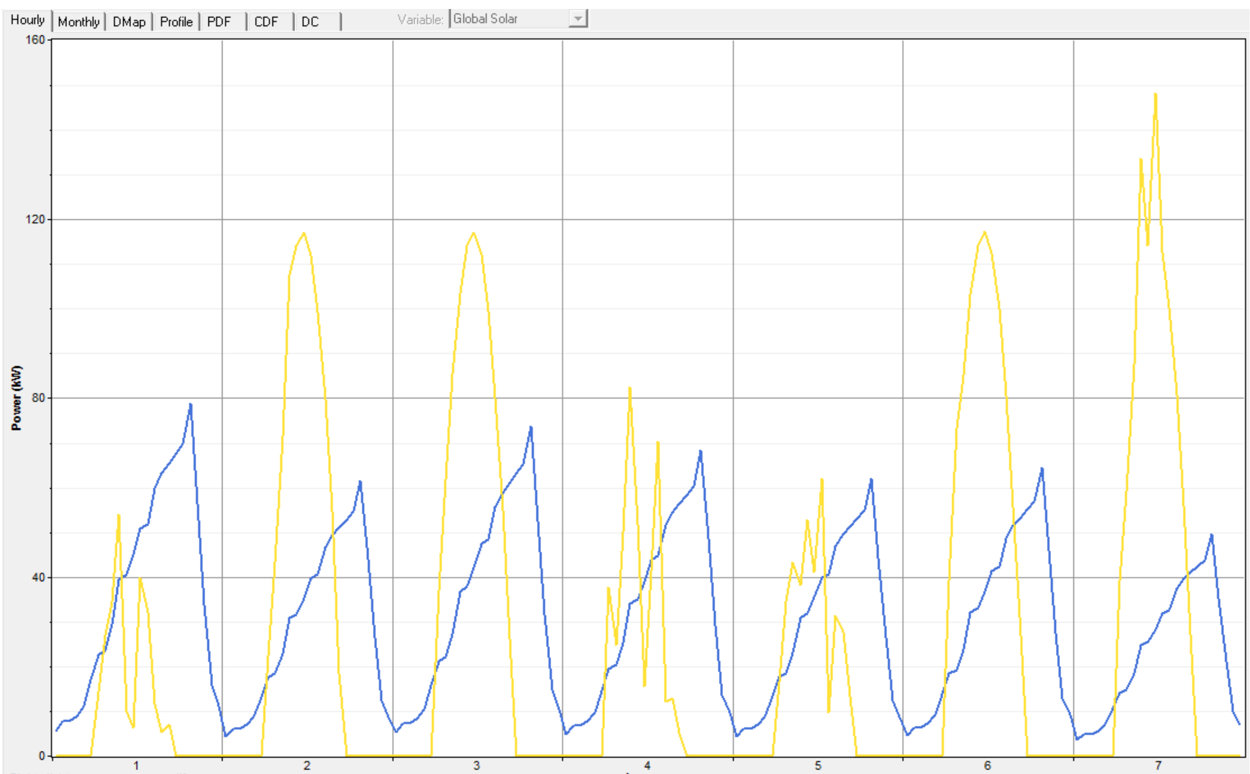


Figure 22: AC primary load and PV power curves

5.3.2 PV power production with zero energy for pumps

The HOMER simulation results, as seen in Figure 23 explains clearly the solar PV production and primary load consumption pattern provided the system is reduced to about 151 kW (no irrigation pumps required completely). Similarly the main production months for the case of Cameroon has approximately same (variations) of the solar PV produced for a given season of the year. Solar PV power produced during this period is purposely for lighting since refrigerators and pumps do not require the same energy as it is the case in the dry season. Less storage for vegetables and fruits needed during this time.

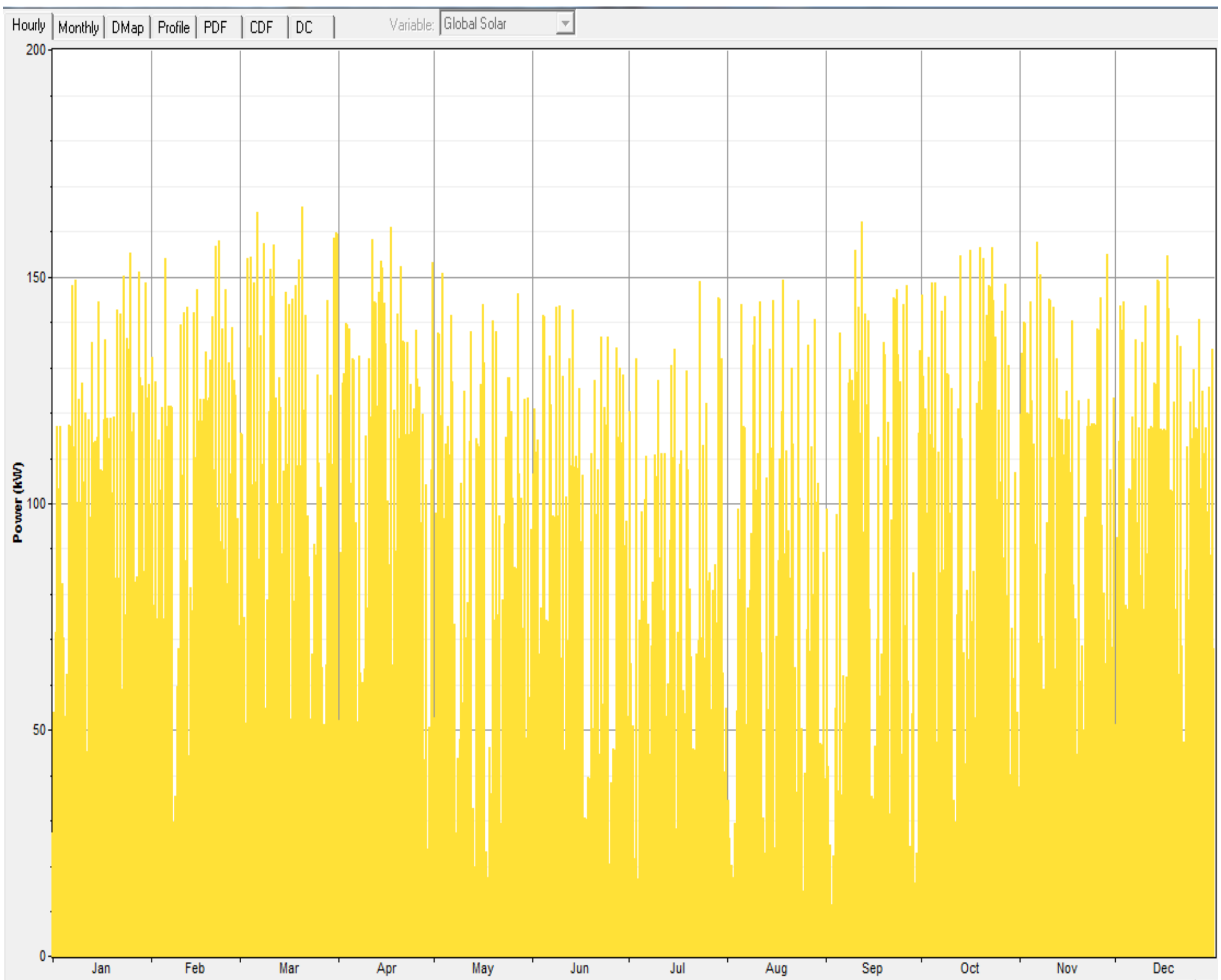


Figure 23: HOMER simulation of PV power output in Cameroon (151kW system)

On average, we consider that a household (family) in Cameroon is, made up of about five persons. Form this assumption, the APV plant supplying a farm's on-site equipment with about 60 kWh of energy per day and also feeding about 80 homes with estimated 10 kWh/day/home however ensures the provision of electric power to a total number of persons as follows:

Total number of energy users per household (E) = 5 persons * 80 homes = 400 persons.

A total, of about 400 persons residing nearby the APV plant can be, supported with regular and clean energy fed from the solar power plant. This amount does not include the on-site equipment electricity (energy) demands.

Table 8: Description of solar system variables.

Variables	**Amount**
Daily energy demand (kWh)	780
Peak sun-hours (h)	5
APV solar system size (kW)	156
Number of panels	624
Number of surrounding homes	80
Total number of energy users (residents)	400
Cost of solar energy consumption (c/kWh)	~ 0.224€

Table 8 clearly describes the system parameters and the number of units that a typical APV solar power plant can be, designed to support based on the electricity demand and the number of end users of energy per household. This also take into consideration, the peak sun-hours of the region and the combined energy demand for both farm tools and residential buildings nearby the APV solar plant, who require sustainable and regular electricity based on month subscription deals. The price (~0.0224€) charged by plant owner per kWh of energy according to the specification in HOMER is less compared to the national grid energy tariff price per kWh which is about 150cfa per kWh (0.230€).

6. Socio economic and environmental impacts

The social impacts vary from one another, but main issue is how the APV system is associated with daily life of people, community and the entire biodiversity and environment. Sustainability is quite broad and some ways to understand the concept of sustainability is by taking into consideration the three pillars of sustainable development (SD), which include; Economic growth, social aspects, and environmental protections. In this thesis, we will examine how solar PV systems satisfies the three areas above in terms of energy productions, distribution and consumption by end users.

- Reduces food waste
- Increases local farmer’s income
- Create jobs for local population
- Reduces malnutrition
- Storage flexibility
- Self-sustainable business for farmers
- Sustainable and affordable electricity

The points above, present some advantages that constructing an APV plant is capable of demonstrating. With suitable storage systems in an APV plant, post-harvest loss is, reduced by 90--95%. Boost up income for farmers through the sales of electricity to communities, large sales of crops harvested from the APV plot, which can directly increase annual income by 40% if utilized properly.

There is absolutely, high possibility to create new jobs in the local communities especially for women and young farmer engaging in intensive fruits and vegetable production. However providing lighting in a completely unpowered village where the electricity grid is far off and boosting standard of living in the surrounding communities and regions.

6.1 Farm to market storage specification

Commercial storage facilities for perishable crops play major roles in a farming solution like the APV system, to keep crops fresh until their arrival in the markets for sales. A good example is Cold-hub storage, a sustainable farming storage facility that has been able to prevent excess losses from harvested fruits, vegetables, potatoes and other crops cultivated on a similar solar farming system. This is possible by using an APV power plant where the safety of perishable farm products is about 90–95 percentage guaranteed before their arrivals to the market. In addition, the fact that an APV system is capable to provide a 24/7 energy required for storage of any kind of farm products, and poultry products to keep them fresh and in good condition before consumption.

Some major observations of farmers and customers in the developing world particular in Cameroon, explains that perishable crops especially fresh fruits and vegetables start to deteriorate as soon as they are, harvested and are, separated from their sources of water and nutrition. They suddenly lose weight, texture, flavor, nutritional value and therefore cooling significantly reduces the rate of damages encountered by almost 20–30% of total crop harvested annually in the regions where intensive farming is, carried out in Cameroon (Cold-hub, 2012).

In Nigeria, Cold-hub an innovative technology is currently providing crop preservation facilities for farmers as an initiative with some plug and play modular powered walk-in cold rooms serving farmers for 24/7 off grid storage. Its main aim is to address the problem of post-harvest losses in fruits, vegetables and other perishable food items. The installations are, done in both major farming areas and around major vegetable markets, where farmers place their products in clean plastic crates stacked inside the cold room powered by solar systems.

However, this can extend the freshness of fruits and vegetables for up to around 21–40 days. The solar powered walk-in cold room is made of 120mm insulating cold room panels to retain cold. Energy from the solar panels mounted on the rooftop of cold rooms are then stored in high capacity batteries to be used in times of low electricity production. Large collection of food items from an APV plant will directly eradicate food scarcity and malnutrition problems in these regions since the preservation of crops will ensure prevent food loss of the farmers (Cold hub, 2012).

The prices of electricity from an APV plant is, expected to be less compared to what the grid is selling or might sell in the future. This is one way to increase customer's loyalty and putting the sustainable energy from solar system as first priority and increase the share of renewable energy in a given area. Especially in developing countries, customer's loyalty and satisfaction needs to be, emphasized in any business strategy by business owners and operators among other competitors trading in same line of business or similar.

6.2 Advantages and disadvantages of solar energy

The advantages of solar energy; are quite enormous due to the fact that it is believed to be able to contribute the highest share of renewable energy in the near future because of vast solar potential globally. It is ecological and does not emit any GHGs or CO_2 during operation. Solar PV panels are easy to install especially for private use in homes such as rooftop solar systems. The cost of obtaining solar energy is falling from time to time due to new technologies, large markets, and numerous government efforts, NGOs, organization supports and incentives for producers. This has helped them to keep costs lower enough and creating the possibility for consumers to have self-sufficient and low subsidized energy alternatives than using energy from conventional sources like crude oil, fossil fuels and other CO_2 emission sources of energy.

Noise free, no moving parts, fixed axis systems, easy maintenance and installations. Being a green energy source, the lives of plants, animals and humans (biodiversity) is, guaranteed as little or no emissions are, released on the environment, which could lead to pollution, toxic chemicals and more. Through solar energy, business owners, farmers and individuals are capable to be self-employed by owning small scale solar systems which generate electricity for local consumption and for animal farming like in the case of APV solar plant. Solar energy also attracts some setbacks, which can be the inability to generate energy at nights when the sunshine has relatively dropped and the irradiation condition not capable to cause any reaction on the PV modules.

However, the sun position directly affects the rate of production of solar energy during day times. Cloudiness, precipitations, shelters from trees, dust particles, snow and other physical quantities can limit production if the solar modules are covered or shaded from the direct sunshine that should have influenced the amount of energy production daily. This makes it harder to assume the amount of energy that a solar system can produce under these hazardous conditions.

To, properly utilize solar potentials and making solar energy self-sufficient and sustainable during night times when the solar condition and radiation has dropped, requires storage capacity of batteries and sometimes these may cost really much when considering the amount of energy to be stored or in demand by the consumer at some particular hours of a day. Most of the energy produced by a solar system is, wasted during the day times if storage facilities are, not properly implemented. This is because during the peak production period of solar energy, most energy users are out of home for work, studies, business trips and other activities.

In Cameroon, peak production hours on a particular day is between 10.00am and 3.00pm when most people are out of homes. During this period enough energy is produced but consumption is not at its peak point until around 6.00pm when residents starting turning their lights and other equipment on and then demand a lot of energy from the solar plant. Without proper storage facilities, there would be inadequate amount of energy in the nights to satisfy consumer's need. Also for the APV solar farm, enough energy would be, needed constantly to keep the animals and poultry under normal temperature and healthy conditions for which lighting in needed.

Currently few streets lights in major cities in Cameroon are using solar power bank to run the lamps. In addition, for local residential homes and for commercial purposes, solar has still a long way to go in Cameroon. In recent years, farmers have constantly suffered the severe problems of poor electricity distribution. Most farm areas lack access to national grids and to these effects, they stand at risk to always lose a great amount of their harvests before reaching the market due to lack of refrigerators and no electricity to power the cooling rooms, freezers and other preservation units within the farm and around the market areas.

With the APV innovation, enough energy can be generated and by the used of battery storage facilities, agricultural products can reach the market areas with absolutely no damages or food losses as it has been the case in previous years according to farmers reports in which they present some of their major challenges faced in the agricultural sectors in Cameroon. Farmers believe energy availability is a big factor to boost their yearly production and preserve perishable crops and vegetables until their arrivals in the markets.

6.3 Estimated solar farm surface area

Determination of total land area occupied by PV panels

AE= 780 kWh/day * 365 days/year = 284700 kWh/year

Annual full load hours (FLH) = $\frac{\text{Annual Energy}}{\text{Capacity}}$ (6.1)

FLH = $\frac{284700\ \text{kWh/year}}{156\ \text{kW}}$ = 1825 hours

Total Annual Energy (TAE) = 284700 kWh/year

We can assume the performance ratio (PR) = 90% = 0.90

Solar panel efficiency (η) = 15.74% = 0.1574 p.u

Annual solar irradiation (ASI) = 1900 kWh/m^2

Total panel area covered (A) = $\frac{\text{TAE}}{\text{ASI} * \eta * \text{PR}}$ (6.2)

Area = 1058 m^2

The total surface area of the piece of plot, takes into account the free spaces for passage (movement) of persons and tools. However, the free spaces are required to prevent shadowing during maintenance work or harvesting of crops. Therefore, it is, assumed that approximately, 50% of the total land is, covered strictly by solar modules as seen below. If the solar modules occupy about 1209m^2 of the plot, then the land total surface area is, given as follows:

Total land area = 1058m^2 * 2 = 2116 m^2 (6.3)

However, one can estimate that the field layout for the cultivation of crops and installation of solar panels forming the APV project has, given dimensions as follows:

Length of field = 52.9m

Width of field = 40m.

An approximately 1209 m^2 of area covered by panels above crops, on a plot with total area of 2418m^2 in this case where an APV solar power system is, designed to enable a farmer achieve his socio-economic and environment sustainability goals as one major advantage of this activity.

6.4 Cost development and energy subsidy.

Compared to conventional power conversion methods, PV systems have become economically competitive particularly for smaller applications requiring less investment costs since the introduction of the Renewable Energy Act and targets by nations to decrease carbon footprint resulting from increasing energy needs and demands for electricity. The situation is likely same for all countries pursuing the excess use of renewable energy in which similar subsidies have been introduced to foster the quick development and rapid expansion of the renewable energy sectors, most especially solar photovoltaics due to its vast global potential and low cost among other renewables. The strong growth the PV market has seen in the last decade is as result of significant cost reduction for the technology, and flexible government policies (low taxation for renewables) and energy subsidies granted to motivate producers (DGS LV 2013, 477).

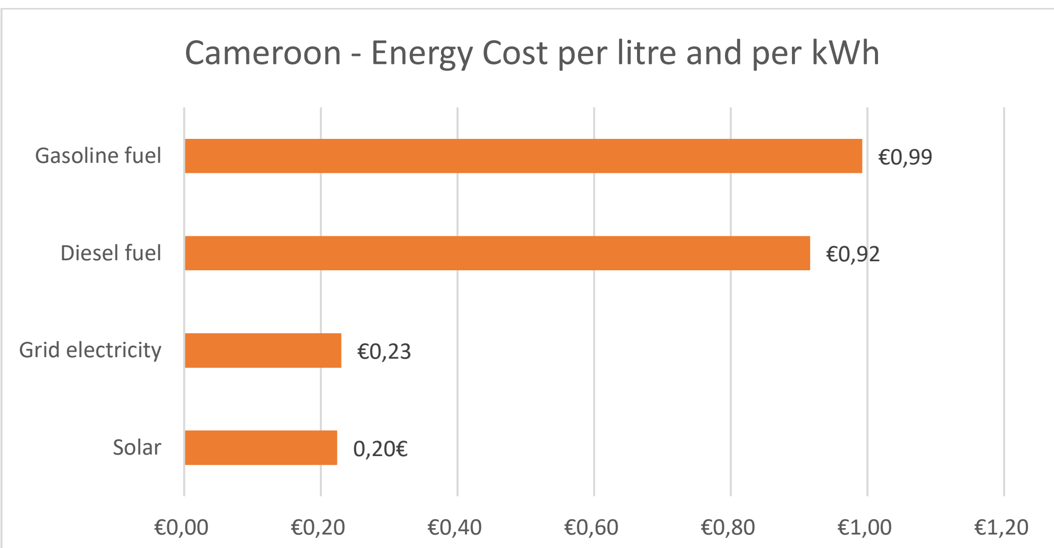


Figure 24: Cost Evaluation for Cameroon energy mix

Currently in Cameroon, the estimated cost of solar energy per kWh of energy consumption has the lowest price due to low taxation on solar panels importation as a means to increase the national share of renewable energy. The Cameroonian government through its long-term action plan to promote the renewable energy sector also provide subsidies through some financial ties with the United Nation Organization and the World Bank.

Through the Cameroonian electricity reform project, on December 7, 2016 the world board of executive director approved an International Bank for Reconstruction and Development (IBRD) loan of US $ 325 million to strengthen Cameroon's national electricity network. The fund was, designed to help Cameroon set up a project that will improve the nation's quality of power and supply investment funds for the implementation of national renewable energy project. The Bank also aimed at addressing some constraints in the energy sector in Cameroon and more specifically in the area of electricity access, by enabling the transfer of power from new hydropower plants and energy-surplus from regions to towns and villages in under-served localities and improving quality of supplies in urban cities.

Currently grid electricity cost around 150 Francs / kWh (0.230€/kWh) on average and it is not affordable by all residents due to low income of some families and citizens (ENEO, 2018). Therefore, through the provision of the World Bank loan to help the government of Cameroon increase its annual production, costs of distribution will be, dropped in order to satisfy the needs of the population, and in addition funding can be, provided to private investors working towards raising the share of renewable energy such as solar PV across Cameroon. The funds are, intended for four main components in the national energy sector, which are as follows:

- To help SONATREL (National Corporation for Electricity Transportation) operates efficiently
- To improve the capacity and reliability of electricity supplies
- To finance technical assistance, analytical work and capacity building
- To promote solar PV by cutting taxes on importation of solar panels.

In Cameroon, major farmers belong to micro finance groups, credit unions, and some agricultural CIG (Common Initiative Groups) where they have access to get loans with relative low interest rates to help them invest in large scale farming as a way to boost up food production and preventing any shortage across the country. Most farmers depend on low interest loans to engage in large scale farming in Cameroon, and paying back through the sales of crops and other farming products such as poultry and meat.

In this study, the APV project has a higher possibility to get low interest loans and some other factors include good government policies that encourages investment in solar energy development and hence the agro-photovoltaics has a huge potential to produce both electricity and crops for sale and recovering any investment cost faster.

In 1999, a recognized microfinance institution was set-up in partnership with the Cameroonian government and with funding from the European Union and the French Agency for Development has been offering a wide range of financial services (loans, savings) tailored to the needs of micro-enterprises, private business owners, and farmers to meet their production targets annually. Another French Agency PROPARCO has been supporting farmer's initiative in Cameroon by providing low interest loans for agricultural activities and growth in the farming sectors to help boost local development and enhance financial inclusion for both small and medium sized enterprises.

With a good business plan, which clarifies three main issues such as; economic and profit margin, social and environmental sustainability, satisfying government regulations and other important issues, solar farming investors are able to get suitable financial assistance (loans) to help foster their activities, which are considered a way to accelerate development and economic growth in Cameroon (PROPARCO, 2017). An agricultural fund (including loans and grants) of the sum of US $25.70 million was, granted to farmers in the northwest region of Cameroon approved by the African Development Bank to help finance the northwest rural agricultural initiative and participatory Development Support Project phase II.

The project main aim was to improve agricultural productions and incomes of beneficiary communities by creating rural infrastructure, which include sustainable energy systems. This will help reduce poverty rate in the rural communities and will improve living conditions of people by providing new sources of clean water and electricity for all. The funding was, sourced by the European Union, African Development Bank and partly by the Cameroonian government (AFDB, 2013). Similar financial resources are capable to satisfy the financial needs of investors in the solar farm or agro-photovoltaics business in Cameroon where there is relatively higher annual average solar irradiation of 5.02kWh/m^2/day, compared to Finland, which has between 2.73kWh/m2/day–3.32 kWh/m^2/day.

Low taxation on solar panels importation, favorable climatic conditions, about 1900–2500 hours of annual sunshine, cheap labor costs for solar installation, flexible government policies and regulations on renewable energy development. The Cameroonian government does not provide any direct feed-in tariff to energy producers but some grants, loans and subsidies partly sponsored by the foreign agencies and organization like the EU and the African development aid.

6.5 The SWOT analysis of solar photovoltaic

The solar photovoltaics has both positive and negative features, though to a greater extend solar energy production presents very convenient facts and have been supporting the increasing energy demand across the globe for residential, commercial and even industrial needs. One main strength is the fact that solar energy is used by most sectors and governments to decarbonize conventional sources such as fossil fuels, diesel generators which, cause relatively high emission of gases and carbon dioxide to the environment. Solar photovoltaics has been a major source of employment and a means of research for energy experts.

Table 9: The SWOT analysis of solar photovoltaics energy.

Strength: 1. Clean energy source with no pollution 2. Easy to install systems 3. Vast global solar potentials 4. High demand for solar energy	Weakness: 1. Requires large storage facilities 2. Often affected by weather conditions 3. Shading by trees, snow and dust 4. Peak production may occur during low demands for energy.
Opportunity : 1. Support increasing energy demands 2. Job opportunities 3. Greatly increases share of RE 4. Reduces grid electricity bills	Threats: 1. Energy monopoly of some countries 2. Poor government policies 3. Lack of funding and subsidies 4. Intense competition in the market

6.6 Supply chain management of PV panels.

A supply chain is, made up of a series of activities and processes that a material or product undergo from their very, initial supplier point, to final point where they are used. Generally, the supply chain consists of all partners involved, directly or indirectly. For solar PV systems, there are different manufacturing approaches that differs from one another. Most commonly, they all require some similar processes and transition stages from raw materials, manufacturing, logistic, installations and end of life cycle.

Some PV supply chain functions vary strictly between product development, marketing, operations, distribution, financing, customer's loyalty and services.

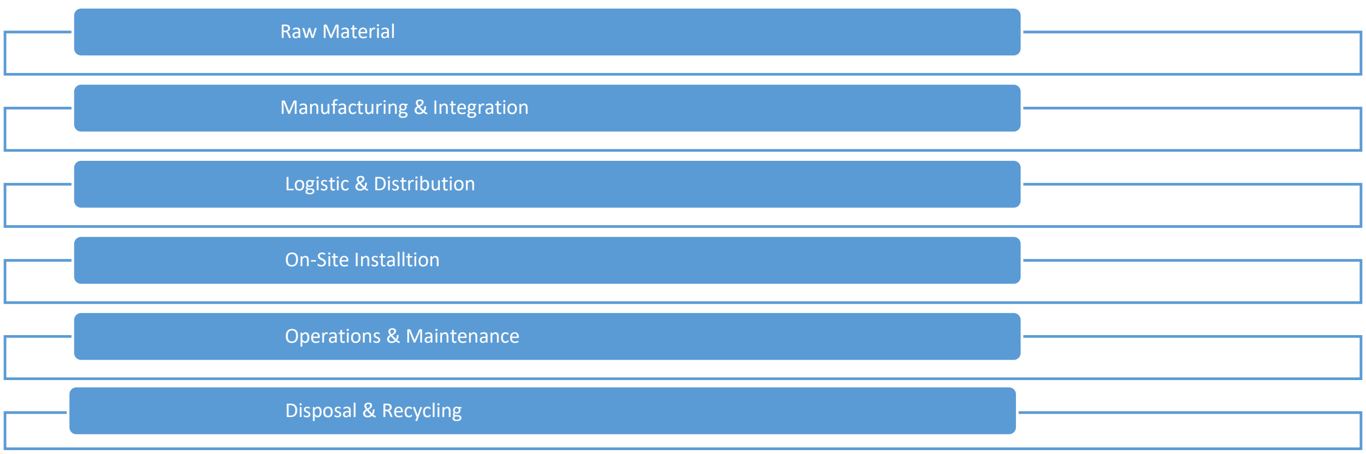


Figure 25: Photovoltaics supply chain management and LCA (E4tech & Avalon consulting, 2012)

The various stages and processes (activities) that are, carried out from the initial stage of a PV material through to its end of life is, represented in Figure 25. Every stage is important and determines the transition between different stages as stipulated for any PV material or panel. To uphold the value that sustainability emphasizes, one important aspect for a PV system with, regards to environmental issues is its end of life. Disposal and recycling criteria setup by governments, environmental pressure groups expect manufacturers prior to sales of PV materials, to state on their business strategy how they intend to prevent environmental hazards caused by old PV materials (Pihlakivi, 2015).

6.7 Lean Manufacturing of PV arrays.

The production, distribution and installation of PV systems can be made more efficient by introducing the lean manufacturing concept; which refers to the use of less resources but still produce the required output or services that is needed (Production). The lean manufacturing is a highly efficient way to minimize the excess use of raw materials, reducing labor cost, limiting material losses but still maintaining a cordial relationship between customers and PV producers. With lean approach, approximately only half of the human resources in the factories, about half the space needed during work, about half of the investment in tools needed less time is required to put a PV equipment together and ready for use (Mukhtar, 2013).

In order to improve PV panel's efficiencies, effectiveness, and profitability producers could focus relentlessly on how to eliminate all irrelevant aspects of a manufacturing system for PV arrays that add relatively no value to their supply chain and customer's loyalty (Lean production, 2013). Main purpose for lean in the photovoltaics industries is to use less resources, labor, space, time, equipment and tools. This strategy helps to reduce the amount of waste disposed during any manufacturing operation for a photovoltaics material such as modules, minimum stocks, and minimum overall cost of manufacturing. Lean approach for PV modules also help to minimize the total costs of logistics to installations sites while keeping the level of customer's satisfaction high as well as makes it cheaper for buyers to afford the same products.

This approach presents some principles, which include:

- Value- This means designing PV panels from less resources that will still maintain customer's loyalty.
- Value stream- This means designing the best processes to make PV modules
- Value flow- This means managing the flow of PV materials through its supply chain
- Pull – This means making PV products only when there is potential market (demand).

These points form the basis for lean manufacturing in the PV sectors by companies. The efficient use of photovoltaics satisfies sustainability requirements where the main idea is to reduce cost, emissions, waste of labor and protect environmental rights (Waters 2003, 66–67)

Considering the case of agro-photovoltaics, where a solar farm is, designed to produce both crops and energy on same fields, farmers could aim to prevent produce waste such as tomatoes and other vegetables by simply estimating the market size before harvesting their crops. Also by making sure that food production only matches the relevant demand could also help them to prevent damages, reduces labor costs, material use and limiting the amount of energy needed for storage of perishable crops and other farming activities such as poultry at any given time. In such system, the main goal is to provide a solution that will enable farmers to produce enough food crops, which will satisfy the customers need and generating more profit for them by not losing a larger part of their harvests due to over production or poor storage facilities.

Ensuring efficient land use by cultivating much on less area of land where both PV modules and crops are, incorporated together in a solar farm called agro-photovoltaics for sustainable farming and energy production. By efficiently introducing labor, financial resources, irrigation, land use and other materials, for an APV farming system. Implies the farmer is, in position to make more profit if he is, still capable to produce enough crops and energy that is needed to satisfy consumer's needs through large sales, but with less energy wasted on storage and transportation to the market. Less energy used for animals farming but with excess profit from annual sales of different kinds of meat from animals raised from the APV solar farm which include chicken, beef, pork, and other dairy products all with the aim to increase the farmer's turnover.

The APV farm is quite sustainable from an economic point of view, due to its diverse yields and produce that is capable to generate more income for the farmers and in addition, a vast possibility for a shorter payback time of the investment costs of the power plant. Provided the agricultural facilities are properly utilized putting in place majors to avoid much waste, damages, or the loss of useful energy that could be stored, sold or used at the right time to provide lighting, heating or to power farm machinery when necessary. The APV satisfies sustainability issues with environmental laws by featuring solar system as an energy outlet, satisfies social impacts by creating jobs for local population, satisfying economic issues by providing electricity and crops for marketing. Other impacts are such as making the soil to bloom and suitable for farming in dry and hot regions where shading from PV arrays is, needed to limit water irrigated into the farmland.

6.8 Solar water irrigation system

As part of the agro-photovoltaic system, water is, periodically needed for the irrigation of dry farmlands where crops are, grown beneath the PV panels. However though the panels are, considered capable to provide enough shading on the crops preventing them from excess sunshine, in most instances especially during the dry season, the farmlands still require regular water irrigation that affects crop yields positively. This study has emphasized the importance of a sustainable solar water system, which takes into consideration, costs efficiency, environmental issues, and efficient energy pumping system that is capable to satisfy technical, economic, environmental and social requirements of an APV plant. By leading the way to develop and provide sustainable solar water solutions. Grundfos present the following advantages for any agro photovoltaics system.

- Low operating costs and low energy costs
- A robust water system with longer product lifetime
- Low maintenance and installation of agricultural solar water systems.
- Advice and support to ensure delivery of the right optimized solar water solution
- Ensures to keep productivity at its best
- Variable speed pumps with automatic response to changing conditions

For the APV application, the Grundfos irrigation system provides most suitable and precise solution that have in the past been helping to solve farmer's irrigation problems by the huge supply of good farming and drinking water for plants, animals and people. In the Santa agro ecological village and most parts of Cameroon, the seasonal irrigation has, mainly been done locally due to the lack of electricity to supply water using pumping systems. With a flexible and economical solution like the Grundfos irrigation system, farmers are most likely able to increase their agricultural yields, and capable to increase the health of their livestock and ensuring highly productive poultry farming in an APV system (Grundfos, 2015).

The Grundfos solar water systems are equipped with special elements such as sensors, gauges to detect water levels and to indicate faulty systems during any operating cycle. Monitoring systems installed to ensure proper functioning of the equipment and to indicate unwanted water leakages. As part of sustainability, and to achieve a desired holistic Life Cycle Management Approach (LCMA), Grundfos products are, designed with the possibility to be, re-cycled with maximum resource extraction and reuse while ensuring high quality and stable functionality to meet the needs of customers who require solar water irrigation for their crops. In addition, the aim is also to figure out how to maximize the use of secondary materials in their future products and wherever possible in order to make it more efficient for the environment after used.

Figure 26: Grundfos solar water irrigation system (Grundfos, 2015).

The irrigation (pumping) system as shown on the setup in Figure 26 ensures efficient ways of supplying water to irrigate agricultural lands powered by solar systems. Particularly in regions where the lack of grid power pose major agricultural problems among farmers. However, the used of sustainable solar powered systems to also operate and manage pumping systems can be seen from this example. This improves food quality, ensuring food security and generating significant income for farmers and communities especially in developing countries. The effective implementation of proper irrigation systems, clearly confirms the vast financial and social benefits that an APV solution has and capable to minimize the challenges that farmers have faced in very hot climatic regions.

6.9 **Comparing shading effects.**

One main reason for which the APV pilot project was, developed by the Fraunhofer institute in Germany was to provide enough shading on cropland in regions with very high sunshine and dryland conditions where the crops are liable for damages caused by the excess heat from the sunshine (Fraunhofer, 2016). According to researchers at the Fraunhofer institute, the pilot APV project near Lake Constance in Germany is capable to increase the land use efficiency by 60% since the shading caused by the solar panels will prevent direct and excess heat from sunshine to fall on the soil where crops are being cultivated.

Figure 27: Shading on crops using PV panels (Fraunhofer, 2016)

Though crop yields reduction might vary between 5.3–18% annually, when compared to cultivation in open space, where the land is naturally suitable for farming and does not require any shading, it is still very beneficial to install PV panels in particular regions. This may be due lack of access to electricity grid around the farm where energy is needed for vegetable preservations, powering farm tools such as pumps, mixers, and providing lighting for poultry and animal rearing. However, PV panels have apparently little or no emissions or environmental constraint when compared to the use of plastic bags or other equipment to provide shading on crops, as a means to limit the amount of sunshine falling on the farmland like the case with most greenhouses where shading is, done using local plastic bags (Fraunhofer ISE, 2017).

6.10 Benefits of using APV.

Other than drastically limiting land use by combining PV panels and crops on same field, the APV project has diverse benefits and researchers are still doing a lot of work to come out with more important aspects and advantages of using the agro-photovoltaics. As a sustainable farming method for farmers in very hot regions where they need to keep their farmlands productive and highly efficient for growing crops under PV panels (Emma Bryce, 2017).
Some of these benefits include:

- A portion of land can be used for construction purposes than vastly used for crops and PV installations separately
- Land can be economize to support the growing of other non-food biofuels crops
- Definitely provide enough shading for crops in dry regions
- Generating electricity as an alternative source of income for farmers
- Contributing in the share of renewable energy to meet national targets
- PV panels limit the amount of water irrigated to farmland due to enough shading
- PV panels present little or no environmental impacts as compared to plastic covers
- Create jobs, self-employment for farmers
- Reduces electricity bills for subscribers and consumers
- Eligibility for tax incentives for operators
- Low cost of maintenance for solar systems

The benefits are not limited to just the few points above, but these are some of the most fundamental benefits for local farmers and investors in solar farming initiatives. These benefits make the agro-photovoltaic project an excellent approach to increase crop yields and to boost standard of living for people in particular communities where there is a constant problem of food scarcity due to hot climate, and lack of access to national electricity grids for lighting. Moreover, by using APV, enough energy is, generated to enable pumping and treatment of large quantity of water for drinking, cooking and domestic use by people.

Almeria in southeast of Spain, has developed one of the largest concentrated greenhouses in the world, covering approximately 26,000 hectares of land but mostly made of plastic materials which have little economic benefits to vegetable producers. This region in Spain produces several tons of greenhouse vegetables and fruits such as tomatoes, peppers, cucumber annually is capable to support more than half of Europe's demand for fresh fruits and vegetables. Some year back, this region was very dry, and arid and desert-like due to very high annual sunshine of the region and this could lead to the generation of excess electricity using solar panels installed above crops, to form an APV system for farmers.

Figure 28: Plastic shading on greenhouse in Almeria Spain (Kaushik, 2013).

The costs of realizing this became more expensive for farmers to import soil and hydroponic system with drip-feed chemical fertilizers in order to make these areas productive for farming. Researchers have explained that solar PV panels could provide enough shading to make these farmlands bloom and create the vast possibility for farmers to grow crops and generate electricity which for communities and the national grid. The plastic bags used for shading on crops, are, considered to absorb and retain excess heat that workers often find it difficult to stay beneath while carrying out their normal farming activities during peak sun hour. However, lot of health challenges are, recorded by the use of plastic, which releases dangerous chemical into the rivers from time to time around the greenhouses regions (Kaushik, 2013).

6.11 Limitations of plastic shading (greenhouse) on crops.

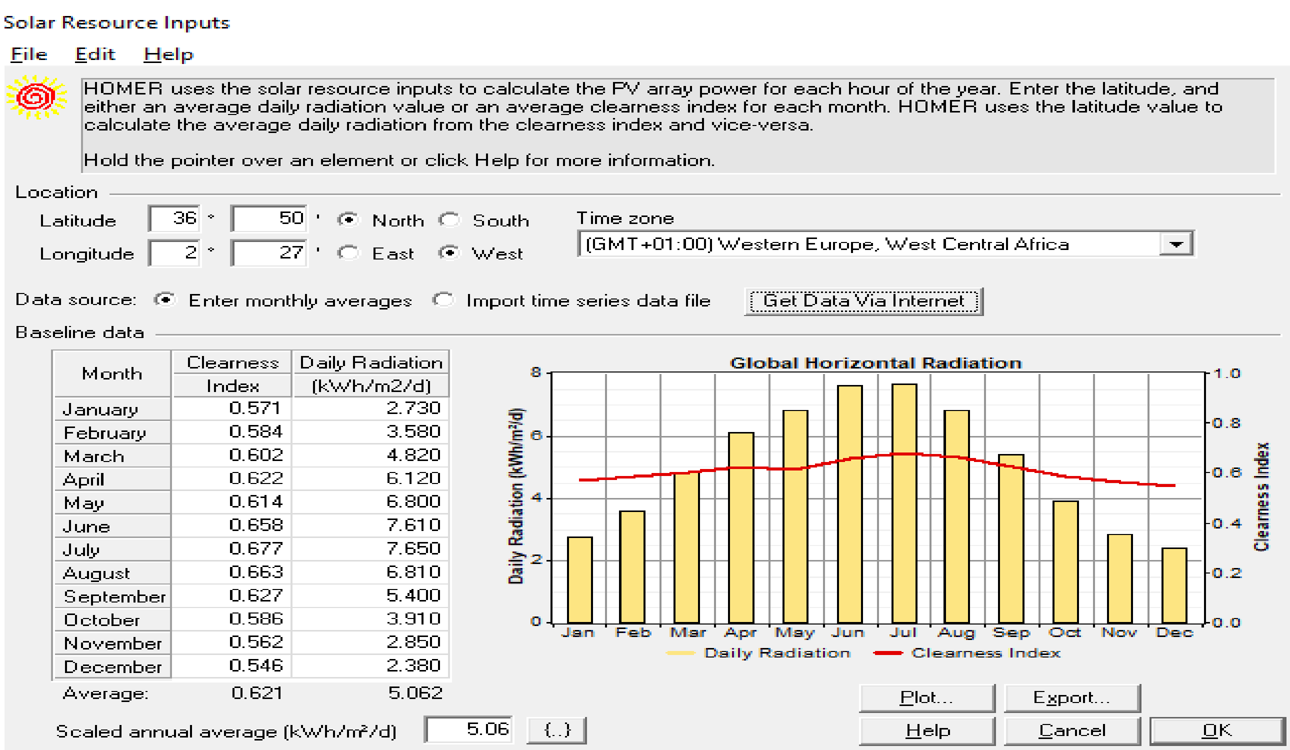
The consequences of using plastic shades on crops in a greenhouse structure are quite severe when compared to the use of solar PV panels. These panels are green technology and have very few or completely no environmental impact. In Almeria, most greenhouses use plastic covers, hence causing some major problems to farmers and have resulted to very high compensation costs for farmers to recover from regular damages on the farms and agricultural yields such as tomatoes, fruits and other vegetables. Dust particles, smog and plastic deterioration can greatly reduce light transmission reaching the crops. Although some farmers are able to provide plastic materials with anti-static properties that repels dust, dirt and smog standing in the greenhouses, these require extra costs, and still not efficient enough to withstand the weight of falling objects or heavy snow standing on the shading plastic cover.

- The temperature rise can sometimes be more than 45 $^{\circ}$Celsius inside.
- Plastic absorbs and retain over heat
- Shorter life span compared to PV panels
- Requires regular maintenance and high resilience costs
- Plastic shades not able to support the weight of snow during winter periods.
- Severe loss in crop during heavy storms and floods
- High humidity that can lead to crop deterioration
- Plastic shades cause environmental pollutions
- Plastic shades can affect wildlife and causes water contamination
- Requires regular replacement due to damages of existing plastic covers

Plastic greenhouse vegetable cultivation (PGVC), generate larger amount of plastic waste annually which have been difficult to control and usually the cost of recycling is often higher for farmers to afford in most regions (Umass, 2018). In Cameroon, one major challenge that urban cities face is the large quantity of urban wastes resulting from improper management skills, poor recycling efforts, and inadequate government regulations to mitigate the amount of plastic released on the environment. Implementing solar PV panels for farmers in regions such as Almeria with relatively higher annual solar irradiation will boost economic output and also improve living conditions of people whereas safeguards the environment and ecosystem from degradation.

Scaled annual solar radiation Almeria Spain

The case study 02 is a typical solar radiation condition of Almeria in Spain, whereby the annual solar condition is near the value of Santa village in Cameroon due to more sunshine and rigid nature of this part of Spain. In the past decades, Almeria has experienced very low level of rainfall, which has left this part of Spain very dry and hot in recent years. But despite of the high solar resource that is capable to produce enough electricity from solar PV that can be distributed locally or sold to neighboring countries grids, Almeria has not properly utilized the vast solar potential but have barely used plastic materials to provide shading on crops and greenhouses. PV panels could replace these plastics in order to help farmers also engage in electrical energy markets as an alternative source of income from their agricultural activities. Scaled annual average radiation in Almeria is 5.06 kWh/m^2/day that is about same value as in Santa agro-ecological village in Bamenda Cameroon being 5.01 kWh/m2/day. Peak production months in Almeria vary between June and July, with December and January having the lowest radiation due to winter climate and changes in solar condition of the region.



Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.571	2.730
February	0.584	3.580
March	0.602	4.820
April	0.622	6.120
May	0.614	6.800
June	0.658	7.610
July	0.677	7.650
August	0.663	6.810
September	0.627	5.400
October	0.586	3.910
November	0.562	2.850
December	0.546	2.380
Average:	0.621	5.062

Figure 29: Solar resource input for Almeria Spain

6.12 Energy stakeholders groups and energy regulators.

Table 10. Cameroon energy stakeholders and regulators (ENEO Cameroon, 2018)

Energy Regulator	- Ministry of energy and water (MINEE) - Electricity regulatory agency (ARSEL) - Rural electrification agency (AER)
Environmental protection	- Ministry of Environment and forestry (MINEF)
Utilities	- The Energy of Cameroun (ENEO)
Top Banks	- Afriland First Bank - ACEP Cameroon - Alios Finance Cameroon
Consumers	- Industrial sectors - Commercial sectors - Residential sectors - Agricultural sectors

The main energy actors and policy makers in Cameroon include the following bodies as mentioned in Table 10. These bodies (agencies) have been laying down very strong regulations that have seen the use of renewable energy such as hydropower and solar in due progress in the country as a way to keep carbon dioxide emission lower as possible. Though very strict monopoly existing in the energy sectors in Cameroon which prevents competitors and independent power producers (IPP) from running their own power plants and involving in the sales of electricity, yet this stakeholder's group have managed to set an action plan which emphasizes the use of more green energy technology such as solar PV and hydro across Cameroon.

The Cameroonian government and ministry of energy and water supply, through the effort of the main national utility agency ENEO Cameroon, has engaged a solar project with a French renewable energy corporation; JCM Greenquest to produce a capacity 72MW of power from a major solar project planned to start in 2019 at Mbalmayo Cameroon. The government of Cameroon believes this will increase the share of renewable energy and will also strengthen and contribute a reasonable increase in power of the electricity distribution to some regions in the country (Solar plaza, 2018, 26). However, this will also reduce high dependence on hydro resources, which has been contributing above 75% share in the total national energy production.

Under the long-term energy development plan (PDSE 2030) and the poverty reduction strategy paper (PRSP), Cameroon is striving to leave its under-developed status behind and seek to increase its renewable energy production, which will ensure self-sufficient of clean and affordable use of energy for its citizens and industries. Heavy expansion towards renewable energy sources to diversify its energy needs and portfolio is of first priority to the national energy distributor in Cameroon, in order to meet its annual and increasing energy challenges such as the current inability to provide every region of the nation with steady and affordable electricity flow.
This development and ambitions are due to the objectives laid down by the government under its 2035 vision to emerge as a stronger economy and leading to high standards of living.

The policy also aims to increase total generation and deliver electricity with an emphasis on renewable energy. The creation of a new legal framework for the promotion of renewable energy is another effort made by the government to reach its 2035 vision for an emerging economy. In 2011, the ministry of finance exempted solar panels manufacturing or importation, from value added taxes as a strategy to grant investors the free access to import and use solar panels to produce electricity in order to meet up their diverse energy needs. This exemption policy is capable to contribute in the significant expansion of the solar systems in the Cameroonian residential PV applications. By 2020, the Cameroonian government aspires to reach electrification rates of 48% countrywide, with about 75% electrification share in urban areas and some 25% in the rural communities in order to create some balance to meet the needs of subscribers across the nation (Solar plaza, 2018, 26).

7. Conclusion

The purpose of this thesis is to study and design a solar system for a farmer in the Santa agro-ecological village northwest region of Cameroon, who intends to generate electricity for daily farm use, and to distribute electricity from his solar farm to surrounding residents at low costs as an alternative source of income from his farm products. In a system whereby the crops are cultivated beneath the solar panels on the same piece of agricultural land (APV). In addition, to increase the land use efficiency by ensuring that; the solar panels provide enough shading on the crops in order to prevent them from very hot climatic condition which in the past has affected crop yields significantly. To promote and encourage the dependence of farmers and energy users on renewable energy such as solar which in addition, protects our natural environments from damages which are caused by the continuous burning of fossil fuels, crude oil and other harmful gases when generating electricity for daily use. The optimization of battery systems to store the energy generated for use is an important aspect.

In order to satisfy the electricity demands by the farm to power on-site equipment such as irrigation pumps, refrigerators, poultry lighting and the estimated electricity for the local population around the solar farm. The rated power (kW) and the operating times for the equipment is, studied in details to size the solar system with actual precision based on the amount of daily energy needed. This thesis also takes into consideration some analysis and comparisons of different shading types and their effects on crops yields. A good example is the case of Almeria in Spain where a large number of greenhouses are, covered with plastic materials. However, there is a vast solar potential in that part of Spain that is capable to generate enough electricity for farmers and for transmission into the national grid, and can as well be supplied to neighboring countries to increase their electricity capacity and as a source of income for farmers in Almeria region.

The different components of the APV power plant as used in the HOMER software for the design of this project which include; a diesel generator, PV modules, inverters, battery storage are simulated according to the system size and costs to match energy consumption and production for any particular year. However, the PV production contributes up to 94% of total annual energy production, whereas the generator provides about 6% of the total annual energy production. Moreover, the APV is, considered an effective way for farmers to promote sustainability, creating jobs, increasing food production and improving standard of living in their communities.

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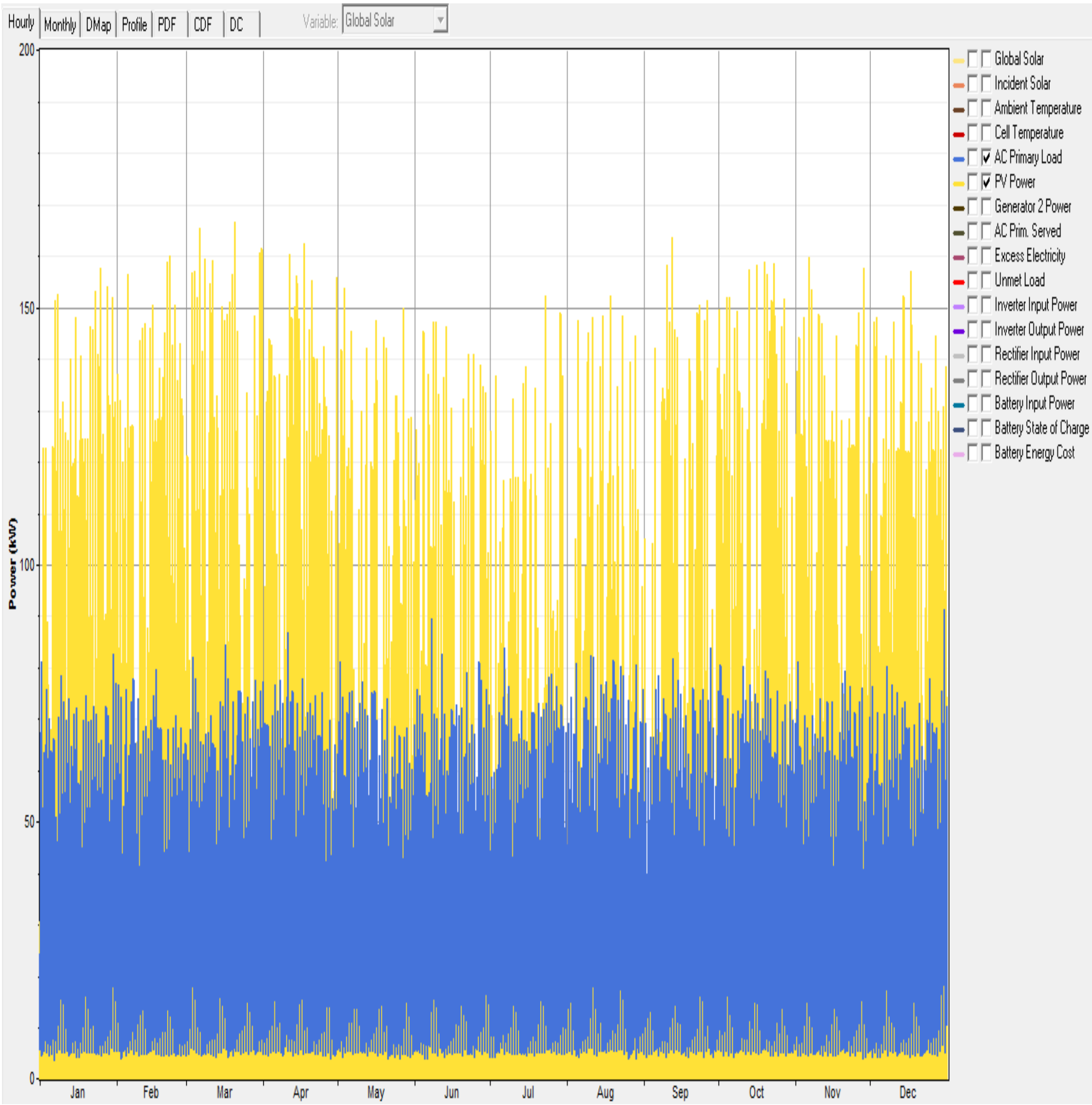
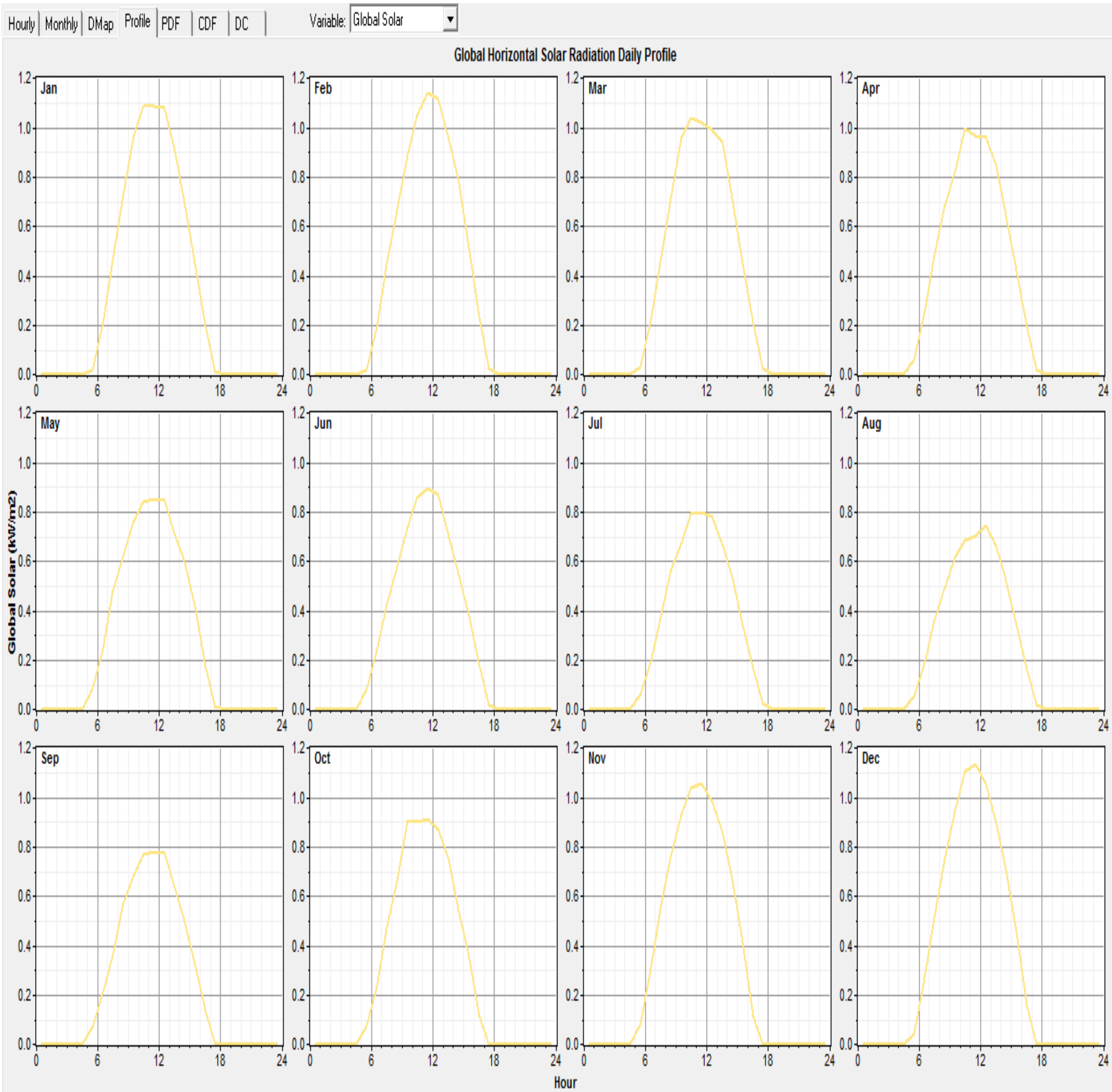
Appendix 1. Annual PV power production in Santa agro-ecological village Cameroon

Optimum system type



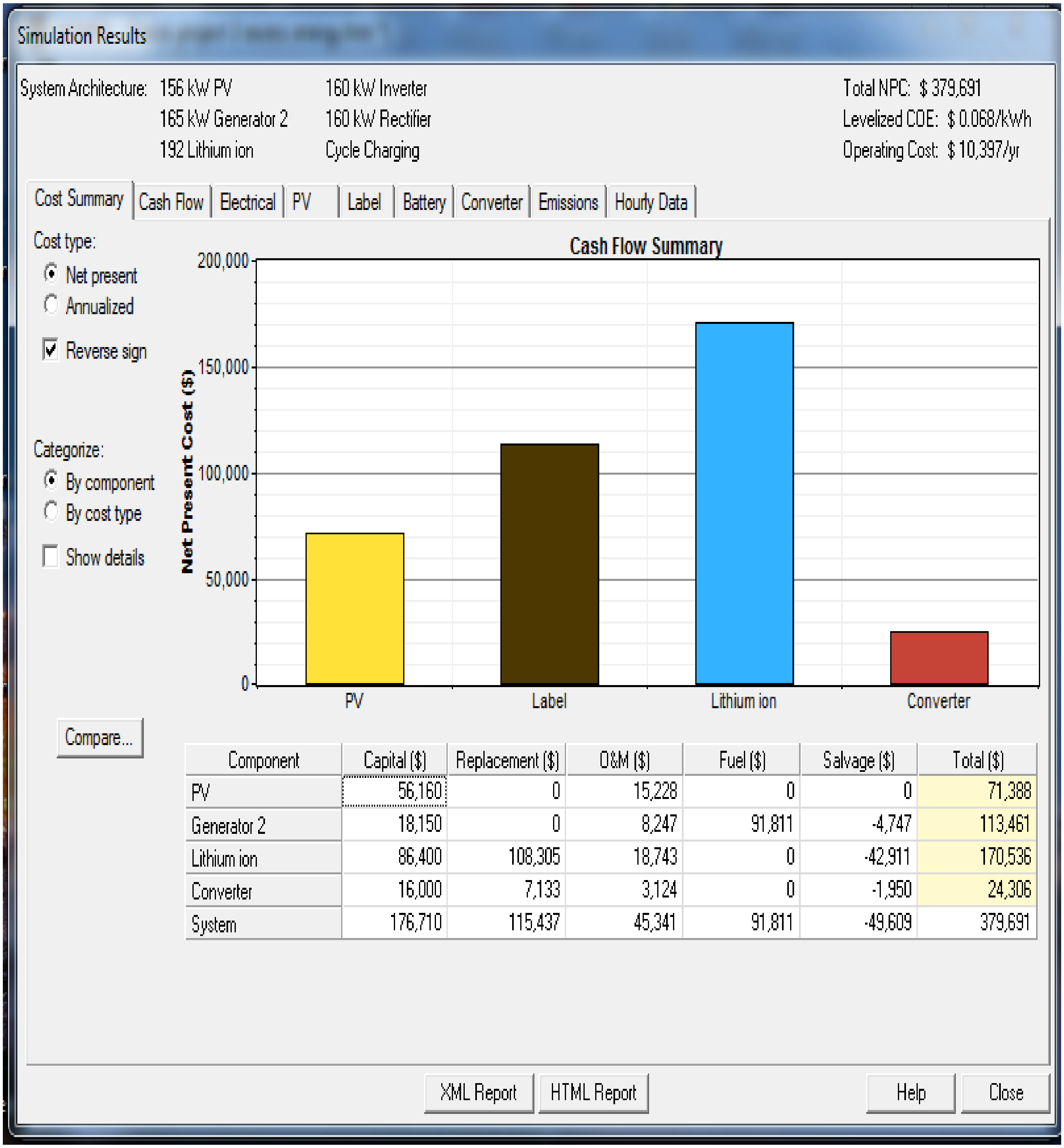
Appendix 2. Global horizontal solar radiation daily profile

Global solar (kW/m^2)



Appendix 3. Cash flow summary

Solar system size 156 kW



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	56,160	0	15,228	0	0	71,388
Generator 2	18,150	0	8,247	91,811	-4,747	113,461
Lithium ion	86,400	108,305	18,743	0	-42,911	170,536
Converter	16,000	7,133	3,124	0	-1,950	24,306
System	176,710	115,437	45,341	91,811	-49,609	379,691