Centralized and Decentralized Solar Power Control and Distribution:

A comparative analysis of operational and economic aspects

A Thesis
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DECLARATION

We hereby declare that research work titled "*Centralized and Decentralized Solar Power Control and Distribution: a comparative analysis of operational and economic aspects.*" is our own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/referred.

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ABSTRACT

Solar power is the cleanest and most plentiful source of renewable energy. As the other alternative sources reduce gradually, solar power is now becoming a very popular source of energy in remote areas as well as urban areas. Solar power system can be provided in two ways, centrally and de-centrally. Centralized solar power system is mainly a large-scale installation of solar plants producing substantial electricity which is supplied to the loads. In contrast, decentralized solar power system refers to solar energy solutions that produce energy on-site or near-site. We have found four cases so far that can be powered by both centrally and de-centrally. Those are home systems, battery charging stations, street lights and traffic lights. Considering the increasing demand of solar energy, Control and Applications Research Centre (CARC), BRAC University, has proposed a complete comparison between centralized and decentralized solar power system which includes economic and technical aspects for establishing a reliable solar energy system. We have used HOMER Pro and RETSCREEN software for the economic analysis for each case. This paper briefly describes the different aspects of these two solar power systems and provides a proper suggestion for a better and sustainable power system.

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CHAPTER 1

INTRODUCTION

1.1 Background:

Recently, Bangladesh's gross domestic product (GDP) growth has reached 7.24 percent fiscal year, which broke all the previous records in the history of the country's economy [1]. A rise in GDP increases the standard of living of the citizens but not necessarily increases the standardof each and every income class of the nation. Sometimes in some cases the rich are getting richer while the conditions of poor are same if not worsening. It has been observed that the higher per capita energy consumption of a country, the more prosperous that country is. Energy, particularly electricity, is considered one of the pre-requisites for technological development, economic stability, and poverty eradication in any community. In our country, the electricity access in city areas can meet the demand effectively, where in the urban and rural areas; it cannot fulfill the demands properly.In Bangladesh, around 70% of people having lack accesses to electricity and most of them are living in the village. Among them about 40% are living in below poverty line.On the other hand climate change has put additional threats to development.As Bangladesh government has set the goal of making a country where poverty will be completely eradicated, the electricity demand must be fulfilled so that the standard of living can be better than before. Considering these situations, renewable energy technology stands out to be one of the expected sources to meet our energy demand and can contribute to attainsustainable development as it is a country with a plentiful supply of renewable sources of energy.

Conventional energy sources like Natural gas, coal, oil etc. arecost ineffective, limited and not environment friendly. More than three-quarters of the nation's commercial energy demand is being met by these sources which likely to be depleted by the year 2020 [2]. Among alternative solution of renewable energy, solar energy is the most convenient and reasonable energy source to produce electricity.Now-a-days, it is being a very popular source of energy because of its endless availability where natural gas is decreasing day by day. Thus solar energy has a large potential to be used in various sectors in Bangladesh to reduce the conventional fossil fuel based power consumption and to ensure a green environment for the future generation.

1.2 Recent condition of electricityin Bangladesh and probability of solar energy:

Electricity is the major power source of country's economicactivities. Today billions of people lack access to the most basic energy services: as world energy outlook 2016 shows 1.2 billion people are without access to electricity [4]. As January 2017 Bangladesh's total installed electricity production capacity was 15,351 MW [3]. 92% urban population and 67% rural population have the access of the electricity for their only source of light [3]. A total average of 77.9% population have the access to the electricity in Bangladesh[3] .Main problems that have been faced in Bangladesh's electric power sector include high system losses, delays in completion of new plants, low plant efficiency, unreliable power supply, electricity theft, blackouts, and shortages of funds for power plant maintenance [3].

Moreover, the country's generation plants have been incapable to meet system demand over the past decade [3]. Noncommercial energy sources, like wood fuel and crop residues are expected to meet over half of the country's energy consumption [3].

Providing electricity to all may be not possible because of the increasing demand for electricitywhich is growing by 10% yearly in Bangladesh. Our country is geo-graphically located in an area that has a potential to utilize different renewable forms of energy. On the other hand, Bangladesh is one of the countries that are seriously vulnerable to the effects of climate change; hence, the use of renewable energy can contribute to decline the effects of both climate change and environmental degradation in the country.

Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.631	4.360
February	0.615	4.920
March	0.599	5.590
April	0.552	5.760
May	0.481	5.300
June	0.405	4.530
July	0.382	4.230
August	0.404	4.290
September	0.415	4.020
October	0.516	4.320
November	0.600	4.280
December	0.643	4.210

Annual Average (kWh/m²/day): 4.65

Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.620	4.420
February	0.609	4.980
March	0.575	5.440
April	0.526	5.510
May	0.465	5.110
June	0.375	4.160
July	0.367	4.040
August	0.394	4.180
September	0.411	4.020
October	0.502	4.280
November	0.578	4.250
December	0.631	4.280

Annual Average (kWh/m²/day): 4.56

Figure 1.1: Solar GHI Data for Dhaka and Chittagong

Source: NASA Surface meteorology and Solar Energy database

The average solar irradiance data indicates that the period of bright sunshine hours in the coastal regions of Bangladesh varies from 3 to 11 hours daily. The insolation here varies from 3.8 kWh/m2/day to 6.4 kWh/m2/day at an average of 5 kWh/m2/day [7]. These indicate that there are good prospects for solar thermal and photovoltaic application in our country.

Energy gained from the sun that reaches the surface of the Earth, may be utilized and exploited for electricity generation. A PV system is the most reliable of all the existing technologies because of its abundant availability compared with other renewable sources (i.e., wind, hydropower, biomass, biogas, and wave). Some unique and competitive features make a PV system more valuable energy source for example high modularity, non-demand for extra resources such as water, fuel and low maintenance cost.

The Earth obtains approximately 3,400,000 EJ solar radiation annually which can deliver 450EJ energy and this amount is 7500 times higher than the energy consumption of the world [5]. We can set up a PV system easily on existing building for example rooftop or open spaces where sufficient sunlight can be reached or other decentralized way to produce power that will reduce the pressure on our conventional national grid.

1.3 Introduction to Centralized and Decentralized solar power system:

Centralized solar power system refers to a large-scale solar plant installation to produce large amount of electricity. Like the conventional national grid system, Centralized solar farms need the same infrastructurewhich includes electrical substations and transmission lines to be run over long distances, to get that clean solar power to the consumer.The main disadvantage of this system is sometimes efficiency and voltages are lost, when electricity has to travel long distances.

Decentralized solar power system is the opposite of centralized system. Decentralized solar plant, refers to solar energy solution that produce energy on-site, or near-site. For some cases, in this system there are less or no voltage losses as no transmission line is required to reach electricity to the consumers. Sometimes the end user owns the solar power system and directly receives the benefits of the system. By this system, energy needs of the owner can be taken care by themselves.

The geographical condition of Bangladesh is not very flexible to draw the transmission lines to a very long distance from national grid due to plenty of rivers or islands or uneven ground condition. As a result, the rural areas are remaining without the access of electricity. Centralized and decentralized solar plant installations can be an effective solution in this regard because of its abundant potential.

In our paper the cases we are considering for both systems are-

1) Home systems
2) Battery charging station
3) Street Lighting
4) Traffic Lighting

1.4 Motivation:

Bangladesh is still at a very low level of Electrification. The government of Bangladesh has announced its vision 2021 to provide electricity for all. Power Sector Master Plan 2010 (PSMP-2010) has been undertaken to accommodate the government's vision 2021, According to PSMP study the electricity demand would be 34,000MW by the year 2030[6]. Government introduced a scheme known as solar home systems (SHS) to provide electricity to households with no grid access. The program achieved 3 million household units starting late 2014 and with more than 50,000 systems being included every month since 2009 [7]. The World Bank has called it "the fastest growing solar home system program in the world" [7]. Beside this, Solar PV based mini-grid projects are installed in remote areas of the country by IDCOL. These projects provide grid quality electricity to households and small commercial users and thus encourage commercial activities in the project areas. The mini-grid project has successfully created access to low-emission electricity for almost 5000 rural households in Bangladesh [8]. Like this some other technologies has been invented throughout the world like street & traffic lights, irrigation system, vehicles, battery charging stations that can run by solar power. We can bring these technologies in our lives too and show our dedication towards them like SHS and mini-grids and achieve 100% electricity access throughout the county.

People of our country are continuously finding out ways how to make effective use of sun power. If we want to eliminate power scarcity, we do not have any choice but to find out a better and sustainable solution between centralized and decentralized solar power system.

1.5 Objective:

Less accessibility to modern energy services is one of the main reasons for a country to have poverty and low economic development. The supply of electricity is not remarkable in our country, especially in rural areas; supply does not meet the demand. Through our thesis we analyzed the operation and economic aspects comparatively between centralized and decentralized solar power system to find out a better and effective solution so that our country can meet its 100% electricity demand as well as our rural villages can turn intro smart villages. Smart villages includes the facility of good education and healthcare, access to clean water, sanitation and nutrition, the growth of productive enterprises to boost incomes and enhanced security, which is completely impossible without the access of electricity. Also, our objective is to make people less dependent on national grid as natural gas is decreasing day by day. By comparative analysis we will try to provide a cost-effective solution between centralized and decentralized solar power system covering all the aspects.

1.6 Summary of the Following Chapters:

The following chapters portrays our thesis work, the details idea and working procedure about centralized and decentralized solar power system, comparative analysis of the appliances and systems, software simulation, decision and future works. The first chapter gives the overall concept about our thesis work, background, motivation and objective. The second chapter gives the idea elaborately about what centralized and decentralized solar power system is andtheir applications. The third chapter shows the details idea and operational and economical comparison between centralized and decentralized solar powered home systems. The fourth chapter elaborates and compare between solar battery charging station and decentralized solar power charging kit. The fifth chapter gives the idea about centralized and decentralized solar powered traffic control system. The sixth chapter shows the comparison between centralized and decentralized solar street light system. In chapter seven we gave economic analysis using HOMER Pro and RETSCREEN software simulation. The eighth chapter gives the overall summary of our entire thesis according with the challenges we faced and also our future works that is yet to be done.

CHAPTER2

Centralized Solar Power System and Decentralized Solar Power System

2.1 Centralized Solar Power System

2.1.1 Introduction:

Centralized plants are usually located at the point where the best resource is available. Centralized solar power system is a large-scale installation of solar panels which serve as generation stations to help the consumers byproducing significant amount of electricity. It needs a large amount of land to install and highly depended on the geographical location of the country. This set up requires a huge capital investment. In some centralized solar farms, electrical substations and transmission lines are required to transfer power from the station to the consumers.

2.1.2 Working Procedure:

Centralized solar power system has almost the same infrastructure like conventional national grid system. This system has main components like:

Solar array: A series of solar module that converts sunlight into direct current (DC) electricity and stores it in batteries to use at day and night.

Battery: Batteries are used for the purpose of storing energy produced by the PV array during the day and to supply it to electrical loads as needed (during the night and periods of cloudy weather). Other reasons batteries are used in PV systems are to operate the PV array near its maximum power point, to power electrical loads at stable voltages, and to supply surge currents to electrical loads and inverters.[9]

Solar charge controller: This equipment controls the progress of energy fulfillment from Array module to the battery.

Inverter: It is the equipment that changes DC voltage into AC in the load side.

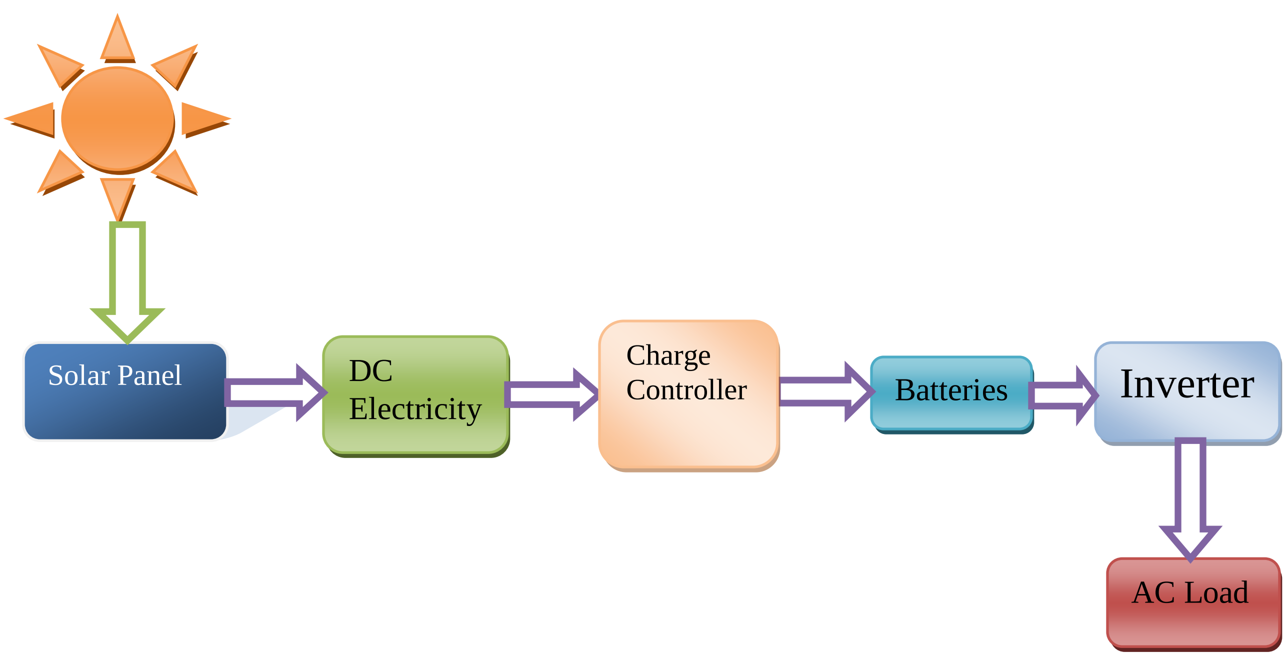


Figure 2.1.1: Energy flow diagram for centralized system

The working procedure of the system changes according to sunlight.The electric energy which is produced by solar module (PV) is directly distributed to the load by inverter. The remaining energy is stored in the battery for further uses.Solar charge controller protects these batteries from overcharging.The amount of energy produced by PV depends on the sunlight intensities and cell efficiency.

The source of solar energy cannot be used anymore at night, so the load will be supplied by the battery. The energy that has been saved in the battery at noon will be used for supply through the inverter. Same process is used during cloudy weather.

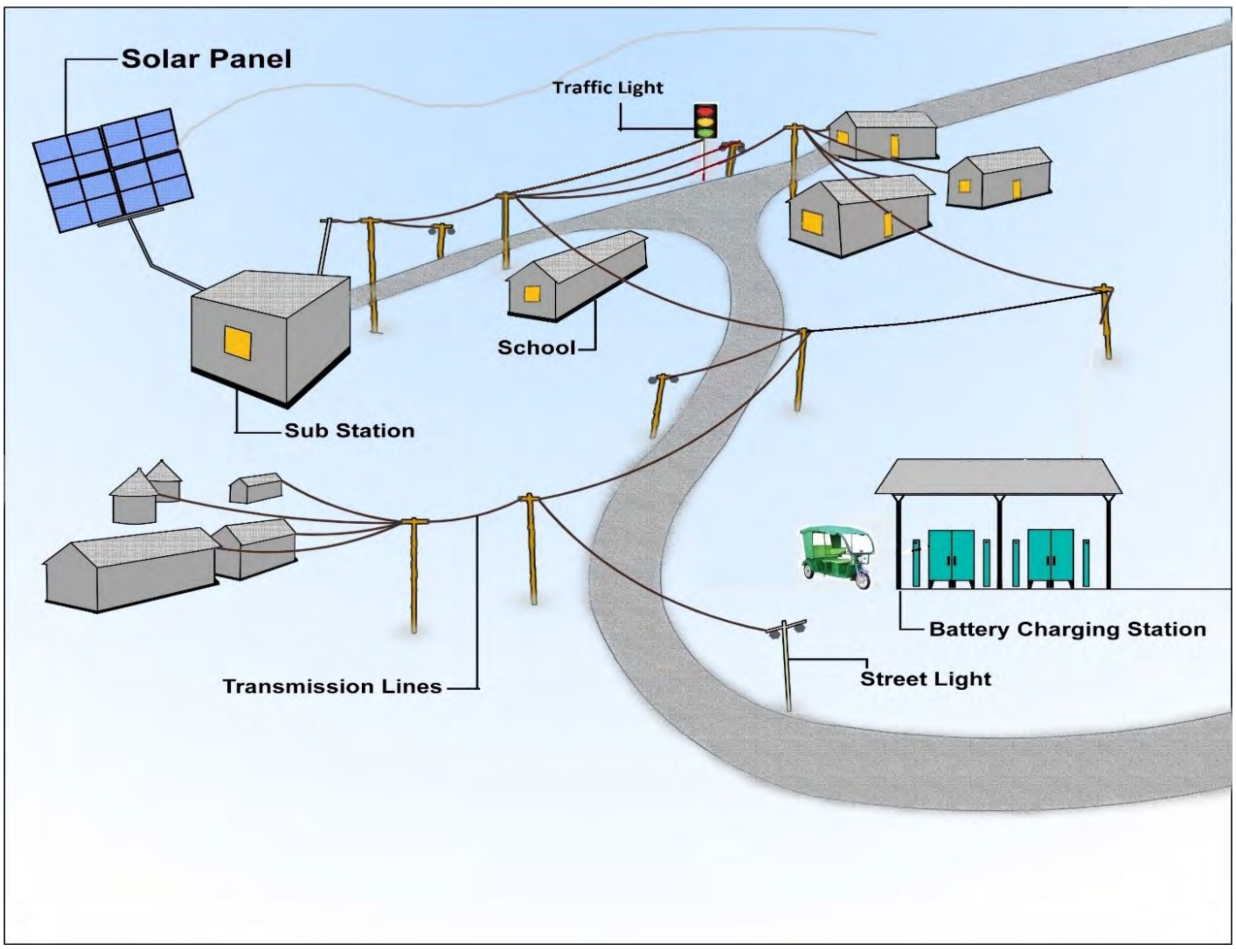


Figure 2.1.2: Centralized solar power system

2.1.3 List ofthe System:

1. Centralized solar mini-grid connected housing system
2. Centralizedsolar street lighting system
3. Centralized solar traffic control system
4. Centralized solar battery charging system

2.2 Decentralized Solar Power System

2.2.1 Introduction:

Decentralized solar power system is also an energy solution with less or no voltage losses. It refers to smaller energy systems that produce energy on-site or near-site. The consumer often owns the system and directly receives the financial benefits of the system.In many locations, excess electricity whichis not used by the owner can be sold to the local service and distributed for more widespread use.Unlike centralized solar energy generation, this system can be more freely operated in any geographic location.

2.2.2 Working Procedure:

The function of this system is not different from the centralized solar energy system. As it the smaller version of the previous one, all the elements can be used according to the willing of the consumer. It depends on the loads it is going to power for both day and night and also in unpredictable situations. Today's technology has been so advanced that many gadgets and electronics have been invented that can run by solar directly. If a consumer owns those technologies, he/she does not need extra energy to run them for a long time. Thus the loads can be eliminated and energy can be saved.

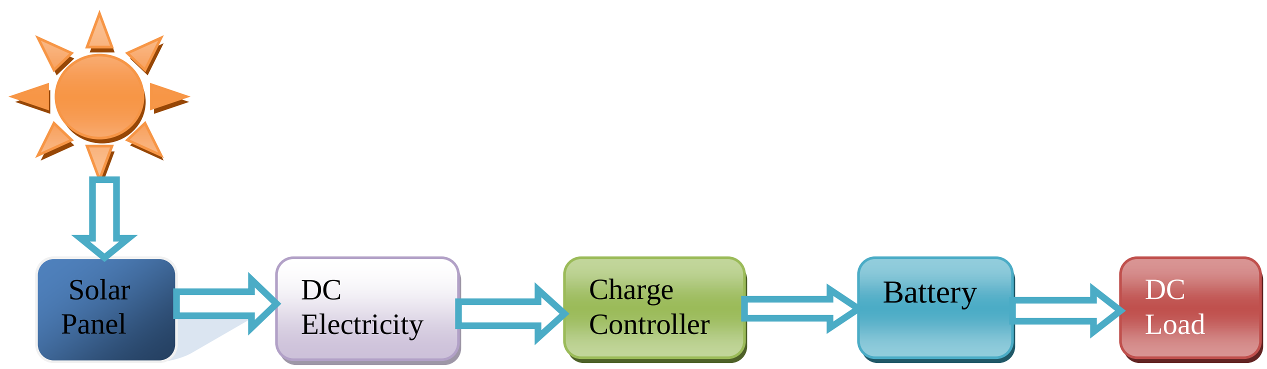


Figure 2.2.1: Energy flow diagram of decentralized system

2.2.3 List of System:

1. Decentralized solar home system

2.Decentralized solar street lighting system

3. Decentralized solar powered traffic control

4.Dedicated solar charging kit

2.3 Some basic terms and formulas of PV system

<u>Mini-grid and Micro-grid:</u>

A mini grid or micro grid refers to a set of electricity generators and energy storage systems interconnected to a distribution network that supplies electricity to a localized group of customers.Mini-grid is larger in size than micro-grid. The types of loads that are served by a micro-grid are usually residential or very small commercial where mini-grid is able to serve larger commercial and small industrial loads.

PV System Designing [29]:

- Power consumption (Wh/day) = ∑(Watt of appliances* hours used)
- PV panel capacity (Wp) = $\frac{Total\ power\ consumption\ *1.3}{Power\ generation\ factor}$

  Here, 1.3 = Energy loss in the system

  Power generation factor (PGF) is used in calculating PV panel size and it varies from location to location depending upon the climate condition of the site.
- No. of PV panels needed = $\frac{Watt-peak}{Panel\ rating}$
- Total watt of appliances = ∑Watt of appliances
- Inverter size should be larger than 25-30% of the total watt of appliances.
- Battery capacity (Ah) = $\frac{Total\ watt-hour\ per\ day*Days\ of\ autonomy}{Battery\ loss*DOD*nominal\ batery\ voltage}$

  Here, days of autonomy is the number of days a battery bank can provide power to the appliances without being recharged by the solar panels.

  DOD or depth of discharge is how deeply the battery is discharged.
- Charge controller rating = Total short-circuit current of PV array*1.3

CHAPTER3

Centralized Solar Mini-grid Connected Home System andDecentralized Solar Home System

3.1 Centralized Solar Mini-grid Connected Home System:

Solar mini-grid or micro-grid connected power systems are one of the alternative ways to use solar energy to power our houses in remote areas. They can be scaled up or down to meet anything from a portion of a household's power requirements. A centralized solar home system is electricity generating solar power system that is connected with transmission network. In this system, the solar panels generate high voltage DC power which is then fed through an inverter which converts it into AC power which feeds into consumers' switchboard. Within the design, there is a backup battery bank to meet short-term peak demand without paying any extra charge. Living with a grid connected solar system is no different than living with just the normal grid power. PV solar systems designed for grid connection are usually designed to meet at least the basic appliances of a homeowner's electrical need.

3.1.1Working Procedure:

1. When sun shines on the solar photovoltaic panels, the solar cells generate DC electricity.

2. The electricity then runs from the solar panels through an inverter that converts it from DC to AC electricity for household appliances.

3. This electricity passes through transmission lines and delivers power from generating stations to the consumers.

4. Any appliances that are AC powered can use the solar power, including lights, fans, television and refrigerator and so on.

5. When used in grid connected solar systems, storage batteries can be classified into short term storage for a few hours or days to cover periods of bad weather and long term storage over several weeks to compensate for seasonal variations in the solar irradiation between the summer and winter months.

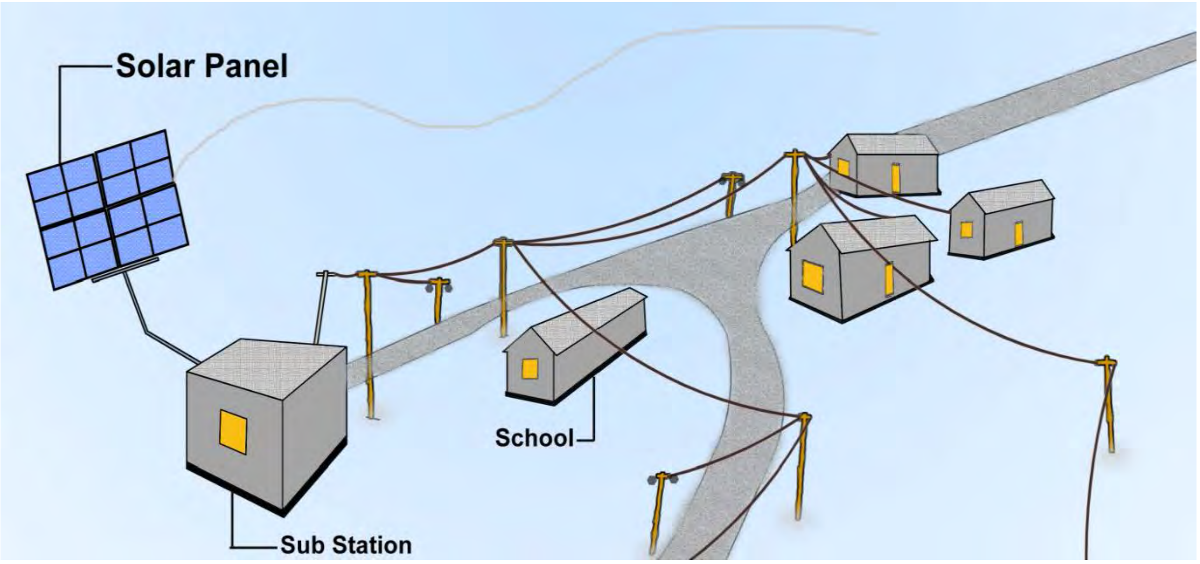


Figure 3.1.1: Centralized solar mini-grid connected home system

3.1.2List of Appliances:

1. AC Light.
2. AC Fan.
3. AC Television.
4. AC Refrigerator.
5. Electric Stove

3.1.3 Merits & Demerits:

<u>Merits:</u>

- Large amount of energy can be produced, so people, who cannot afford SHS individually, can be benefitted.
- Mini-grids are capable of generating three-phase AC electricity which is used for many diverse applications and also economic emancipation.
- There is a realistic abandonment option, as solar equipment can be reasonably repositioned to a market with higher demand, or can be recycled into solar home systems.

<u>Demerits:</u>

- Transmission losses.

  For example, for 11kV distribution line, the losses are given below:

  Total nos. of Distribution Transformer on Feeder 25 KVA= 3 No, 63 KVA =3 No,100KVA=1No.

  Total Annual Iron loss is 10424Kwh

  Total Annual Copper loss is 6490Kwh

HT Line Losses = 831 Kwh

Peak Power Losses= 3.0

LT Line Losses = 3315 Kwh

Total Technical Losses = 21061 Kwh

% Technical Loss=4.30%

- Government subsidy plays an important role for the establishment of this plant. It is seen that without subsidy, the cost will not be feasible.
- The cost of land in Bangladesh in rural areas increases at a high rate every year because of rising population and shortage of serviced land. The cost of land adds a huge challenge for installing solar plants.
- The battery bank requires suitable space as well as ventilation for temperature control. Storage system management is one of the challenges of developing mini grids.
- Bangladesh is a densely populated country so use of lands only for solar PV installation may not be viable considering the crop yield per year.

Some Solutions:

- Remote and isolated locations are ideal for mini-grid site. Generally island, remote village those are far away from national grid network.
- To avoid high transmission losses it needs to be ensured that the distance between end users and central units are not too long. So densely populated areas are the best choice for a mini grid.
- Usually power generated from the solar alone has high unit energy cost. However, combining both solar and fossil fuel, the total power problem can be solved with a less per unit cost of energy.

- The installation of a solar plant takes a fraction of the time. As a result it will be feasible to delay the project to get benefitted from the falling price of PV or the rising price of fossil fuels.
- We can monitor how the price of electricity changes if we choose to make the investment in the land now, but install the solar grid in the future. Delaying the project will make us enable to offer electricity at a cheaper rate, as long as we buy the land now. [12]
- Designing a solar power plant with a small diesel generator not only reduces the requirement of storage system but also can provide energy in low insolation days.
- As the lands are very costly now, south facing rooftops of rural households for placing PV panels can be an alternative solution.

3.2 Decentralize Solar Home System

Solar home systems (SHS) are decentralized photovoltaic systems that offer a cost-effective solution of supplying power to appliances to remote off-grid households. In rural areas where grid connections are unreachable, SHS can be a reliable source of electrification to meet a household's energy demand fulfilling basic electric needs. Rural electrification through decentralize solar technology is becoming more popular day by day in Bangladesh. Solar Home Systems (SHSs) are particularly suitable for isolated, inaccessible areas. This solar program mainly targets those areas, which have no access to conventional electricity and little chance of getting connected to the grid within 5 to 10 years. SHSs can be used to light up homes, charge cellular phones, run televisions, refrigerators, radios etc. SHSs have become increasingly popular among users because the system offers an alternative way to conventional electricity such as no monthly bills, no fuel cost, very little repair, maintenance costs, easy to install anywhere etc. [10] Also, in the off grid areas of Bangladesh, solar home system is getting popular day by day due to its declining price and due to favorable financial packages. On the other hand, Bangladesh's solar power has largely been a success story. The Solar Home Systems (SHSs) that power rural households is both economically feasible and environmentally friendly. The government and international communities are in favor of it because it produces power in an eco-friendly and sustainable manner. This program is more preferable to the end-users, who are mostly poor rural inhabitants, because the monthly installments for each set-up are less than the equivalent monthly amount spent on kerosene to meet their power needs.[11]

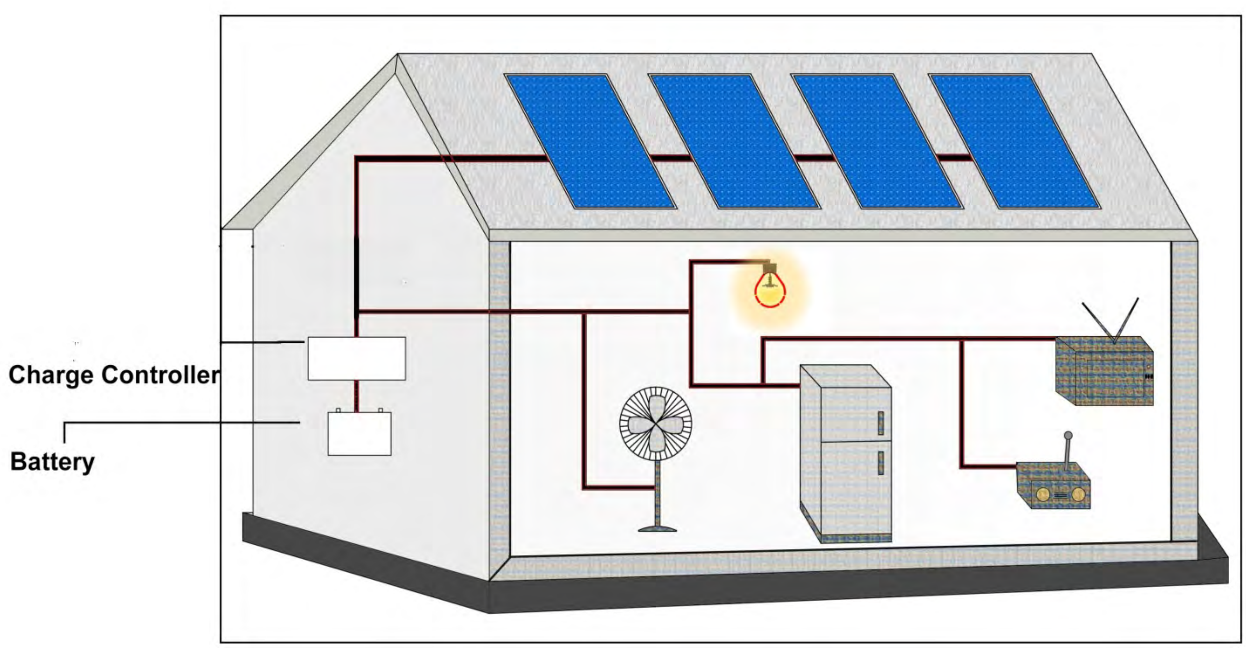


Figure 3.2.1: Decentralized solar home system

3.2.1Working procedure:

The working principle of SHS is almost as same as grid connected system. But SHS can be run in two ways with the invention of latest technologies now a days. Recently some appliances has been invented that run successfully with the help of solar power which has lessen the use of AC power. Solar heater, solar refrigerator, solar cooker, solar fan etc. along with DC powered fan, light etc. will terminate the use of inverter in SHS system. On the other hand, if anyone wants to use inverter in his home system, he needs to use all the AC appliances like the grid connected system. The system consists of batteries, charge controller, panels and sometimes inverter.

The role of each part as follows:

- Solar panel is the main and highest valuable part of the system. Its role is to convert the sun's radiation to electrical energy and then make the electrical energy store in batteries or directly power the loads.

- Lead-acid batteries are the most popular in solar home system. Its role is to store energy when there is sunlight and release it when necessary. Mainly in night time or when the sun light in not enough, batteries are the supplier of the energy to the loads.

- Charge controller plays a role of battery over-charge protection as well as over-discharge protection. In areas with large temperature difference, the qualified controller should have temperature compensation function.

- As solar home system is a stand-alone system for powering individual houses, installing it in a cost-efficient way is a challenge. Inverter alone costs a huge amount of money so appliances with battery facility can be an option to reduce the cost of inverter.

- In many occasions, it needs to provide 220VAC, 110VAC power to the loads. As the direct solar energy output are generally 12VDC, 24VDC, 48VDC, in order to provide the AC electrical power, the DC power needs to be converted into AC power. So we should use the DC-AC inverter. In some cases, if it needs to use a variety of voltage load, we also should use DC-DC inverter.

3.2.2 List of Appliances:

1. DC Light.
2. DC Fan.
3. DC Television.
4. DC Refrigerator.
5. DC Stove

3.2.3 Merits & Demerits:

Merits:

- No transmission loss as the PV panels is installed in the individual owner's house.
- No converter is required; all the appliances are mainly DC components.
- Easy to set up.
- Less space is required.
- Easier transferability than mini grids.

Demerits:

- Difficulties in maintenance facilities.
- Dust accumulation, shading etc. reduces the output.
- Hot spots are generated in the SHS due to shading that reduces the operating life as well as output of the panel.
- People are not aware about the life of the battery with regard to depth of discharge (DOD) and lack of knowledge about proper operation & maintenance of solar panel.
- The batteries are not giving proper back up and life of the battery is reduced appreciably.
- SHS is sold at high interest installments.
- From a technical design perspective, much of the challenge in minimizing costs in an SHS centers on the successful optimization of battery lifetime.
- One of the main reasons for unsatisfied customers is systems that are undersized and/or overused, resulting in power failure.
- DC appliances are not still acceptable to the consumers due to its high price.
- Difficulties in obtaining loans from private financial institutions.

- Some of the packages that are offered to the customers were found to suffer design defects, such as the number of lamps being larger than the system could provide for.

Some solutions:

- Increasing awareness among rural peoples about maintaining of solar panels. Also, some training programs can be introduced.
- A mini solar grid model may solve many of these existing problems. This may help to meet their future demands with reasonable price.
- High-efficiency DC appliances (fans, TVs, and refrigerators), which, while being more expensive, result in a reduction of the size of PV and battery due to their lower energy consumption.

3.3 Comparison between Centralized Solar Mini-grid connected Home System and Decentralize Solar Home System

- From our software simulation we got the energy cost of a mini grid connected house is 542 BDT per month and investor's payback period is 10.5 years. On the other hand, a decentralized SHS consumer monthly saves 542 BDT by installing his own system. So per year the system saves 6504 BDT and thus we can get the payback period is 9.6 years. Here, decentralized solar home system is better than centralized mini-grid home system.
- Grid expansion is challenging and costly but we can install SHS in our existing places easily without affecting huge lands and forests. Yet, where

land is very costly, rooftops of rural households or institutions can be an alternative solution for the installation of solar PV panels for mini grid. Here, SHS is more space efficient but solar mini grid can also be used efficiently.

- As our target is to use electricity efficiently, SHS is the ideal way to reduce the wastage and loss of energy. Mini-grid produced electricity that is passed by transmission lines, waste a lot of energy while transmitting. But if the distance between consumers and grid can be minimized or densely populated area is chosen, the transmission loss can be avoided. However, SHS is better than centralized solar grid in this respect.
- It has been found that the satisfaction level of the people is not that encouraging because of low backup time in the evening and high cost involved in battery replacement, difficulties in maintenance facilities in decentralized SHS system.
- If we consider future loads, the amount of electricity demand will be increased with the rapid growth. To minimize the power consumption, DC appliances are the best solution though they are very expensive. In contrast, AC appliances can be used with the connection of mini grid, but power consumption will be higher in that case. So, decentralized system is better for long run.
- People or rural areas want constant source of electricity now a days because of their increasing demand. If load is increased, it is easier to supply the additional energy from the centralized system where it is harder to add additional power source as well as backup facility for increasing load. Here, centralized solar mini grid is a better option for this.

- In a centralized system there is a facility of backup fuel generator which can be helpful for disastrous weather to supply power to the consumer but in decentralized SHS, only battery is the backup source which can act insufficient in such weathers. So, centralized can be a better option for such conditions.

3.4 Decision:

Decentralized solar home system is loss-less as well as space-efficient system where centralized home system wastes a large amount of lands and energies. On the other hand, centralized system can provide a constant source of energy if the load is increased but it is difficult to increase the energy source as well as back-up facility for a decentralized system consumer. Considering all the sides including cost analysis it is seen that decentralized home system is the better option for long run.

CHAPTER 4

Centralized Solar Battery Charging Station and Decentralized Dedicated Solar power Charging Kit

In modern time, among all new immersing technologies battery electric vehicle is one of the best for upcoming days. It is because these vehicles are run by electric motors powered by rechargeable batteries which make them different from vehicles with internal combustion. Electric vehicles convert about 59–62%[14] of the electrical energy from the grid to power at the wheels where conventional gasoline vehicles only convert about 17–21% of the energy stored in gasoline to power at the wheels. [15] However, charging the batteries from national electricity grids consume a significant amount of electricity everyday which puts pressure on the electricity used for our daily purpose. Also, EV may not produce any harmful pollutants like other conventional fuel vehicles but the power plants that produce electricity may pollute the environment. There is expected to have a vast demand of purchasing the electric vehicles in the next decade. Considering all the sides we found that using solar power in charging these batteries can be a great way to run electric vehicles. There is two ways we can operate the battery charging process-centrally and de-centrally.

4.1 Centralized Solar Battery Charging Station

4.1.1 Introduction:

A solar battery charging station (SBCS) is designed so that batteries can be charged in an environmentally friendly way. This system is a comparatively large set-up so that a numerous numbers of batteries can be charged at a time. It converts solar energy to electricity and stores it in a battery bank. The potential benefit of SBCS is highest for electricity assisted rickshaw in our country. These rickshaws have opened a new sector of automation ofvehicles in Bangladesh and have the potential of making an enormous contribution to the growing economy of this country. [16] The true prospect of these rickshaws is still unexplored because its commercialization is banned as they consume energy from the national grid. Not only rickshaws, other recent popular solar inventions like cargo hauler, human hauler, ambulance, tri-wheeler etc. needs SBCS for battery recharging and swapping.

4.1.2 Working Procedure:

Although the energy consumption of the electric vehicles can be reduced by recently developed torque-sensor paddle technology and solar PV array support, still they need to charge their batteries from national grid at some point of the day. The SBCS is designed to utilize the abundant solar energy to charge the batteries of the electrically assisted vehicles both in urban and rural areas. The station will also have a diesel generator for emergencies like cloudy days, where the irradiation is not sufficient enough to charge the batteries or any fault in the PV array system.

The system consists of solar PV array depending on the number of batteries needs to be charged daily, battery banks, charge controllers, DAQ card and a back-up generator. The procedure is that the solar arrays catch energy from the sunlight and converts it to electrical energy which is stored in a bunch of batteries. Two sets of batteries are allocated for each vehicle [16]. One that is discharged about 50% needs to be handed over for charging at the station and another fully charged battery will be provided for further use from the station. Consumer can pay the bill either in rental or permanent basis.

The idea of the whole setup is to charge multiple batteries within a certain period of time. When the solar irradiance is not sufficient enough to meet the charging time, the system will automatically switch to the backup power generator. For example, many customers need their batteries to be charged within a fixed time. It might be possible if the solar irradiance is high and constant within that time period. However, weather conditions can be changed and the solar irradiance might not be enough to charge the batteries within that time. In this case “automated switching system” will switch the power source from solar panel to the generator for charging the batteries. [16]

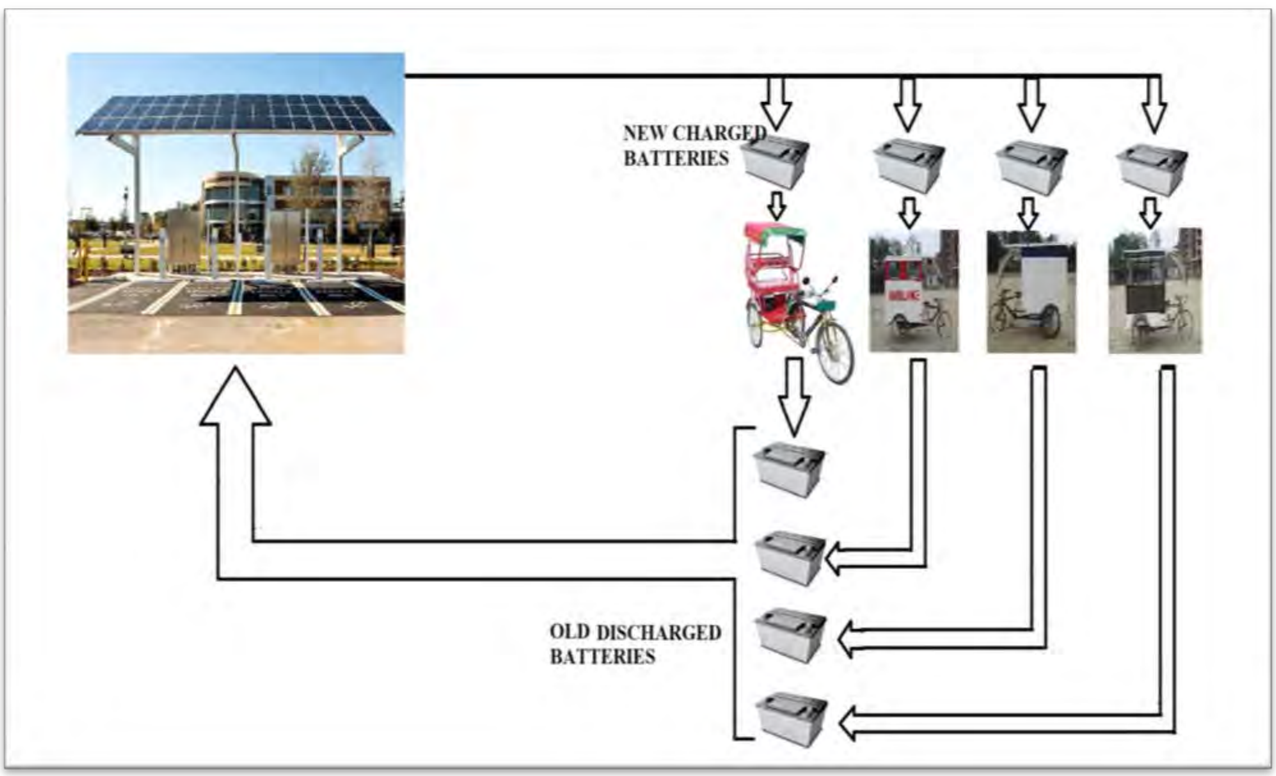


Figure 4.1.1: Centralized Solar Battery Charging Station

Also, A DAQ (Data Acquisition) card provides areal time monitoring system showing the current condition of the batteries and tells if there is any problem in any of the unit. It prevents the batteries from overcharging and also from being used when the batteries need charging. When a unit is fully charged the user is being notified about the unit.

4.1.3 Advantages and Disadvantages of the system:

Advantages:

- Large set-up provides service to a large number of electric vehicles.
- Real-time monitoring of all the status and measurement.
- Eliminates human effort and errors.
- Problems can be detected easily without any difficulties.
- Automatic switching when backup generator is needed.
- Battery condition remains good as this system prevents overcharging.
- Service at any weather condition.

Disadvantages:

- Stations are installed at distant places, so vehicles need to travel all the way for battery swapping.
- Large set-up consumes a large space.
- For any emergencies, it is not helpful as placed at comparatively far places.

4.2 Decentralized Dedicated Solar power Charging Kit

4.2.1 Introduction:

Dedicated solar power charging kit (DSPCK) is a solar power solution of charging batteries without going to any charging station. This system is solely made for charging up vehicle batteries staying at home with the help of solar energy instead of depending on the national grid [17]. This kit is easy to use and requires not much skill to use it [17]. It is smaller in size than the solar battery charging station. In a charging kit only one car can accommodate in a car port (small garage) for battery swapping. The vehicle can be kept there and at the same time batteries can be charged. As the solar charging kit supports charging of batteries of one vehicle at one time on a single car port, it is named “dedicated solar powered charging kit” [17].

4.2.2 Working Procedure:

This dedicated solar charging kit consists of solar panels, charge controller, batteries, battery voltage indicator, Arduino Uno and also an irradiance meter. Solar energy captured from the sun light are converted into electrical energy and stored in some batteries. Here an Arduino board is used to read the battery voltage at the same time showing the corresponding percentage charge on a LCD display. Mainly two sets of batteries have been used for a whole system. While one set of batteries are being used in the vehicle, the other set is being charged in the solar charging garage. When the used set is discharged to 50%, it is driven out of the vehicle and left for charging. The other charged one is replaced in the vehicle in place of the previous one.

This whole arrangement is done in a solar charging garage or car port where the vehicle is supposed to be parked. The panels are fitted on the roof of the garage and the batteries along with the charge controller are installed inside the garage.The battery voltage indicator is used to know the state of battery charge level.

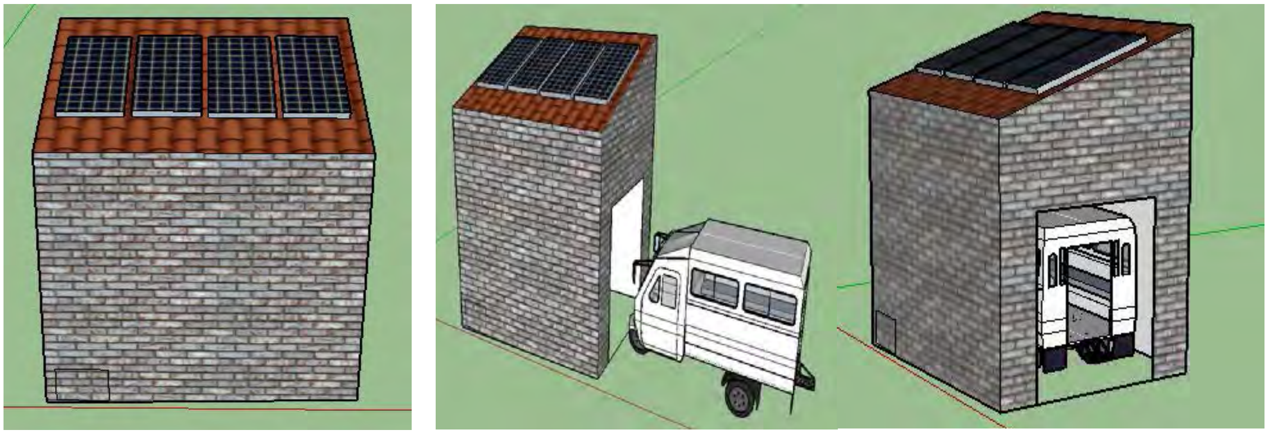


Figure 4.2.1: Solar charging garage, one vehicle comes and fit in one kit.

4.2.3 Advantages and Disadvantages of the system:

Advantages:

- One kit for one vehicle.
- No need to wait in queue.
- Small in size, so many kits can be established in an area.
- No need to travel a long way to SBCS.
- Car port can also be used as garage.

Disadvantages:

- No backup facility is available, so batteries cannot be charged at bad weather condition.
- Uncertainty of full battery charging.
- No service at night.
- No real-time monitoring and error identification facility.
- If load increases, the system will not be feasible.

4.3 Comparison between Centralized Solar Battery Charging Station and Decentralized Dedicated Solar power Charging Kit

- From our simulation, for centralized SBCS, per month energy cost for one vehicle is 728.8 BDT and payback period of investors is 34.8 years. On the other hand, in Decentralized DSPCK the payback period is 9.7 years. So centralized system is better for battery charging if we consider the costs.
- The main issue for DSPCK is that there is no back-up generator facility for the system, so after a certain period of time of a day the PV cannot produce energy for the batteries and no new charged batteries can be provided from the system. However, SBCS effectively handles this process. It monitors the power needed for the batteries and if there is not enough power, it automatically switches from the PV array to the generator for the charging process. Here centralized station is better.
- The whole design of the SBCS is effective for providing service to a large number of electric vehicles at a time where only one vehicle is getting service from one kit in DSPCK system. If we see this way, every vehicle should need its own kit. Here centralized kit is better.
- DSPCK is suitable for emergencies because it is a near-site installation but SBCS is far from one another so drivers need to travel a long way.
- Real-time monitoring system for measuring all the status and data in SBCS where in DSPCK, everything is done manually.
- Increase of load doesn't affect the whole SBCS system that much but a DSPCK cannot afford any extra load.

4.4 Decision:

It is pretty obvious now that centralized solar battery charging station is a better option for charging the batteries. Not only can the vehicles, charged batteries also be supplied to the solar home systems if needed. A large set up is needed in this respect as backup facility can’t be afforded by small charging kits. Also, without backup facility, this charging kit might not be feasible. So it is better option to choose SBCS for battery charging facility.

CHAPTER 5

Centralized Solar Traffic Light and Decentralized Solar Traffic Light

Traffic lights are signaling devices positioned at road intersections, pedestrian crossings and other locations to control the flows of traffic. They allocate the right of way to road users by using the lights in standard colors (red - amber/yellow - green), using a universal color code. Vehicular travel is increasing throughout the world, especially in urban areas. As a result the traffic signal installation is also increasing. However, it is not still economically easy to provide traffic signal service all over the country due to the cost of building power infrastructure over long distances. Also, traffic signal remains active for almost 24 hours a day, so it consumes a huge amount of energy every day. If we could eliminate the power consumption of traffic lights from the national grid, it might save a significant amount of energy every day. Application of solar energy has been increased to power-up the traffic lights all over the world recently. We can provide power using solar energy to these lights in two ways- Centrally and De-centrally.

Figure 5.1: Traffic Light

5.1 Centralized Solar Traffic Lighting System

5.1.1 Introduction:

Centralized Solar Traffic Lighting System refers to a system where solar panels, batteries and charge controller are installed in one place and power is provided to the traffic signal lights via transmission lines. It is like the conventional traffic lighting system; just the power comes from the solar grid instead of national grid. LED lights can be used in traffic signal as they are energy efficient. No new infrastructure is required; we can use the existing traffic signal lights. Back-up generator is needed for bad weather.

5.1.2 Working Procedure:

Solar array, batteries, charge controller, generator and wiring etc. are the main equipment that makes a centralized traffic lighting station. PV panels collect energy from the sun during the day time and stores this in a battery through a charge controller to drive the traffic signals at night. The charge controller has been used to supply the battery with the maximum amount charge possible, while protecting it from overcharge by the solar panels as well as over discharge by the lights.An optimum tilt angle for the solar panels needs to be determined which will help efficient energy collection all throughout the year to support the load. As traffic signal has to active for 24 hours a day, the working procedure can be divided into three ways.

1. In daytime, solar panel catches the sun power and supplies this DC energy directly to the lights.
2. Excess energy will go to the batteries & charge them which will provide power to the lights at night.

3. During bad weather condition, when sunlight is not sufficient enough to power the lights and charge the batteries, back-up generator will power-up the whole system.

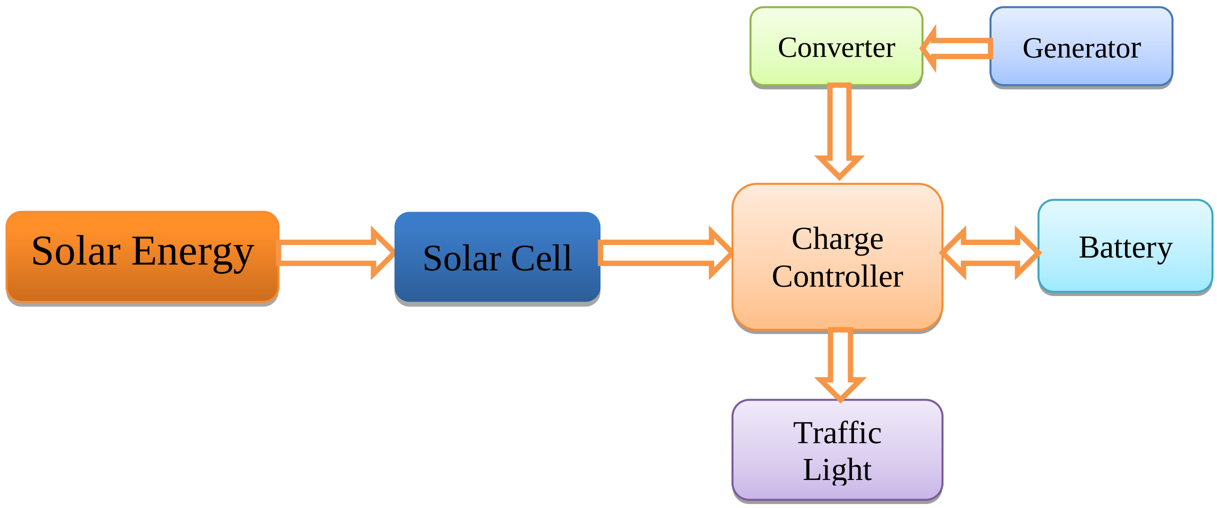


Figure 5.2: Energy flow of a Centralized Solar Traffic Lighting System

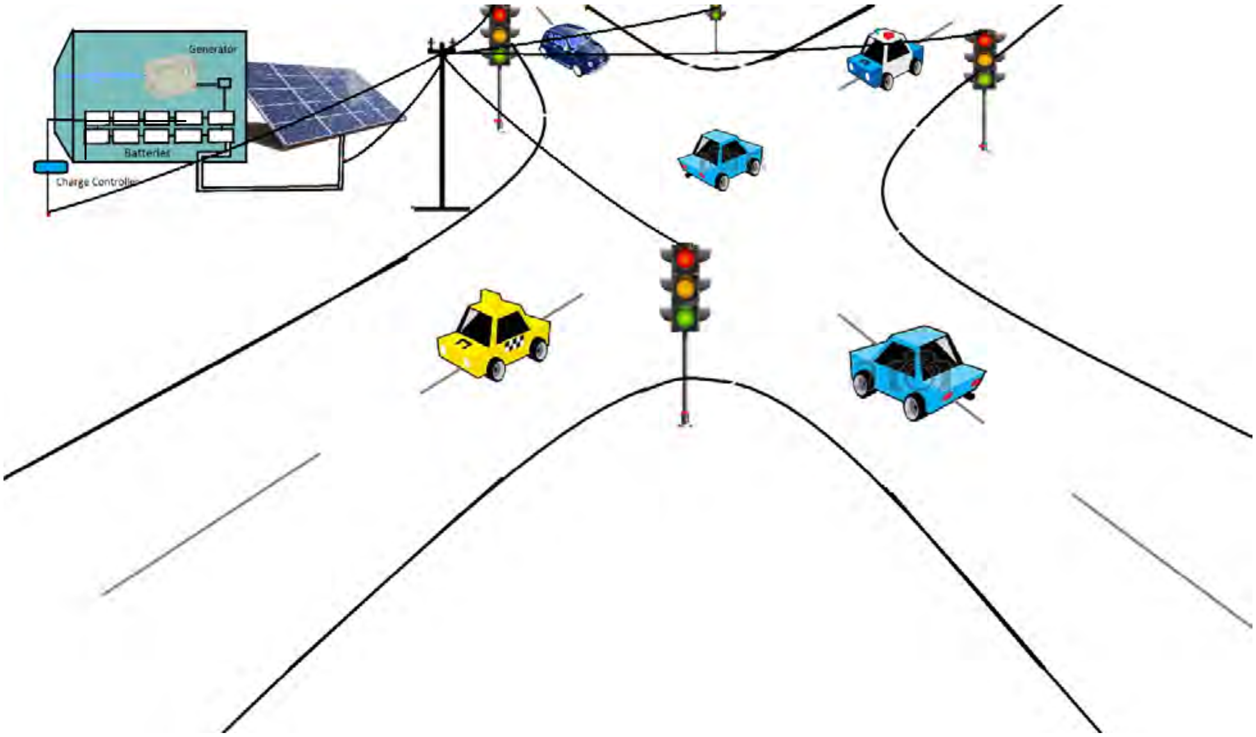


Figure 5.3: Centralized solar traffic lighting system

5.1.3 Advantages and Disadvantages of the System:

Advantages:

- Full new infrastructure is not required; where there is already traffic lights are positioned, we can use those to run centralized system.
- Equipment maintenance is easy.
- Less rick of theft
- Shadow effect on the roads is not a problem in centralized system.

Disadvantages:

- A huge amount of energy is lost during transmission because distance is high from one light to another.
- Not space-efficient.

5.2 Decentralized Solar Traffic Lighting System

5.2.1 Introduction:

The decentralized traffic lights are invented to use at the urban transport system to achieve both energy conservation and easy traffic management. It is a wireless transmission system where solar panel, batteries, charge controller and lights are mounted all together on top of every pole. This system is powered 100% from the solar power. As all the equipment is mounted together, a whole new infrastructure of street light is needed.

5.2.2 Working Procedure:

Decentralized solar traffic light consists of solar module, battery, charge controller, LED light, poles and wiring. Solar module catches the solar power and converts it intro electrical energy. The LED lights get power directly from the solar panel in daylight. The excess energy solar panel produce are stored into batteries for using at night. A charge controller is used to control the charge flow through the battery during charging and discharging time. Sometimes DC-DC converter is used for voltage regulation.

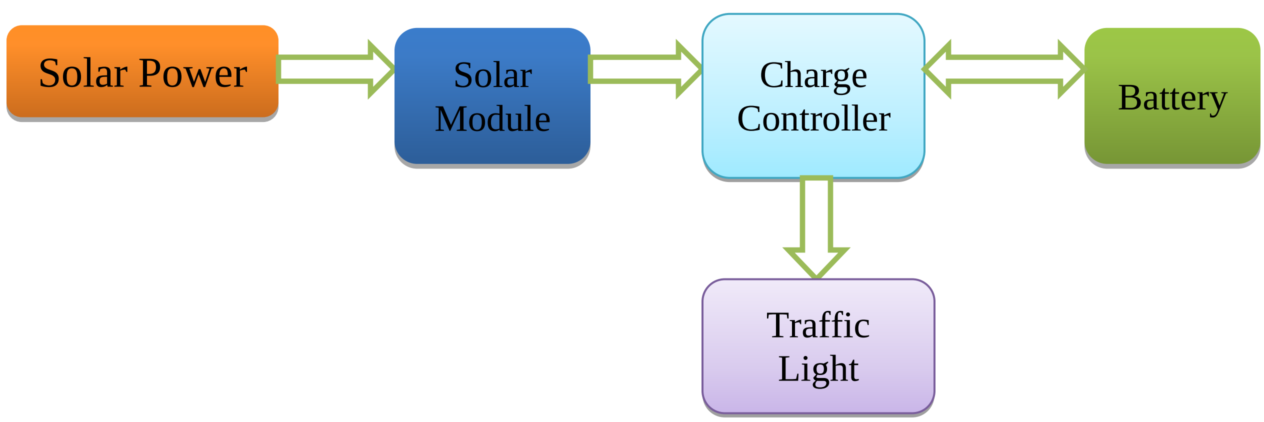


Figure 5.4: Energy flow of a decentralized solar street lighting system

Figure 5.5: Decentralize Solar Traffic Lighting System

5.2.3 Advantages and Disadvantages of the system:

Advantages:

- Self-sufficient, do not need external power sources.
- Easy to set-up and operate
- As they have no moving parts, very little maintenance is required
- Space-efficient
- No transmission loss
- Wireless connection, so risk of accidents is less

Disadvantages:

- back-up of back-up power is not available
- Shadow effect on roads can create problem
- Snow or dust can reduce energy production
- Risk of theft

5.3 Comparison between centralized solar traffic lighting system and decentralized solar traffic lighting system:

- The total system cost of one traffic light in centralized system is 664$ in 25 years where in decentralized system it is 634$. Here, decentralized system is more cost-effective.
- It is important to have a back-up of back-up power. Like in centralized system, batteries are the main back-up power source to lighten up the traffic signal lights at night but it also has a back-up generator for powering the lights when there is not sufficient sunlight for many days. Hence, in decentralize system there is no such thing. So it is better to choose centralized system in order to get continuous power supply.
- Shadow effect on roads can eliminate the amount of energy production by solar panel. Here decentralized set-up can face shadow effect sometimes. Centralized system set-up is better for shadow affected area as we can choose site according to that.
- Decentralized system is loss-less because it is a wireless system and also it eliminates risk of accident that happened due to transmission lines. On the other hand centralized system wastes a lot of energy while transmitting. So decentralize system is better in this respect.
- Decentralized system doesn’t require space to set-up a system, we need existing traffic lights only. But a centralized system require spaces for setting up and also it is a matter of fact that the lands of city areas are so expensive to set-up a centralized system. Here decentralized system is better option.

- Maintenance cost is higher in centralized system but the maintenance is easy. On the other hand, maintenance cost is low but maintenance is harder and it is easier to steal the equipment of decentralized street light. So considering everything centralized system is better here

5.4 Decision:

Considering all the aspects, we can say that centralized solar traffic lighting system can be better if the place is non-developing area. Therefore, for city areas as well as for any places decentralized solar traffic lighting system is better option. Just proper monitoring and maintenance is required to make this system the best.

CHAPTER 6

Centralized Solar Street Lighting System and Decentralized Solar Street Lighting System

6.1 Introduction:

A Street light or lamppost is positioned at the edge of a street in order to lighting the road at night or when there is not enough sunlight. Incandescent lamps were primarily used for street lighting until the high-intensity discharge lamps were invented. Nowadays high-intensity discharge lamps, often HPS (high pressure sodium lamps) are used commonly for lighting the streets. But the new technology of LED is replacing all the existing lights due to its low power consumption ability and lower Photopic lumens. This light emits a white light that provides high levels of Scotopic lumens. It reduces energy consumption as well as light pollution. Using solar energy to power LED street lights can also be a great innovation for recent days. Using solar technology for street lighting is an affordable and efficient off-grid solution. Solar Street lighting system can be designed in two ways,

Figure 6.1: Street Light

Centrally and de-centrally.

6.2 Concept of Centralized and Decentralized Solar Street Lighting System:

Centralized system refers to setting up solar panel, battery and charge controller in one place and the LED lights are mounted on each top of the pole. The lights get power from the central solar grid via some distribution cables. On the other hand decentralized or stand-alone solar street lighting system consists of pole mounted solar module, battery, charge controller and LED bulb each. No converter is required for both of the cases. In centralized system the LED lights can be of AC type and in decentralize system they can be of DC type.

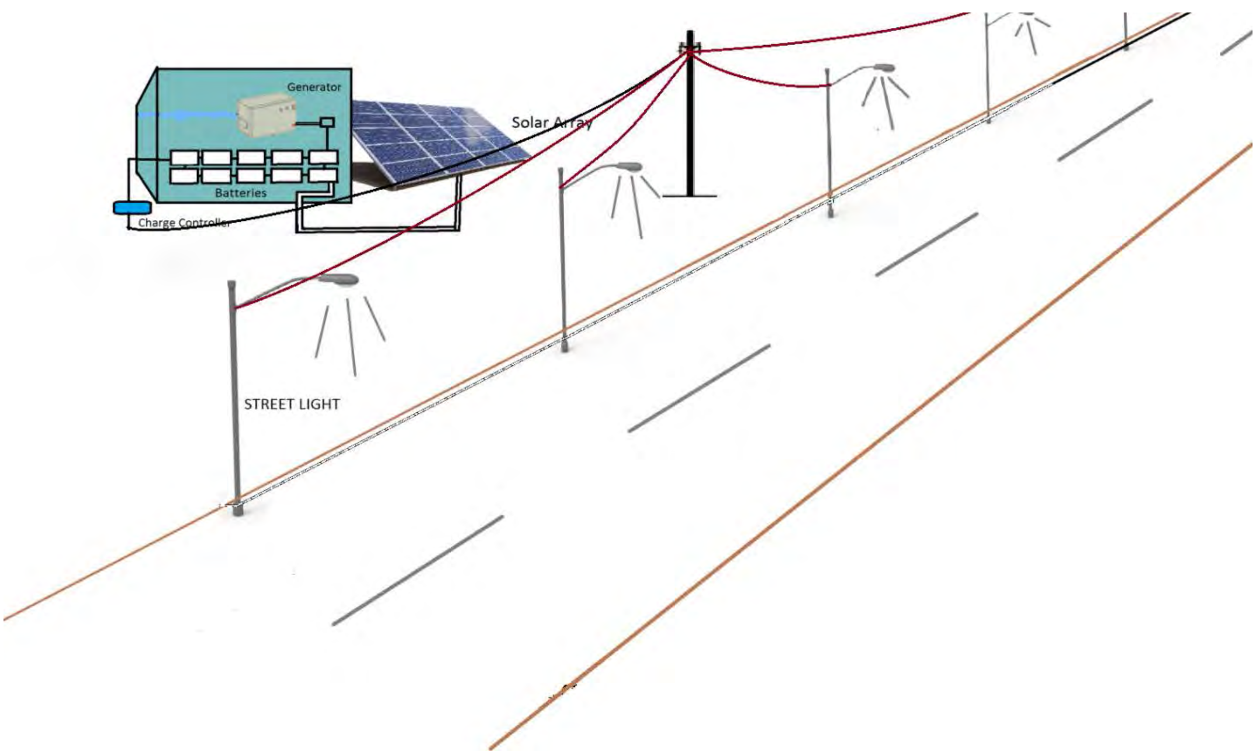


Figure 6.2: Centralized solar street lighting system

Figure 6.3: Decentralized Solar Street Lighting System

6.3 Main Equipment and Requirements according to IDCOL:

LED Light:

Depending upon the luminary requirement, the power consumption of the LED lights should vary from 10W to 50W with minimum 90 Lumen/watt. LED should provide minimum 80% of the initial lumen output after 3 years and should be "white" with CRI (Color Rendering Index) of minimum 70. The input voltage range should be from 11.6V to 14.4 V and input power of the LEDs must not vary by more than 15% of the rated power.

Solar Module:

The solar PV array should consist of one or more flat-plate photovoltaic modules. Each module should contain no less than 36 series-connected single or poly-crystalline silicon solar cells and should have a peak power output of at least 10

Wp.

Battery:

Battery can be Lead Acid/LiFePO4/ Li-ion type. Tubular plate lead acid batteries may be used in case of centralizedsolar street lighting system. Battery size in Ah should not be more than 1.5 times of panel size in Watt peak. Depth of discharge of the battery should be minimum 90% and for tubular lead-acid batteries, it is 70% allowed.

Charge Controller:

The input current rating has to be greater than 120% of the solar module's rated short circuit current.Self-consumption should be less than 0.5% of the total power required.Reverse current leakage protection is recommended. When battery and load is disconnected, charge controller should have the capacity of withstanding 25V at PV terminal. Each charge controller should have at least 90% efficiency.

System Requirements:

IDCOL (Infrastructure Development Company Limited) has fixed some requirements for both Centralized and Decentralized systems:

1. System should be installed in a way so that it can be dismantled or replaced easily when needed.
2. Charging time should be 8 hours and discharging time should be minimum 12 hours.
3. System must be IP 65 protected and tested accordingly. Application package must be included in the test report.

   IP code(International Protection Marking) classifies and rates the degree of protection provided against intrusion dust, accidental contact, and water by mechanical casings and electrical enclosures. [1]

   ‘6’- No ingress of dust; complete protection against contact (dust tight).

‘5’- Water projected by a nozzle against enclosure from any direction shall have no harmful effects. [1]

4. Ventilation is mandatory to avoid early degradation of the battery.
5. System should work in ambient temperature of 15 degree Celsius to 45 degree Celsiusand 100% Relative Humidity.
6. Total system warranty should be minimum 3 years.
7. Centralized system voltage can be high voltage DC (up to 125V) or 230V AC.

6.4 System Structure:

According to IDCOL, the system structure should be like this:

1. Pole height should be minimum 6 meters depending upon the requirements of the roads.
2. **Galvanized Iron** (GI) or powder coated poles should be used.
3. Minimum thickness of the pole is 3.5 mm which can only be relaxed in case of centralized solar street lighting.
4. The poles should rest on a 2’x 2’ **RCC**(Roller-compacted concrete) base embedded at 3’ depth inside the ground.

6.5 Advantages and Disadvantages of the two systems:

❖ Advantages of Centralized Solar Street Lighting:

- Existing infrastructure of poles can be used.
- Solar panel and battery is maintained easily.
- No worry of shadow effect on poles.
- Less risk of theft as monitored centrally.

❖ Disadvantages of Centralized solar Street Lighting:

- Lights get power via distribution lines, so transmission losses are occurred.
- Not space-efficient.

❖ Advantages of Decentralized Solar Street Lighting System:

- Independent of the grid system, so operation cost is less.
- No external wires, hence risk of accidents are minimized.
- No transmission loss.
- Space-efficient.
- System can be carried easily to the remote areas.
- It allows saving of energy and also maintenance cost.

❖ Disadvantages of Decentralized Solar Street Lighting System:

- For the roads that do not have enough shadow free areas, this system is not suitable.
- Risk of theft is higher.
- New infrastructure needs to be established.
- Snow or dust, combined with moisture can accumulate on PV-panels and reduce or even stop energy production. [19]
- Lack of maintenance.

6.6 Comparison between Centralized solar Street Lighting System & Decentralized solar Street Lighting system:

- From our simulation, the total system cost of one street light in centralized system is 936.81$ in 25 years where in decentralized system it is 825.85$. Here, decentralized system is more cost-effective
- Decentralize solar street lighting system is not suitable if there is shadow effect on the roads. For this kind of situation we can select a specific place where sunlight is sufficient to set up a central solar grid system which can provide power to the street lights via transmission lines. Here centralized solar street lighting system is better.
- The existing poles can be used for the centralized system; just the power will come from solar grid; where for decentralized system every pole need to be mounted with solar panel, battery, charge controller etc. separately. Here centralized system is better than the decentralized one.
- Transmission lines waste a huge amount of energy in centralized street light system. Hence decentralized system is wireless so no chance of energy loss here and also risk of accidents may also be reduced. Also, it is space efficient. So decentralized system is better in this case.
- Space is also a challenge for centralized system. It is easier to use solar power for decentralize system as it is totally a space-efficient system.

6.7 Decision:

Considering all the aspects, it is seen that decentralized street lighting system is comparatively better for powering the street lights. The total system cost is less in decentralized system and also a loss-less and space-efficient system. Just proper monitoring and maintenance can be a solution for its disadvantages.

CHAPTER 7

Economic Optimization Analysis Using HOMER Pro and RETScreen

7.1 HOMER

HOMER (Hybrid Optimization Model for Electric Renewables) is a computer based micro power system optimization model which allows the user to simulate, optimize and also has the ability to do sensitivity analysis on a system consisting of multiple energy sources like wind, PV, diesel generator, battery bank etc. and various loads like AC, DC and thermal loads along with converters and the grid. It is generally used for the design and analysis of hybrid power system [24]. HOMER simulation models the best system design and the optimization finds the best possible system configuration which gives the least total NPC that satisfies user defined constraints. It can also provide economic analysis and feasibility of the system .Here in our study we are not considering any sensitivity analysis but homer has the ability to do sensitivity analysis .Sensitivity analysis gives the effect of change in the input variables on the optimization results [22]. One of the main advantage of HOMER pro software is resource data (solar and wind) is provided via the tool from internal resource data. Homer provides the best source of solar radiation data for free from the US National Renewable Energy Laboratory and also from the data set of the NASA’S Surface Solar Energy. Homer also provides monthly average wind speeds of any specific location via the US Renewable Resource Data Centre [23]. HOMERS goal is to find the least cost combination of equipment for consistently meeting the electrical load. This micro grid analysis tool is globally used for quickly finding economically viable options for micro grids and distributed generation system [26]. One of the most significant update of HOMER is "HOMER optimizer" which finds best feasible systems from which the user can be more specific about what sizes should be considered viable for their proposed project.

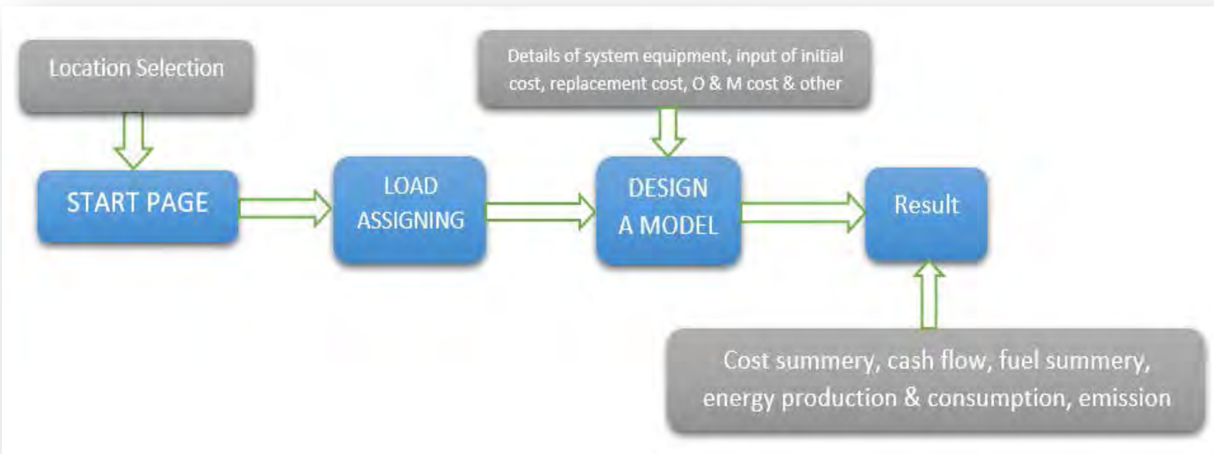


Figure 7.1: Flowchart

Cost analysis procedure by HOMER:

1)Net Present Cost: The net present cost of a component is the present value of total costs of installing and operating the component over the project lifetime , minus the present value of all the revenues that it earns through the project lifetime.

NPC=TAC\CRF(i,Rproj)

Where TAC = Total annualized cost

CRF = capital recovery factor.

i=annual real discount rate (%)

Rproj = the project lifetime [25].

2) Total annualized cost: The total annualized cost is the annualized value of the total net present cost.

$$C_{ann,tot} = CRF(i,R_{proj}).C_{NPC,tot}$$

$C_{NPC,tot}$ = the total net present cost [25].

3) Capital recovery factor: The capital recovery factor is a ratio used to calculate the present value of an annuity. (A series of equal annual cash flow)

$$CRF\,(i, N) = \frac{i(1+i)^N}{(1+i)^N-1}$$

i=real discount rate

N = number of years [27].

4) Real discount rate: The real discount rate is used to convert between one-time costs and annualized costs.

$$i=\frac{i'-f}{1+f}$$

i=real discount rate

i' =nominal discount rate

f=expected inflation rate [27].

5) Cost of energy: It is the average cost/kwh of useful electrical energy produced by the system.

$$COE = \frac{TAC}{Lprim\,,AC+Lprim\,,DC}$$

Here, $L_{prim,AC}$ and $L_{prim,DC}$ are the AC and the DC primary load respectively [27].

In our thesis we have considered four case studies to do the comparative analysis between centralized and decentralized solar power system.

The cases are:

1) Centralized solar Mini-grid connected home system and Decentralized solar home system
2) Centralized solar battery charging station and Decentralized dedicated solar power charging kit
3) Centralized solar street lighting system and Decentralized solar street lighting system
4) Centralized solar traffic lighting system and Decentralized solar traffic lighting system

In this section we are going to show the design, calculation and cost optimization result for each cases using HOMER PRO and try to find out the better solution by comparing those results so that it could be beneficial for both investors and consumers in future.

CASE 1:

1. CENTRALIZED SOLAR MINI-GRID CONNECTED HOME SYSTEM:

Here we are considering our project location is Chittagong, Bangladesh. For our Centralized solar grid connected home system simulation we are considering 30 households and assume all are using same appliances. Here we are considering every household are using LED Light, fan and television. The load information is given below in a chart [28]:

Appliances	Watt	No. of equipment	Total load(Watt)	Hours use/day	No. of houses	Total Unit (Wh/day)
LED Light	10	4	40	5	30	6000
AC Fan	25	2	50	15	30	22500
Television	60	1	60	5	30	9000
						Total=37,500

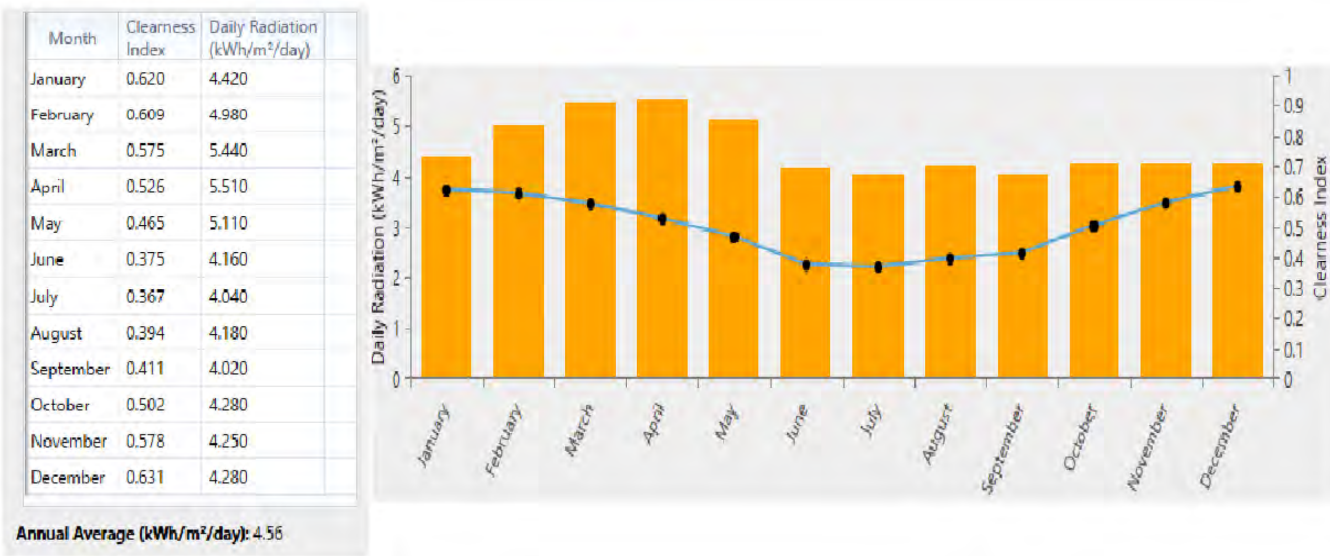
Figure 7.2: Load of 30 households

Therefore for 30 households 37500Wh or 37.5 kWh is required per day.

HOMER requires information such as location, load information, load type, initial cost, replacement cost, operational and maintenance of the components, component type.

Solar resource:

Solar irradiance data for the study area is obtained from the official NASA Surface meteorology and solar energy database which is provided by HOMER tool.



Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.620	4.420
February	0.609	4.980
March	0.575	5.440
April	0.526	5.510
May	0.465	5.110
June	0.375	4.160
July	0.367	4.040
August	0.394	4.180
September	0.411	4.020
October	0.502	4.280
November	0.578	4.250
December	0.631	4.280

Annual Average (kWh/m²/day): 4.56

Figure 7.3: Solar irradiance data

From figure 7.3 it is seen that the daily average radiation of our proposed area is about 4.56 kWh/m^2/day and average clearness index is 0.5.

PV system calculation:

Total PV Panel energy needed =37,500*1.3

=48,750 Wh/day

Here, 1.3 = Energy lost in the system

Total unit for 30 households = 37,500 Wh/day

Total Wp of PV panel capacity needed = $\frac{48,750}{4.56}$

=10690 Wp ≈ 11kWp

So for our system we need 11kW solar panel. In HOMER we are considering Generic flat plate PV. A de-rating factor of 80% is taken for each panel. De-rating factor refers to some environmental parameters that effect to decrease PV efficiencies such as cloud, temperature, high dust, shadow, snow etc.

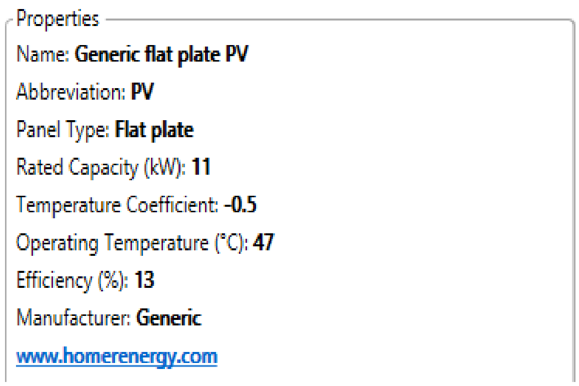


Figure 7.4: PV panel specification

The capital cost and O&M (operation and maintenance) cost are considered $600/kW and $6/kW (1% of the capital cost) respectively [31]. The replacement cost is zero as the lifetime of PV panel is considered 25 years and our project lifetime is considered 25 years as well.

Battery Calculation:

In solar PV system the preferable battery type is deep cycle battery. Deep cycle battery is specially designed for to be discharged when the energy level is low and it supports rapid recharging or cycle charging. Here an important thing we should keep in mind that the battery should be large enough to store sufficient energy to operate the appliances at night and cloudy days.

$$\text{Battery capacity (Ah)} = \frac{37{,}500 * 1}{0.85 * 0.5 * 12}$$

$$= 7352.94 \text{ Ah}$$

Here,

Total unit for 30 households = 37,500 Wh/day

Battery Days of autonomy = 1

Battery loss = 0.85

Depth of discharge = 0.5

Nominal battery voltage = 12

So for our system we need total 7352.94 Ah battery capacity .In homer we are considering Generic 1kWh Lead acid battery. The battery specification is given below:

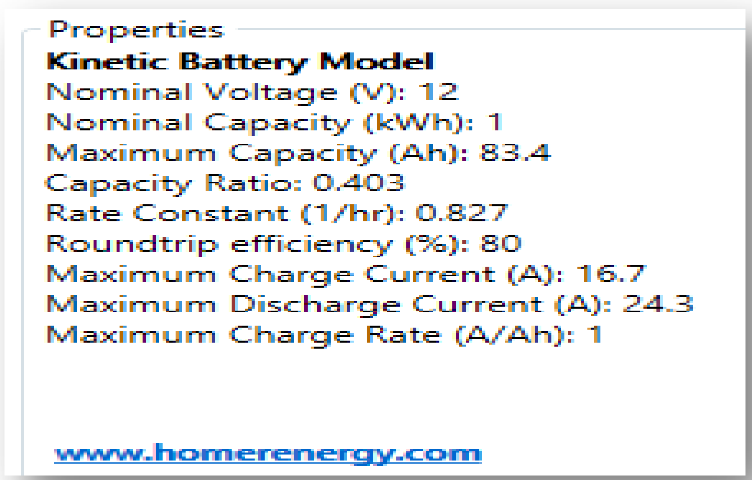


Figure 7.5: Battery Specification

So the number of batteries required for our system = $\frac{7352.94\ Ah}{83.4\ Ah}$

$$= 88.16 \approx 88$$

A total 88 battery is needed for the proposed system. A number of total 22 strings are designed in homer .Each string contains 4 numbers of batteries and the string rating is 48V, 83.4 Ah.

The capital cost and replacement cost both are considered $80/kW [32]. The O&M cost is considered $1.6/kW (2% of capital cost) and the battery lifetime is considered 5 years.

Converter Calculation:

Converter is required for any system that contains both AC and DC elements. In HOMER both inverter and rectifier options are included into one segment termed as "converter". Inverter converts DC to AC and rectifier converts AC to DC. For the proposed system we used both inverter and rectifier as our system contains both DC and AC elements. It's a matter of concern that the inverter size should be 25-30% bigger than total Watts of appliances.

(Figure 7.2)Total Watt of appliances for one house = (10*4) + (25*2) + (60*1)

=150Watt

Total Watt of appliances for 30households = (150*30)

=4, 500 Watt

Inverter capacity = 4500 + (4500 * 30%)

= 5850 Watt ≈ 6 Kw

So for our system we need total 6 Kw inverter.

The capital cost and replacement cost both are considered $180/kW [33]. The O&M cost is considered zero and the inverter lifetime and efficiency is considered 5 years and 90% respectively.

Back-up Generator Calculation:

A generator is a device that produces electric energy and consumes fuel. A backup generator is a backup electrical system that operates when there is not sufficient energy to supply to the load i.e. cloudy days. Solar panels produce the most electricity on clear days with abundant sunshine but on a cloudy day solar panels can produce 10-25% electricity of their rated capacity. In our simulation we have taken 10 kW Fixed Capacity Genset so that it can provide sufficient power to fulfill the load demand in bad weather. The generator specification is given below:

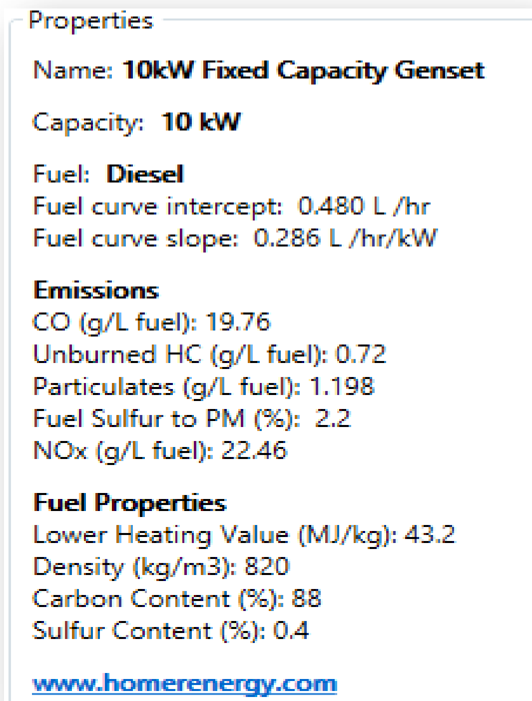


Figure 7.6: Generator Specification

The initial capital cost and replacement cost both are considered $1456 [34]. The O&M cost in per hour is considered $0.09 and the diesel fuel price is considered $0.78/liter [30].

Here, we considered system fixed capital cost with 25% government subsidy. In fixed capital option we included land [37], equipment and infrastructure setup cost.

System fixed capital cost = 3, 00,000 + 7, 00,000

= 10, 00,000 BDT

Land cost = 3, 00,000 BDT

Equipment and infrastructure set-up cost = 7, 00,000 BDT

Total fixed capital cost of the system = 7, 50,000 BDT (25% govt. subsidy)

=$9,200

We considered System fixed O&M (operation and maintenance) cost $184 which is 2% of our fixed capital cost.

Summary of all the cost:

NO.	Equipment	Total Cost/ unit	Total Cost/ kW	Repl. cost	O & M/ year	O & M/ hour	Fuel/liter
1.	Generic 1kWh lead acid	$80	n/a	$80	$1.6	n/a	n/a
2.	Generic flat plate PV	n/a	$600	n/a	$6.00	n/a	n/a
3.	Converter	n/a	$180	$180	n/a	n/a	n/a
4.	10kW Fixed Capacity Genset	$1,456	n/a	$1,456	n/a	$0.09	$0.78
5.	System Fixed Capital Cost	$9,200 (25%subsidy)	n/a	n/a	$184	n/a	n/a

Figure 7.7: Summary of all the technological resources cost

Schematic Diagram of proposed model:

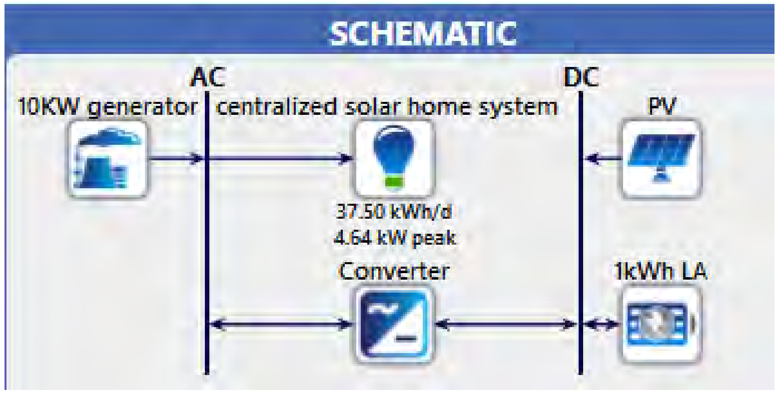
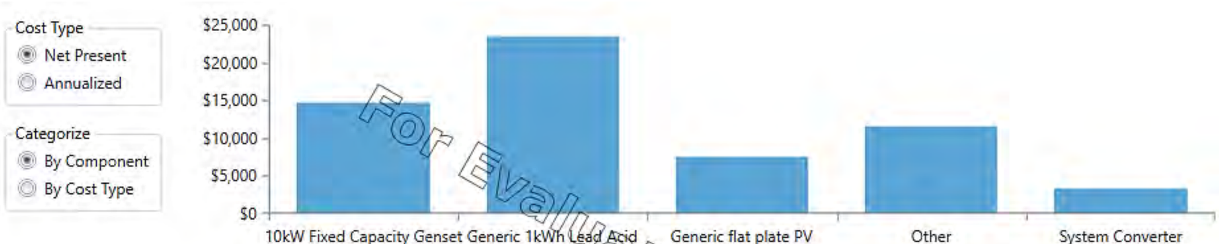


Figure 7.8: Schematic Diagram of the proposed model

Simulation Result:



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
10kW Fixed Capacity Genset	$1,456.00	$0.00	$555.00	$12,659.32	($71.50)	$14,598.82
Generic 1kWh Lead Acid	$7,040.00	$14,496.28	$1,820.17	$0.00	$0.00	$23,356.45
Generic flat plate PV	$6,600.00	$0.00	$853.23	$0.00	$0.00	$7,453.23
Other	$9,200.00	$0.00	$2,378.65	$0.00	$0.00	$11,578.65
System Converter	$1,080.00	$2,223.86	$0.00	$0.00	$0.00	$3,303.86
System	$25,376.00	$16,720.14	$5,607.05	$12,659.32	($71.50)	$60,291.01

Figure 7.9: Total cost summary in HOMER

From figure 7.9 it is seen that the total capital cost for the system is $25,376.00. The total net present cost (NPC), replacement cost, O&M cost, fuel cost over the 25 years lifetime period is given as $60,291.01, $16,720.14, $5,607.05 and $12,659.32 respectively.

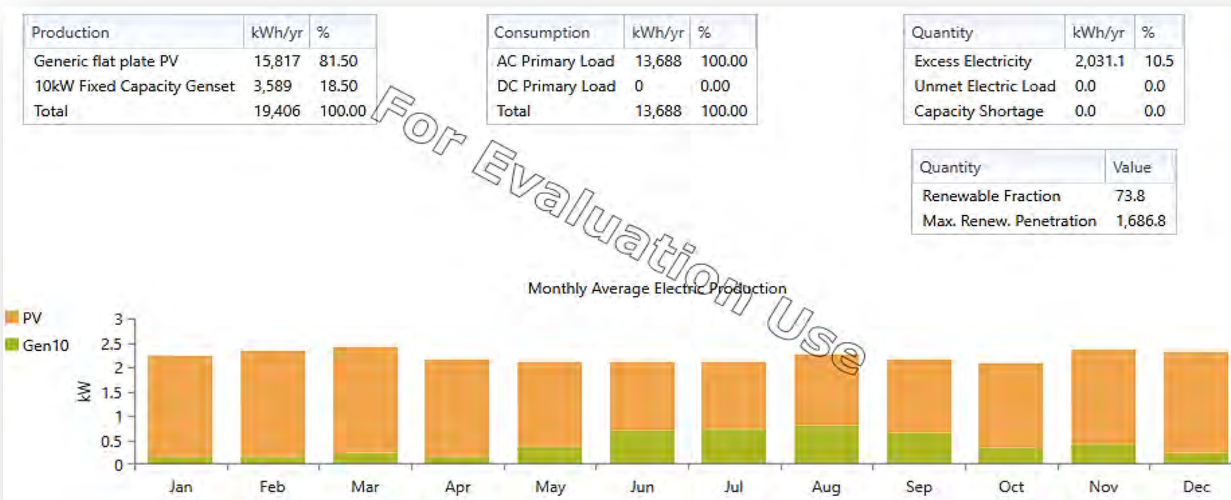
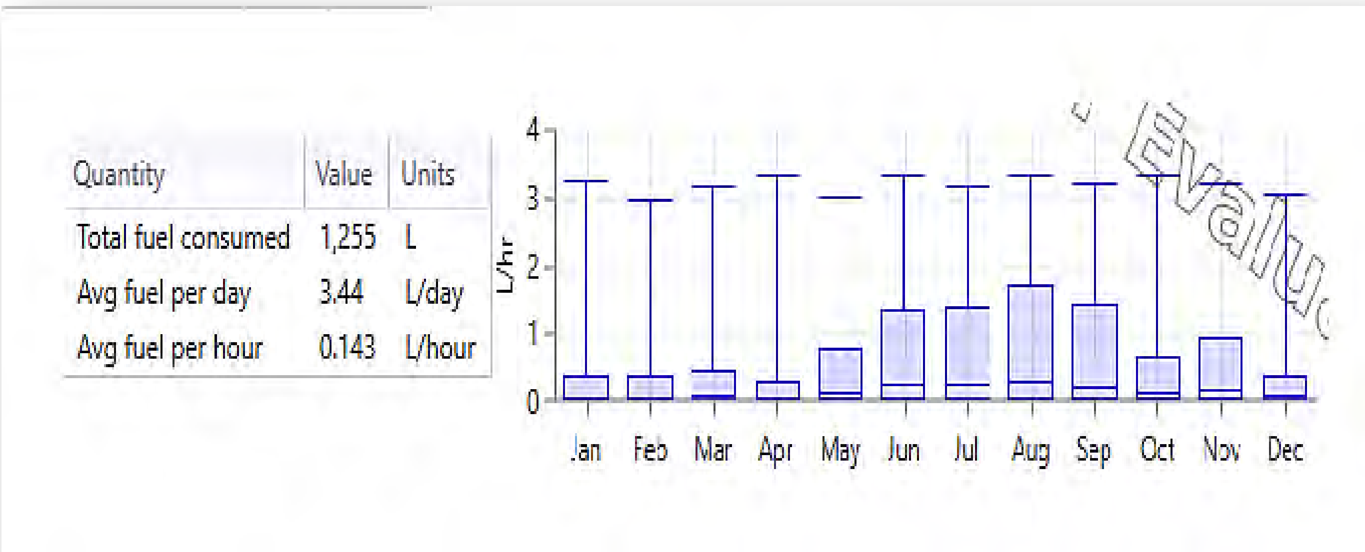


Figure 7.10: Annual production, consumption and load demand

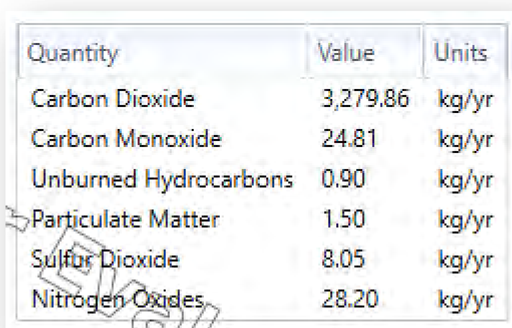
Figure 7.10 shows that the annual production of Generic flat plate PV and 10 kW Fixed Capacity Genset is 15,817 kWh and 3,589 kWh respectively. The annual electricity demand that is consumed by the load is 13,688 kWh.



Quantity	Value	Units
Total fuel consumed	1,255	L
Avg fuel per day	3.44	L/day
Avg fuel per hour	0.143	L/hour

Figure 7.11: Fuel summary of the generator

From Figure 7.11 it is seen that the average fuel per day is needed 3.44 liter.



Quantity	Value	Units
Carbon Dioxide	3,279.86	kg/yr
Carbon Monoxide	24.81	kg/yr
Unburned Hydrocarbons	0.90	kg/yr
Particulate Matter	1.50	kg/yr
Sulfur Dioxide	8.05	kg/yr
Nitrogen Oxides	28.20	kg/yr

Figure 7.12: Annual Emission

Cost calculation:

Per unit cost = $\frac{Total\ \ system\ \ cost}{per\ \ day\ \ energy\ \ \ consumption\ \ \ (Wh/day\,) * lifetime\ \ *365/1000}$

$=\frac{60{,}291.01 * 82}{37{,}500*25*365/1000}$

= 14.45 BDT [35]

(Figure 7.10) Total energy consumption by AC primary load = 13,688 kWh/year

So total energy consumption per day = $\frac{13{,}688}{365}$

= 37.50 kWh (for 30 households)

Total energy consumption per month = 37.50 * 30

= 1125.04 kWh (for 30 households)

Per month electricity cost = $\frac{1125.04}{30}$ kWh * 14.45

= 542 BDT

Payback Calculation:

The payback period is the predictable amount of time that an investment will be returned in the form of income.

(Figure 7.9) Total capital cost of the system = \$25,376.00

=20, 80,832 BDT

1 USD = 82 BDT

Cost of per unit is 14.45 BDT.

Total energy consumption = 13,688 kWh/year

So, payback period = $\frac{20,80,832}{14.45*13,688}$

= 10.5 years

2. DECENTRALIZED SOLAR HOME SYSTEM:

In decentralize solar home system simulation we have considered one household. We assume same project location for both (Chittagong, Bangladesh). For comparative analysis we have taken the same appliances as centralized system. The load information is given below in a chart:

Appliances	Watt	No. of equipment	Total load(Watt)	Hours use/day	Total Unit(Wh/day)
LED Light	10	4	40	5	200
Dc Fan	20	2	40	15	600
Television	60	1	60	5	300
					Total=1100

Figure 7.13:Total load of a single household

Solar resource:

As we have selected the same location for decentralized SHS, our solar irradiance data is same as figure 7.3.

Component:

For decentralized SHS simulation our system design contains solar PV module and battery storage to fulfill the load demand. The model of the PV panel and battery storage is taken same that has been used in centralized. The PV panel capital cost and O&M (operation and maintenance) cost is considered same as centralized. The replacement cost is zero and our project lifetime is considered 25 years as well.

For the battery storage, capital cost and replacement cost both are considered similar. The O&M cost is considered $1.6/kW as before and the battery lifetime is considered 5 years.

NO.	Equipment	Total cost/unit	Total cost/kw	Repl. Cost	O&M/Year	O&M/hour	Fuel/liter
1.	Generic 1kWh lead acid	$80	n / a	$80	$1.6	n / a	n / a
2.	Generic flat plate PV	n / a	$600	n / a	$6.00	n / a	n / a

Figure 7.14: summary of cost

In decentralized SHS system we didn't use the size of PV panel or capacity of batteries that can be acquired from the conventional calculated way rather we used "HOMER OPTIMIZER" option which provides best feasible system with lowest net present cost (NPC). The reason behind considering HOMER OPTIMIZER tool is because it is seen that people often face capacity shortage in their houses because of undersized system design resulting in power failure [36]. In centralized system there is no chance of facing this problem as system contains battery storage as well as back-up generator which allocates power during the time of necessity. Hence, if we put the values that are got from calculation in Homer system design, HOMER shows us "Infeasible, due to capacity shortage" message. That's why we considered HOMER OPTIMIZER here to design our decentralize system with best feasible option.

Schematic diagram:

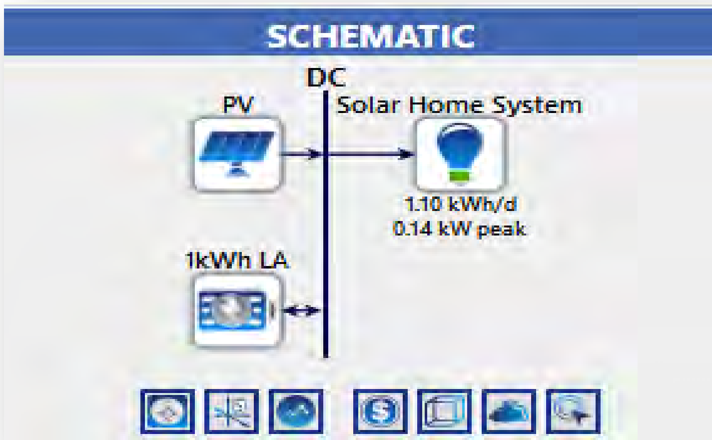
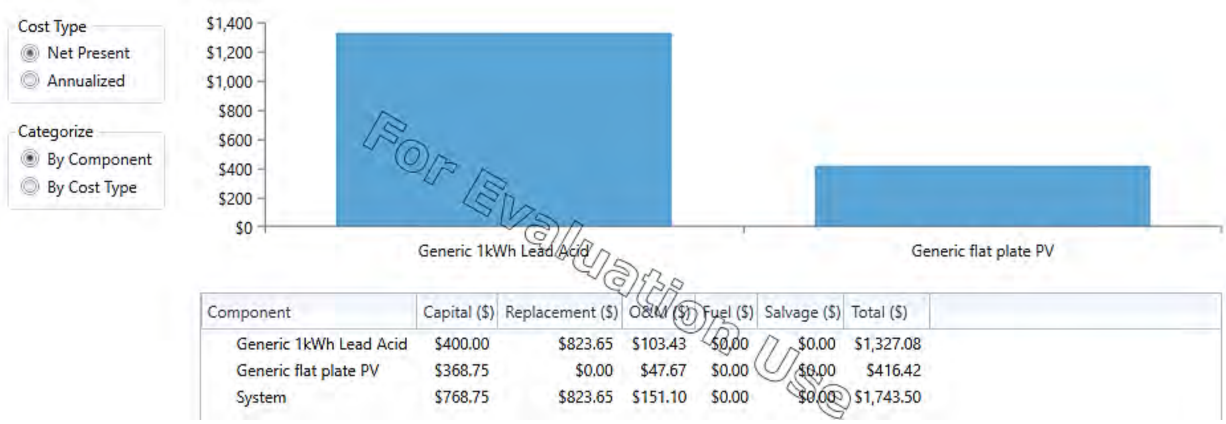


Figure 7.15: Schematic diagram of the proposed model

Simulation result:

From the simulation, HOMER finds a total of 0.615 kW PV panel and 5 no. of batteries which is the best fit for the system.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 1kWh Lead Acid	$400.00	$823.65	$103.43	$0.00	$0.00	$1,327.08
Generic flat plate PV	$368.75	$0.00	$47.67	$0.00	$0.00	$416.42
System	$768.75	$823.65	$151.10	$0.00	$0.00	$1,743.50

Figure 7.16: Total cost summary in HOMER

From figure 7.16 it is seen that the total capital cost for the system is $768.75. The total net present cost (NPC), replacement cost, O&M cost over the 25 years lifetime period is given as $1743.50, $823.65, $151.10 respectively.

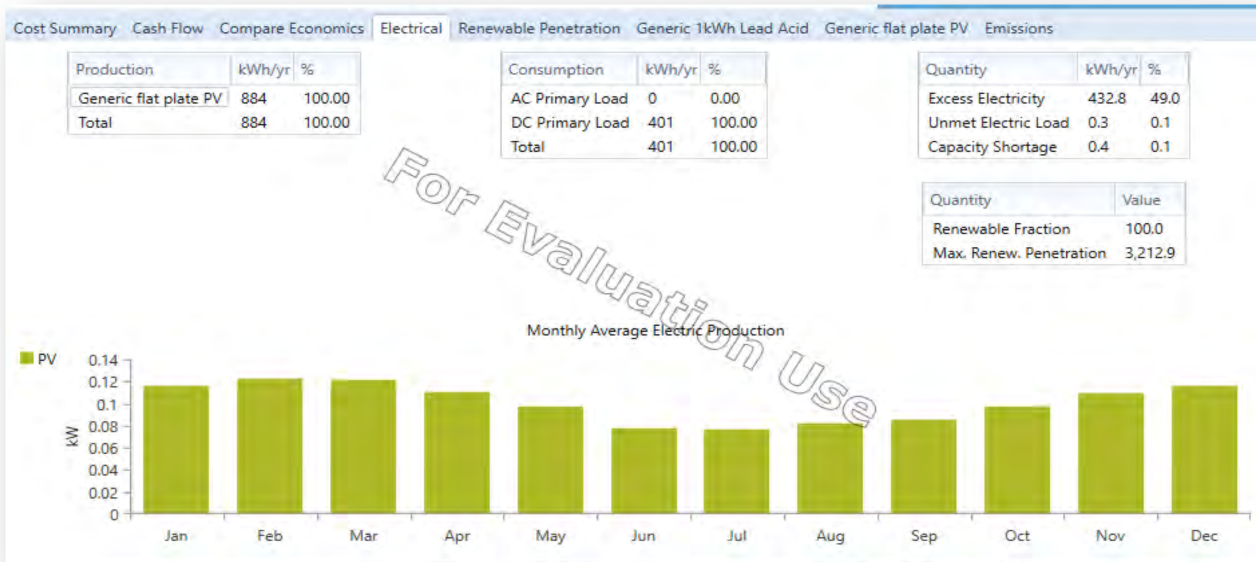


Figure 7.17: Annual production, consumption and load demand

Figure 7.17 shows that the annual production of Generic flat plate PV is 884 kWh. The annual electricity demand that is consumed by the load is 401 kWh.

Payback period:

Payback period = $\frac{Capital\ \ cost}{Annual\ \ savings}$

(Figure 7.16) capital cost of the system = \$768.75

= 63,037.5 BDT

From centralized home system per month energy cost for 1 household is 542 BDT

So, annual savings will be (542*12) = 6,504 BDT

Payback period = $\frac{63{,}037.5}{6{,}504}$ = 9.6 years

Comparative Analysis Summary:

Centralized Solar mini-grid connected home system	**Decentralized solar home system**
Capital cost for 30 houses is $25,376 and total system cost is $60,291.01. So per house installation cost is $845.87 and system cost is $2009.70	Capital cost for one household is $768.75 and total system cost is $1,743.50
Per month electricity cost for one household is BDT. 542	No electricity cost
Payback period is 10.5 years	Payback period is 9.6 years
If load is increased, the capital cost increases slightly which is $25,556 for 30 houses.	If load is increased, capital cost is almost three times of the previous cost which is around $2,634.37

CASE 2:

1. CENTRALIZED SOLAR BATTERY CHARGING STATION:

For the Centralized solar battery charging station simulation we have considered our location is Chittagong, Bangladesh.

Load measurement:

Here we considered a small station where a no. of 10 battery sets are being charged randomly. The batteries that are charging in solar battery charging station are basically the battery of electric vehicles.

Power rating of a single battery is 12V 25 Ah.

Each battery set contains 4 no of batteries .The rating of battery set is 48V 25Ah.

Load	Watt-hour	No. of Battery bank	Total load (Watt-hour)	Total Unit (Wh/day)
Battery bank (48V - 25Ah)	1200	10	12000	12,000

Figure 7.24: Load of CSBCS

Therefore for our proposed system required 12,000 Wh or 12 kWh per day.

Solar resource:

Solar irradiance data for the study area is obtained from the official NASA Surface meteorology and solar energy database. For both centralized SBCS and decentralized dedicated solar power charging kit our location is Chittagong so solar irradiance data is figure 7.3.

Daily average radiation = 4.56 kWh/m^2/day

Average clearness index = 0.5.

PV calculation:

Total PV Panel energy needed = 12,000 * 1.3

= 15,600 Wh/day

Here, 1.3 = Energy lost in the system

Total Wp of PV panel capacity needed = $\frac{15,600}{4.56}$

= 3,421.05 Wp ≈ 3.5Wp

Converter Calculation:

Total Watt of batteries = 300 * 5

= 1,500 Watt

Inverter capacity = 1,500 + (1,500 * 30%)

= 1,950 Watt ≈ 2 kW

So for our system we need total 2 kW inverter.

Back-up Generator:

For the system we considered Auto size Genset.

The initial capital cost and replacement cost both are considered $145.6. The O&M cost in per hour is considered $0.009 and the diesel fuel price is considered $0.78/liter.

Here, we considered system fixed capital cost where land cost and equipment cost has been added. For our centralized SBCS design we have taken another 10 sets of batteries which will be used after battery swapping.

Each battery price is 3,500 BDT

Each battery set contains 4 batteries and battery rating is 12V 25Ah.

Total 10 sets (10*4 = 40) of battery price =3500*40

=1, 40,000 BDT

System fixed capital cost = 60,000 + 1, 40,000

= 2, 00,000 BDT

= $2,440

Land cost = 3, 00,000 BDT

1 USD = 82 BDT

We considered System fixed O&M (operation and maintenance) cost $49 which is 2% of our fixed capital cost.

Summary of all the cost:

NO.	Equipment	Total Cost/ unit	Total Cost/ kW	Repl. cost	O & M/ year	O & M/ hour	Fuel/liter
1.	Generic 1kWh lead acid	$80	n/a	$80	$1.6	n/a	n/a
2.	Generic flat plate PV	n/a	$600	n/a	$6.00	n/a	n/a
3.	Converter	n/a	$180	$180	n/a	n/a	n/a
4.	Auto size Genset	$145.6	n/a	$145.6	n/a	$0.0090	$0.78
5.	System Fixed Capital Cost	$2440	n/a	n/a	$49	n/a	n/a

Figure 7.25: Summary of all the technological resources cost

Schematic Diagram of proposed model:

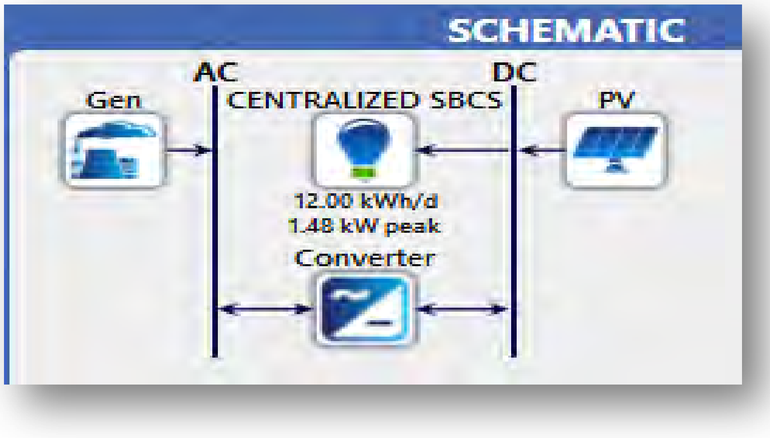
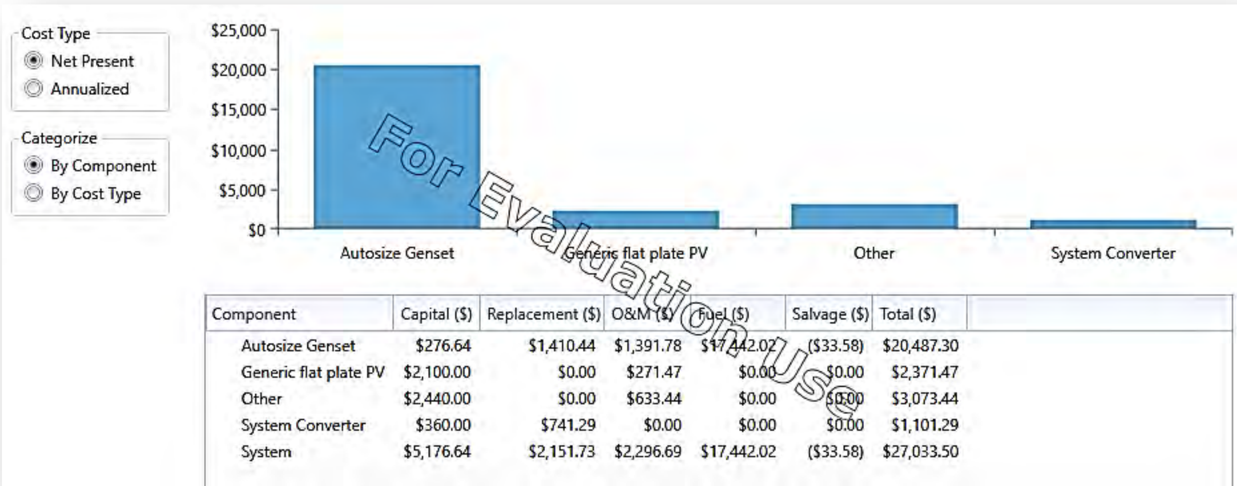


Figure 7.26: Schematic diagram of proposed model

From the simulation, HOMER finds a total of 1.9 kW Genset which is the best fit for the system.

Simulation Result:



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Autosize Genset	$276.64	$1,410.44	$1,391.78	$17,442.02	($33.58)	$20,487.30
Generic flat plate PV	$2,100.00	$0.00	$271.47	$0.00	$0.00	$2,371.47
Other	$2,440.00	$0.00	$633.44	$0.00	$0.00	$3,073.44
System Converter	$360.00	$741.29	$0.00	$0.00	$0.00	$1,101.29
System	$5,176.64	$2,151.73	$2,296.69	$17,442.02	($33.58)	$27,033.50

Figure 7.27: Total cost summary in HOMER

From figure 7.27 it is seen that the total capital cost for the system is $5,176.64. The total net present cost (NPC), replacement cost, O&M cost, fuel cost over the 25 years lifetime period is given as $27,033.50, $2,151.73, $2,296.69 and $17,442.02 respectively.

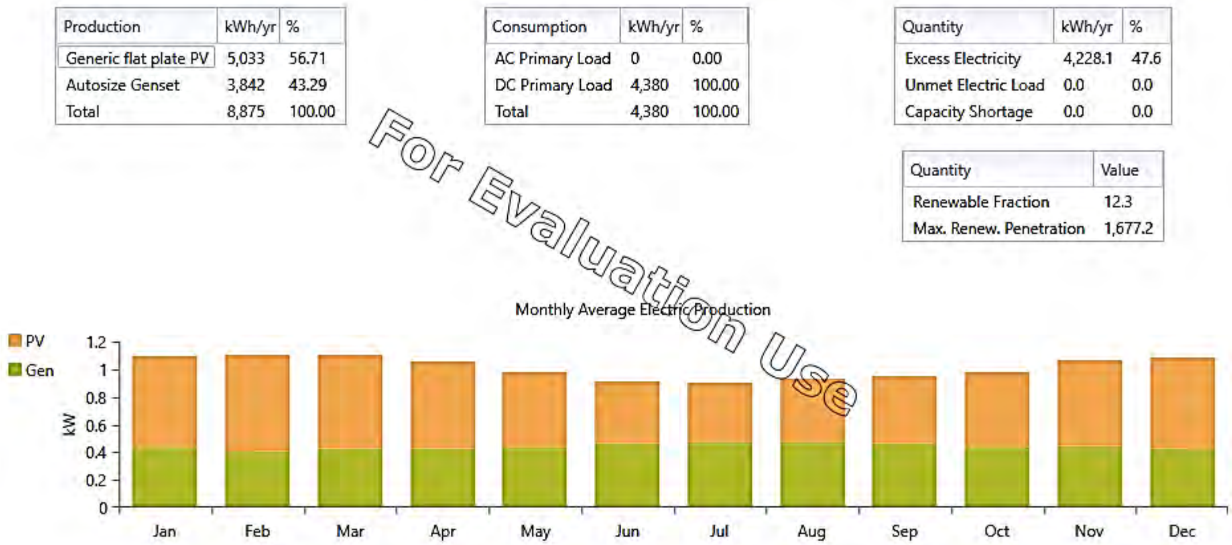


Figure 7.28: Annual production, consumption

Figure 7.28 shows that the annual production of Generic flat plate PV and Auto size Genset is 5,033 kWh and 3,842 kWh respectively. The annual electricity demand that is consumed by the load is 4,380 kWh.

Quantity	Value	Units
Total fuel consumed	1,730	L
Avg fuel per day	4.74	L/day
Avg fuel per hour	0.197	L/hour

Figure 7.29: Fuel summary of the generator

From Figure 7.31 it is seen that the average fuel per day is needed 4.74 liter

Cost calculation:

$$\text{Per unit cost} = \frac{27,033.50 * 82}{12,000 * 25 * 365/1000}$$

$$= 20.24 \text{ BDT}$$

(Figure 7.28)Total energy consumption by AC primary load = 4,380 kWh/year

So total energy consumption per day = $\frac{4,380}{365}$

= 12 kWh (for 10 battery bank)

Total energy consumption per month = 12 * 30

= 360 kWh (for 10 battery bank)

Per month energy cost = $\frac{360}{10}$ kWh * 20.24

= 728.8 BDT

Payback Calculation:

(Figure 7.27)Total capital cost of the system = $5,176.64

= 4, 24,484.48 BDT

1 USD = 82 BDT

Cost of per unit is 20.24 BDT.

Total energy consumption = 4380 kWh/year

So, payback period = $\frac{4,24,484.48}{20.24 * 4,380}$

= 4.8 years

2. Decentralized dedicated solar power charging kit:

In this simulation we have considered one set of battery. Our project location is same as centralized (Chittagong, Bangladesh). The load information is given below in a chart:

Load	Watt-hour	No.of Battery bank	Total load (Watt-hour)	Total Unit (Wh/day)
Battery bank (48V – 25Ah)	1200	1	1200	1200

Figure 7.30: LOAD INFORMATION

Solar resource:

In this part solar irradiance data is the data of figure 7.3. As our location is same Chittagong, Bangladesh.

Component:

The system contains PV module and battery storage only. The model of the PV panel and battery storage is taken same that has been used in centralized. The PV panel and battery storage lifetime, capital cost, replacement cost and O&M (operation and maintenance) cost is considered same as centralized.

Here, we considered system fixed capital cost where another 1 set of battery price has been added. This extra set of battery will be used after battery swapping.

Each battery price is 3,500 BDT

One battery set contains 4 no. of batteries and each battery rating is 12V 25Ah.

One set (1*4 = 4) of battery price = 3500*4

= 14,000 BDT

System fixed capital cost =14,000 BDT

= $171

1 USD = 82 BDT

We considered System fixed O&M (operation and maintenance) cost $3.42 which is 2% of our fixed capital cost.

NO.	Equipment	Total Cost/ unit	Total Cost/ kW	Repl. cost	O & M/ year	O & M/ hour	Fuel/liter
1.	Generic 1kWh lead acid	$80	n/a	$80	$1.6	n/a	n/a
2.	Generic flat plate PV	n/a	$600	n/a	$6.00	n/a	n/a
3.	System Fixed Capital Cost	$171	n/a	n/a	$3.42	n/a	n/a

Figure 7.31: Summary of all the technological resources cost

Schematic diagram:

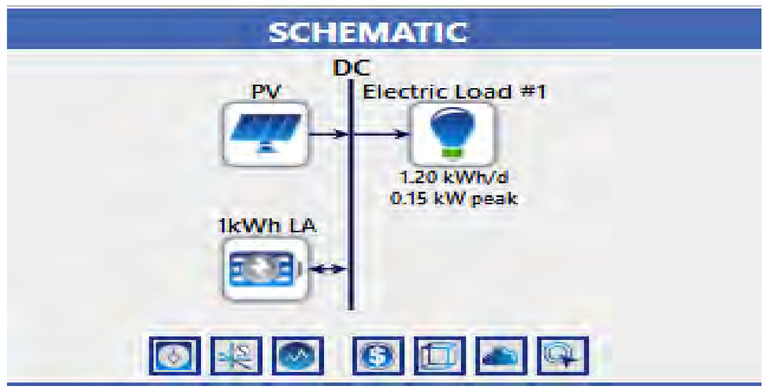
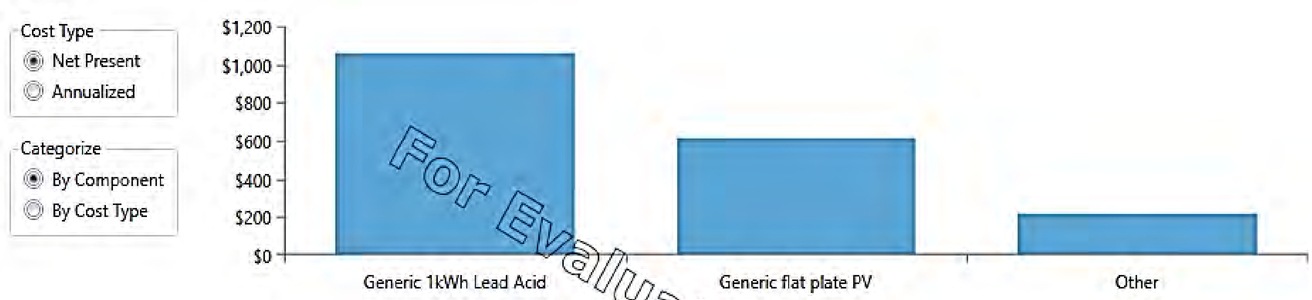


Figure 7.32: Schematic diagram in HOMER

Simulation result:

From the simulation, HOMER finds a total of 0.908 kW PV panel and 4 no. of batteries which is the best fit for the system.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 1kWh Lead Acid	$320.00	$658.92	$82.72	$0.00	$0.00	$1,061.64
Generic flat plate PV	$545.07	$0.00	$70.47	$0.00	$0.00	$615.54
Other	$171.00	$0.00	$44.19	$0.00	$0.00	$215.19
System	$1,036.07	$658.92	$197.38	$0.00	$0.00	$1,892.37

Figure 7.33: Total cost summary in HOMER

From figure 7.33 it is seen that the total capital cost for the system is $1,036.07. The total net present cost (NPC), replacement cost, O&M cost over the 25 years lifetime period is given as $1,892.37, $658.92, $197.38 respectively.

Figure 7.34: Annual production and consumption

Figure 7.34 shows that the annual production of Generic flat plate PV is 1,306 kWh. The annual electricity demand that is consumed by the load is 438 kWh.

Payback period:

(Figure 7.33) capital cost of the system = $1036.07

= 84,957.74 BDT

From centralized SBCS per month energy cost for 1 battery bank is 728.8 BDT

So, annual savings will be (728.8 * 12) = 8,745.6 BDT

Payback period = $\frac{84{,}957.74}{8{,}745.6}$ = 9.7 years

Comparative Analysis Summary:

Centralized SBCS	Decentralized DSPCK
Capital cost of the system for 10 battery banks is $5,176.64 and total system cost for 25 years is $27,033.50 So, capital cost for 1 battery bank is $517.66 and total system cost is $2,703.35	Capital cost of the system is $1,036.07 and total system cost or 25 years is $1,892.37
Per month energy cost for 1 battery bank is 728.8 BDT	No energy cost
Payback period is 4.8 years	Payback period is 9.7 years

CASE 3:

1. CENTRALIZED SOLAR STREET LIGHTING SYSTEM:

For the Centralized solar street lighting system simulation we have considered our location is Dhaka, Bangladesh.

Load measurement:

Here we considered a small area where a no .of 60 street lights are connected with our proposed system.

Power rating of a single street light - 50 Watt

The operating time is considered 12 hr. in a day.

LED street lighting is very popular now a days because LEDs are highly energy efficient than other fluorescent lamps and has low maintenance cost

Appliances	Watt	No.of equipment	Total load (Watt)	Hours used/day	Total Unit (wh/day)
LED Street Light	50	60	3000	12	36000

Figure 7.35: Load of 60 street lights.

Therefore for 60 street lights 36,000 Wh or 36 kWh is required per day

Solar resource:

Solar irradiance data for the study area is obtained from the official NASA Surface meteorology and solar energy database.

Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.631	4.360
February	0.615	4.920
March	0.599	5.590
April	0.552	5.760
May	0.481	5.300
June	0.405	4.530
July	0.382	4.230
August	0.404	4.290
September	0.415	4.020
October	0.516	4.320
November	0.600	4.280
December	0.643	4.210

Annual Average (kWh/m²/day): 4.65

Figure 7.36: Solar irradiance data

From figure 7.36 it is seen that the daily average radiation of our proposed area is about 4.65 kWh/m^2/day and average clearness index is 0.52.

PV calculation:

Total PV Panel energy needed =36,000*1.3

=46,800 Wh/day

Here, 1.3 = Energy lost in the system

Total Wp of PV panel capacity needed = $\frac{46,800}{4.65}$

=10,064.52 Wp ≈ 10kWp

Battery Calculation:

Battery capacity (Ah) = $\frac{36,000*1}{0.85*0.5*12}$

=7058.82Ah

So the number of batteries required for our system = $\frac{7058.82\ Ah}{83.4\ Ah}$

= 84.64 ≈ 85

A total 85battery is needed. Each battery rating is 12V 83.4 Ah.

Converter Calculation:

Total Watt of equipment's = 50 * 60

=3000 Watt

Inverter capacity = 3000+ (3000 * 30%)

= 3900 Watt ≈ 4 Kw

So for our system we need total 4 Kw inverter.

Back-up Generator:

For the system we considered a backup generator of 10 Kw capacity.

Here, we considered system fixed capital cost where land cost has been taken.

System fixed capital cost = 6, 30,000 BDT

= $7683

We considered System fixed O&M (operation and maintenance) cost $1153.66 which is 2% of our fixed capital cost.

NO.	Equipment	Total Cost/ unit	Total Cost/ kW	Repl. cost	O & M/ year	O & M/ hour	Fuel/liter
1.	Generic 1kWh lead acid	$80	n/a	$80	$1.6	n/a	n/a
2.	Generic flat plate PV	n/a	$600	n/a	$6.00	n/a	n/a
3.	Converter	n/a	$180	$180	n/a	n/a	n/a
4.	10kW Fixed capacity Genset	$1,456	n/a	$1,456	n/a	$0.09	$0.78
5.	System Fixed Capital Cost	$7,683	n/a	n/a	$153.66	n/a	n/a

Figure 7.37: Summary of all the technological resources cost

Schematic Diagram of proposed model:

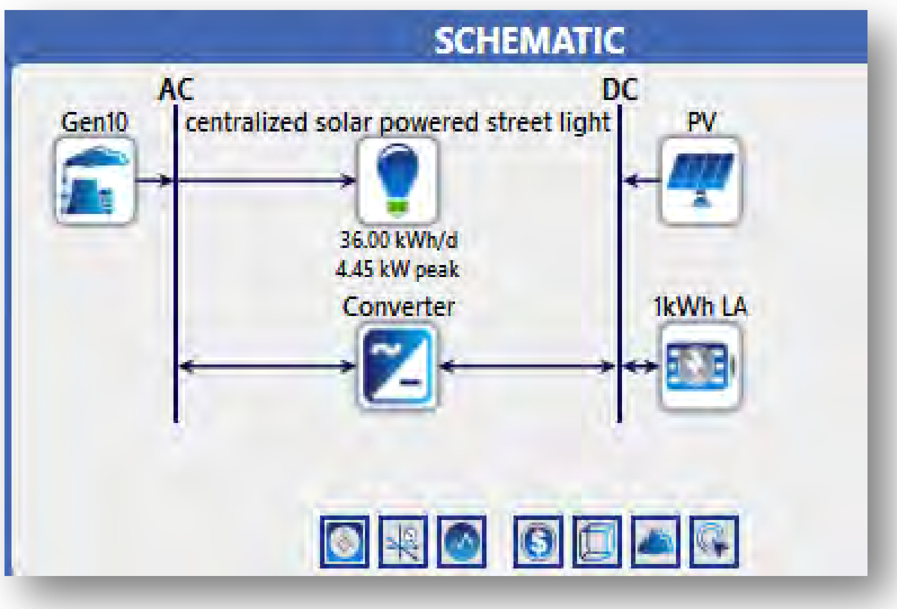
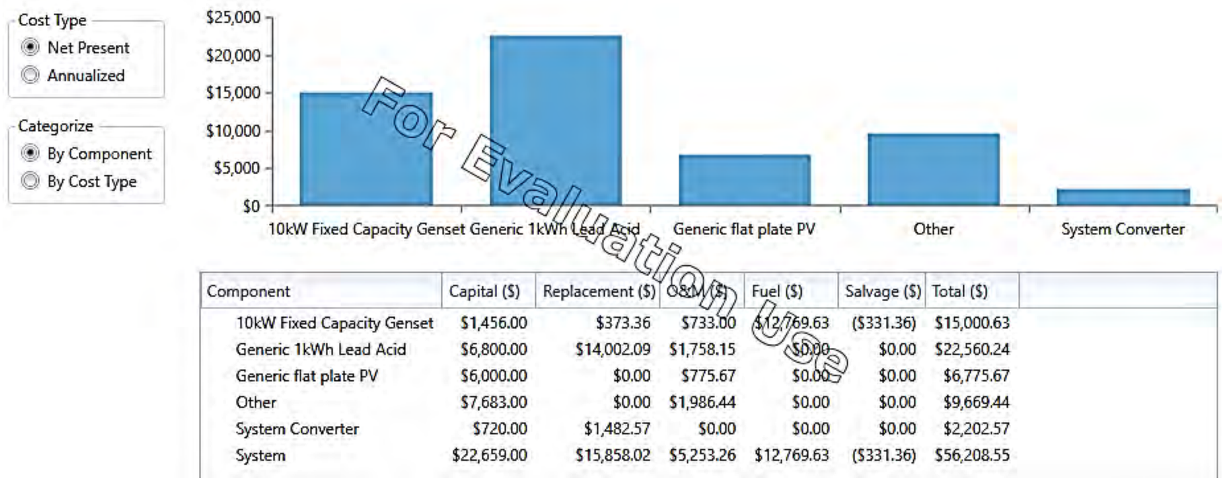


Figure 7.38: Schematic diagram in HOMER

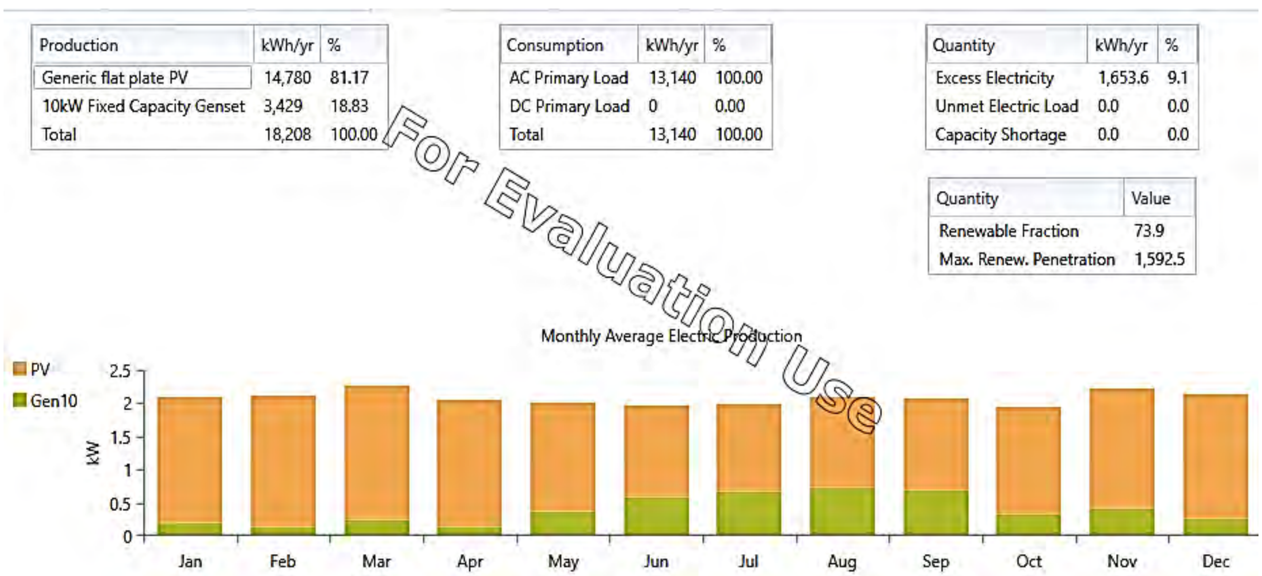
Simulation Result:



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
10kW Fixed Capacity Genset	$1,456.00	$373.36	$733.00	$12,769.63	($331.36)	$15,000.63
Generic 1kWh Lead Acid	$6,800.00	$14,002.09	$1,758.15	$0.00	$0.00	$22,560.24
Generic flat plate PV	$6,000.00	$0.00	$775.67	$0.00	$0.00	$6,775.67
Other	$7,683.00	$0.00	$1,986.44	$0.00	$0.00	$9,669.44
System Converter	$720.00	$1,482.57	$0.00	$0.00	$0.00	$2,202.57
System	$22,659.00	$15,858.02	$5,253.26	$12,769.63	($331.36)	$56,208.55

Figure 7.39: Total cost summary in HOMER

From figure 7.39 it is seen that the total capital cost for the system is $22,659.00. The total net present cost (NPC), replacement cost, O&M cost, fuel cost over the 25 years lifetime period is given as $56,208.55, $15,858.02, $5,253.26 and $12,769.63 respectively.



Production	kWh/yr	%
Generic flat plate PV	14,780	81.17
10kW Fixed Capacity Genset	3,429	18.83
Total	18,208	100.00

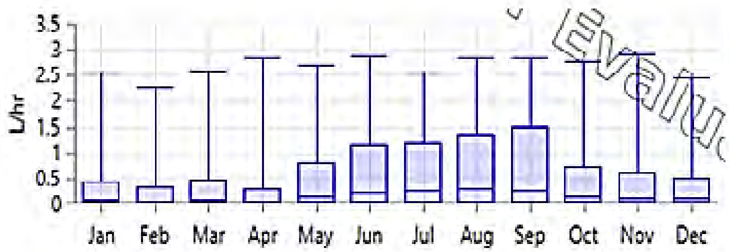
Consumption	kWh/yr	%
AC Primary Load	13,140	100.00
DC Primary Load	0	0.00
Total	13,140	100.00

Quantity	kWh/yr	%
Excess Electricity	1,653.6	9.1
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	73.9
Max. Renew. Penetration	1,592.5

Figure 7.40: Annual production, consumption

Figure 7.40 shows that the annual production of Generic flat plate PV and 10 kW Fixed Capacity Genset is 14,780 kWh and 3,429 kWh respectively. The annual electricity demand that is consumed by the load is 13,140 kWh.



Quantity	Value	Units
Total fuel consumed	1,266	L
Avg fuel per day	3.47	L/day
Avg fuel per hour	0.145	L/hour

Figure 7.41: Fuel summary of the generator

From Figure 7.41 it is seen that the average fuel per day is needed 3.47 liter.

Quantity	Value	Units
Carbon Dioxide	3,376.81	kg/yr
Carbon Monoxide	25.54	kg/yr
Unburned Hydrocarbons	0.93	kg/yr
Particulate Matter	1.55	kg/yr
Sulfur Dioxide	8.29	kg/yr
Nitrogen Oxides	29.03	kg/yr

Figure 7.42: Annual emission

Cost calculation:

(Figure 7.39) Total cost of the system = $56208.55

(For 60 street lights)

Total cost of the system = $936.81

= 76,818.42 BDT

(For 1 street lights)

1 USD = 82 BDT

Payback Calculation:

Per unit = $\frac{\$56,208.55*82}{36000*25*365/1000}$

= 14.03 BDT

Annual consumption by AC primary load= 13,140 kWh/year (for 60 street lights)

Annual consumption by AC primary load= 219 kWh/year (for 1 street light)

Per year energy cost = 219*14.03

= 3072.73 BDT

Per month energy cost = 256.05 BDT

Payback period = $\frac{\$22,659*82}{14.03*13140}$

=10.8 years

2. Decentralized Solar street lighting system:

In decentralize solar street lighting system simulation we have considered one streetlight. We assume same project location for both (Dhaka, Bangladesh). The load information is given below in a chart:

Appliances	Watt	No.of equipment	Total load (watt)	Hours used/day	Total unit (Wh/day)

LED Street Light	50	1	50	12	600

Figure 7.43: Load of one street light

Solar resource:

As we have selected the same location for decentralized street lighting, our solar irradiance data is same as figure 7.36.

Component:

For decentralized SHS simulation our system design contains solar PV module and battery storage to fulfill the load demand. The model of the PV panel and battery storage is taken same that has been used in centralized. The PV panel and battery storage lifetime, capital cost, replacement cost and O&M (operation and maintenance) cost is considered same as figure 7.14.

Schematic diagram:

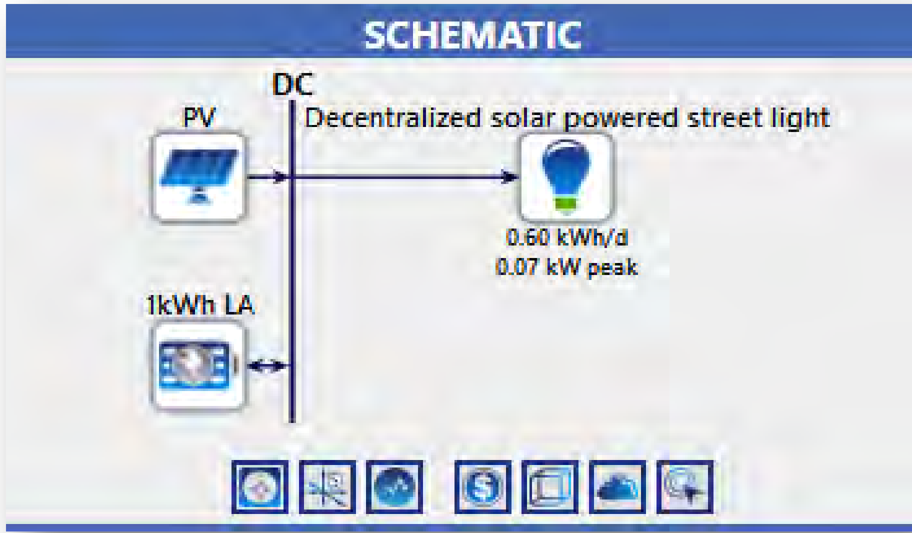
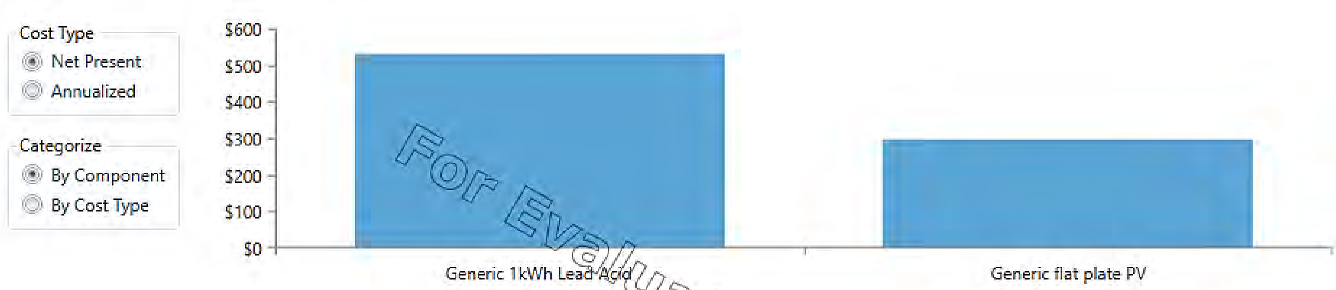


Figure 7.44: Schematic Diagram in HOMER

Simulation result:

From the simulation, HOMER finds a total of 0.435 kW PV panel and 2 no. of batteries which is the best fit for the system.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 1kWh Lead Acid	$160.00	$329.46	$41.36	$0.00	$0.00	$530.82
Generic flat plate PV	$261.27	$0.00	$33.76	$0.00	$0.00	$295.03
System	$421.27	$329.46	$75.12	$0.00	$0.00	$825.85

Figure 7.45: Total cost summary in HOMER

From figure 7.45 it is seen that the total capital cost for the system is $421.27. The total net present cost (NPC), replacement cost, O&M cost over the 25 years lifetime period is given as $825.85, $329.46, $75.12 respectively.

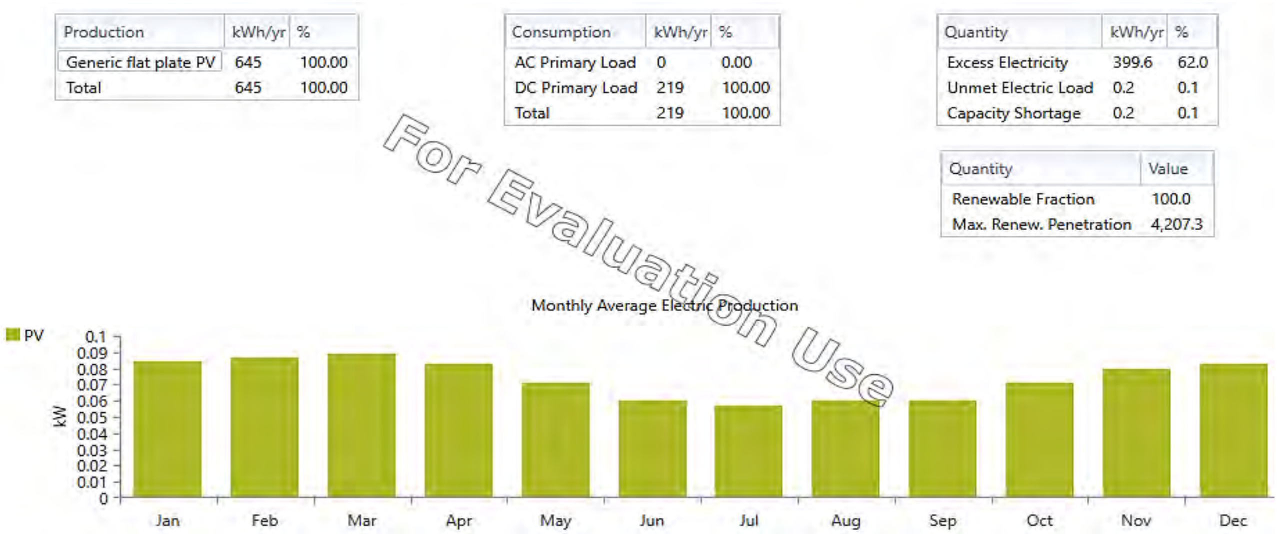


Figure 7.46: Annual production and consumption

Figure 7.46 shows that the annual production of Generic flat plate PV is 645 kWh. The annual electricity demand that is consumed by the load is 219 kWh.

Cost Calculation:

Total cost of the system = $825.85

= 67,719.7 BDT

(For 1 street lights)

1 USD = 82 BDT

Payback Calculation:

Annual savings= 3072.57 BDT

Payback period = (421.27∗82)/3072.57

= 11.2 years

Comparative Analysis Summary:

Centralized Solar street lighting system	Decentralized Solar street lighting system
Capital cost for 60 street lights is $22,659 and total system cost is $56,208. So per light installation cost is $377,65 and system cost is $936.8	Capital cost for one street light is $421.27 and total system cost is $825.85.

CASE 4:

1. CENTRALIZEDSOLAR TRAFFIC LIGHTING SYSTEM:

For our Centralized solar traffic lighting system simulation we have considered our location is Dhaka, Bangladesh.

Load measurement:

Here we considered a small area where a no .of 12 LED traffic systems are connected with our proposed system.

Power rating of a single traffic light – 15 Watt

The operating time is considered 24 hrs. In a day.

Appliances	Watt	No.of equipment	Total load (Watt)	Hours used/day	Total Unit (wh/day)
LED traffic Light	15	12	180	24	4320

Figure 7.47: Load of 12 traffic lights.

Therefore for 10 traffic lights 4,320 Wh or 4.32 kWh is required per day.

Solar resource:

Solar irradiance data for the study area is obtained from the official NASA Surface meteorology and solar energy database. For both centralized street lighting and traffic lighting system our location is Dhaka so solar irradiance data is figure 7.36.

Daily average radiation = 4.65 kWh/m^2/day

Average clearness index = 0.52.

PV calculation:

Total PV Panel energy needed =4,320 * 1.3

= 5,616 Wh/day

Here, 1.3 = Energy lost in the system

Total Wp of PV panel capacity needed = $\frac{5{,}616}{4.65}$

=1,207.7 Wp ≈ 1.3 kWp

Battery Calculation:

Battery capacity (Ah) = $\frac{4{,}320 * 1}{0.85 * 0.5 * 12}$

= 847.06 Ah

So the number of batteries required for our system = $\frac{847.06\ Ah}{83.4\ Ah}$

= 10.2 ≈ 11

A total 11 battery is needed. Each battery rating is 12V 83.4 Ah.

Converter Calculation:

Total Watt of equipment's = 15 * 12

=180 Watt

Inverter capacity = 180+ (180 * 30%)

= 234 Watt ≈ 0.3 kW

So for our system we need total 0.3kW inverter.

Back-up Generator:

For the system we considered Auto size genset.

Here, we considered system fixed capital cost where land cost has been taken.

System fixed capital cost = 1, 20,000 BDT

= $1463.4

We considered System fixed O&M (operation and maintenance) cost $29.3 which is 2% of our fixed capital cost.

NO.	Equipment	Total Cost/ unit	Total Cost/ kW	Repl. cost	O & M/ year	O & M/ hour	Fuel/liter
1.	Generic 1kWh lead acid	$80	n/a	$80	$1.6	n/a	n/a
2.	Generic flat plate PV	n/a	$600	n/a	$6.00	n/a	n/a
3.	Converter	n/a	$180	$180	n/a	n/a	n/a
4.	Auto size Genset	$145.6	n/a	$145.6	n/a	$0.0090	$0.78
5.	System Fixed Capital Cost	$1,463.40	n/a	n/a	$29.30	n/a	n/a

Figure 7.48: Summary of all the technological resources cost

Schematic Diagram of proposed model:

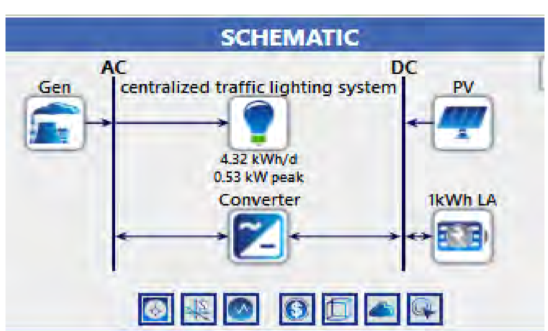
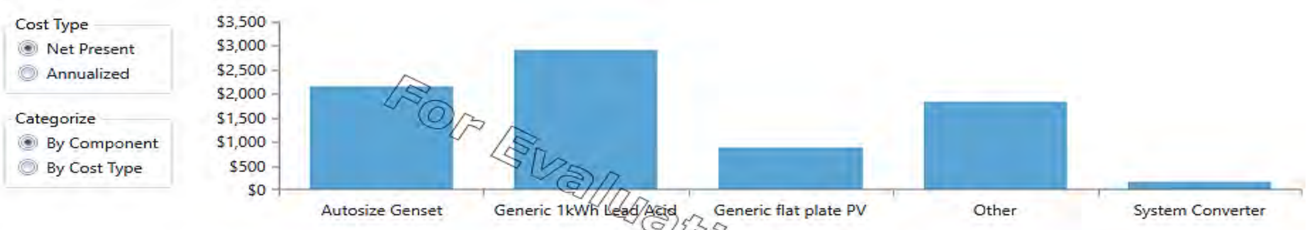


Figure 7.49: Schematic Diagram of the proposed system.

From the simulation, HOMER finds a total of 0.590 kW Genset which is the best fit for the system.

Simulation Result:



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Autosize Genset	$85.90	$83.85	$118.01	$1,874.52	($2.78)	$2,159.50
Generic 1kWh Lead Acid	$880.00	$1,812.03	$227.52	$0.00	$0.00	$2,919.55
Generic flat plate PV	$780.00	$0.00	$100.85	$0.00	$0.00	$880.85
Other	$1,463.40	$0.00	$378.76	$0.00	$0.00	$1,842.16
System Converter	$54.00	$111.20	$0.00	$0.00	$0.00	$165.20
System	$3,263.30	$2,007.08	$825.14	$1,874.52	($2.78)	$7,967.26

Figure 7.50: Total cost summary in HOMER

From figure 7.50 it is seen that the total capital cost for the system is $3,263.30. The total net present cost (NPC), replacement cost, O&M cost, fuel cost over the 25 years lifetime period is given as $7,967.26, $2,007.08, $825.14 and $1,874.52 respectively.

Production	kWh/yr	%
Generic flat plate PV	1,924	81.28
Autosize Genset	443	18.72
Total	2,368	100.00

Consumption	kWh/yr	%
AC Primary Load	1,577	100.00
DC Primary Load	0	0.00
Total	1,577	100.00

Quantity	kWh/yr	%
Excess Electricity	465.9	19.7
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	71.9
Max. Renew. Penetration	1,744.6

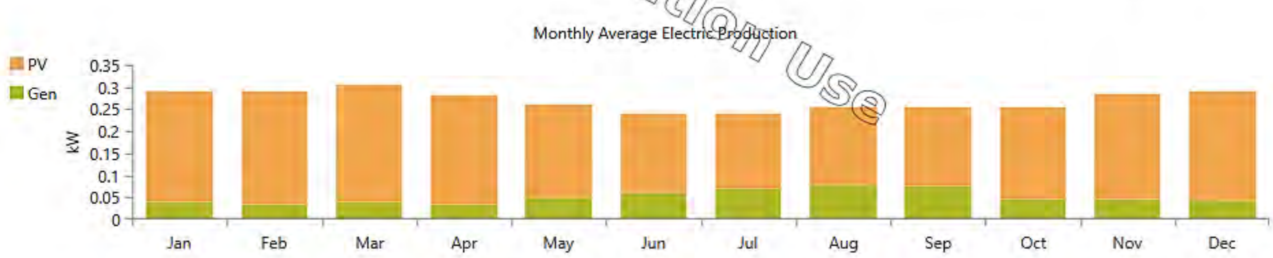


Figure 7.51: Annual production & consumption

Figure 7.51 shows that the annual production of Generic flat plate PV and Auto size Genset is 1,924 kWh and 443 kWh respectively. The annual electricity demand that is consumed by the load is 1,577 kWh.

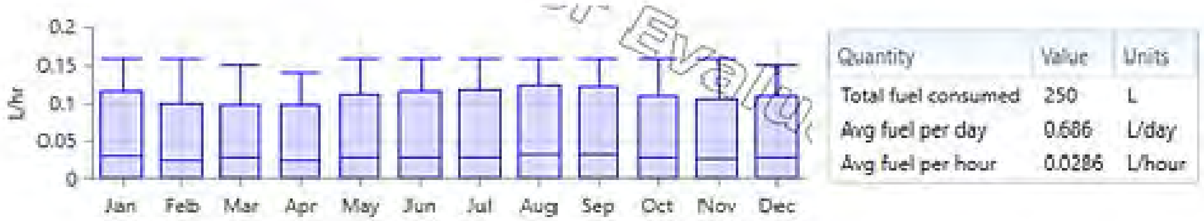


Figure 7.52: Fuel summary of the generator

From Figure 7.52 it is seen that the average fuel per day is needed 0.686 liter

Quantity	Value	Units
Carbon Dioxide	655.52	kg/yr
Carbon Monoxide	4.13	kg/yr
Unburned Hydrocarbons	0.18	kg/yr
Particulate Matter	0.03	kg/yr
Sulfur Dioxide	1.61	kg/yr
Nitrogen Oxides	3.88	kg/yr

Figure 7.53: Annual emission

Cost calculation:

(Figure 7.50) Total cost of the system = $7,967.26

(For 12 traffic system)

Total cost of the system = $663.94

= 54,443 BDT

(For 1 traffic system)

1 USD = 82 BDT

Payback Calculation:

Per unit $= \frac{\$7967.26 * 82}{4320 * 25 * 365 / 1000}$

= 16.6 BDT

Annual consumption by AC primary load= 1577 kWh/year (for 12 traffic lights)

Annual consumption by AC primary load= 131 kWh/year (for 1 traffic light)

Per year energy cost = 16.6*131

= 2171.1 BDT

Per month energy cost = 180.92 BDT

Payback period = $\frac{\$3263 * 82}{16.6 * 1577}$

=10.2 years

2. Decentralized solar traffic lighting system:

In decentralize solar traffic lighting system simulation we have considered one traffic light. For both centralized and decentralized traffic lighting system we select same project location (Dhaka, Bangladesh). The load information is given below in a chart:

Appliances	Watt	No.of equipment	Total load (watt)	Hours used/day	Total unit (Wh/day)
LED traffic Light	15	1	15	24	360

Figure 7.54: Load of one traffic light

Solar resource:

In this part solar irradiance data is the data of figure 7.36. As our location is same Dhaka, Bangladesh.

Component:

The system contains PV module and battery storage only. The model of the PV panel and battery storage is taken same that has been used in centralized. The PV panel and battery storage lifetime, capital cost, replacement cost and O&M (operation and maintenance) cost is considered same as Figure 7.14.

Schematic diagram:

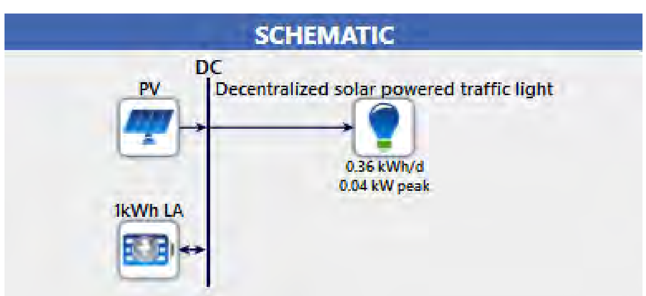
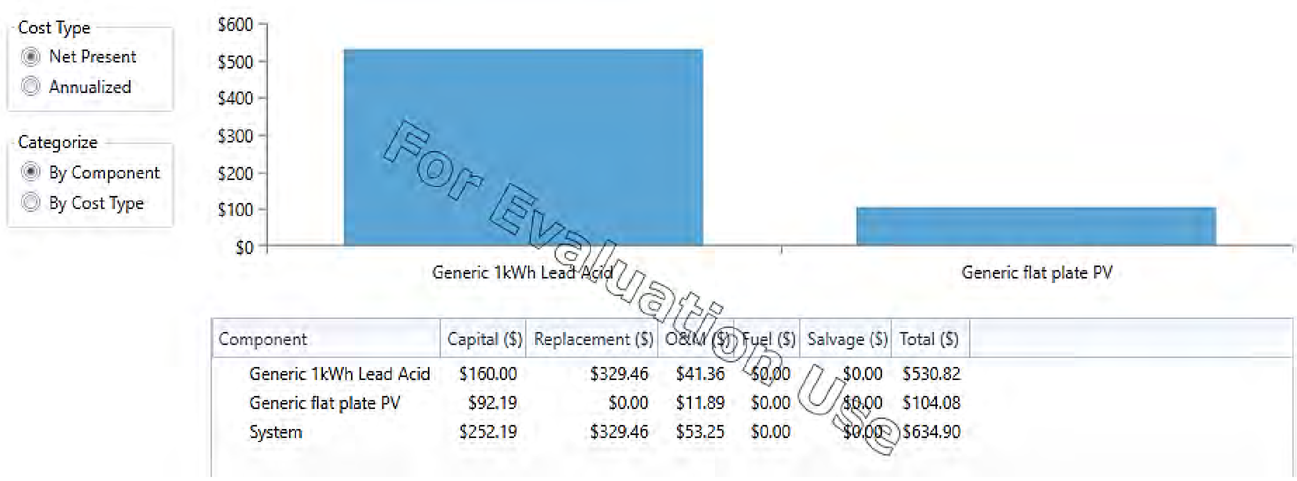


Figure 7.55: Schematic diagram in HOMER

Simulation result:

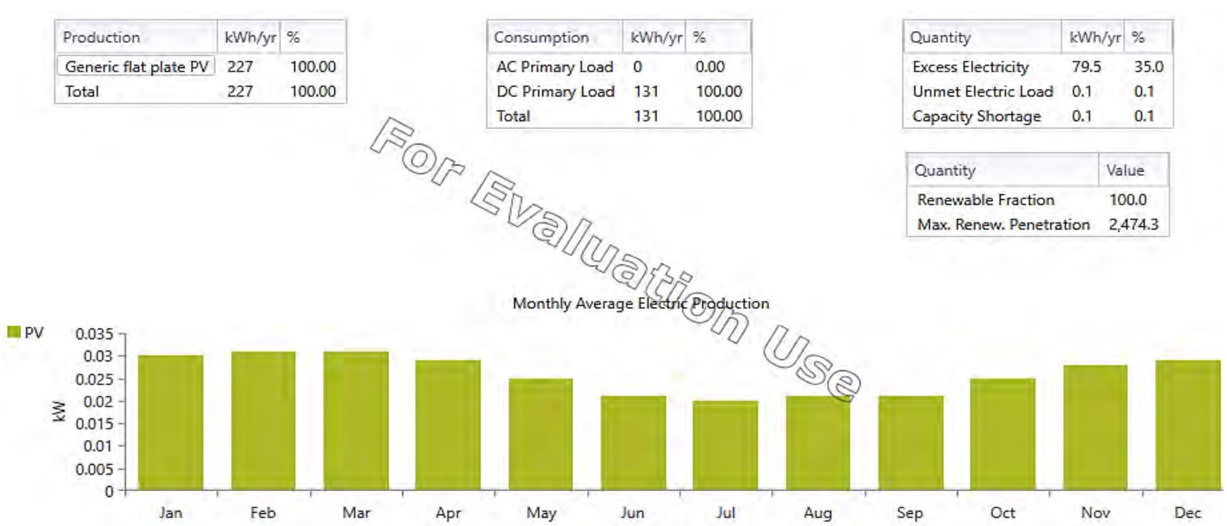
From the simulation, HOMER finds a total of 0.154 kW PV panel and 2 no. of batteries which is the best fit for the system.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 1kWh Lead Acid	$160.00	$329.46	$41.36	$0.00	$0.00	$530.82
Generic flat plate PV	$92.19	$0.00	$11.89	$0.00	$0.00	$104.08
System	$252.19	$329.46	$53.25	$0.00	$0.00	$634.90

Figure 7.56: Total cost summary in HOMER

From figure 7.56 it is seen that the total capital cost for the system is $252.19. The total net present cost (NPC), replacement cost, O&M cost over the 25 years lifetime period is given as $634.90, $329.46, $53.25 respectively.



Production	kWh/yr	%
Generic flat plate PV	227	100.00
Total	227	100.00

Consumption	kWh/yr	%
AC Primary Load	0	0.00
DC Primary Load	131	100.00
Total	131	100.00

Quantity	kWh/yr	%
Excess Electricity	79.5	35.0
Unmet Electric Load	0.1	0.1
Capacity Shortage	0.1	0.1

Quantity	Value
Renewable Fraction	100.0
Max. Renew. Penetration	2,474.3

Figure 7.57: Annual production and consumption

Figure 7.57 shows that the annual production of Generic flat plate PV is 227 kWh. The annual electricity demand that is consumed by the load is 131 kWh.

Cost Calculation:

(Figure 7.56) Total cost of the system = \$634.90

= 52061.8 BDT

(For 1 traffic system)

1 USD = 82 BDT

Payback Calculation:

Annual savings= 2171.1 BDT

Payback period = $\frac{\$252.19*82}{2171.1}$

= 9.5 years

Comparative Analysis Summary:

Centralized solar traffic lighting system	Decentralized solar traffic lighting system
Capital cost for 12 traffic lights is $3,263.30 and total system cost is $7,967.26 So per light installation cost is $272 and system cost is $663.94.	Capital cost for one traffic light is $252.19 and total system cost is $634.90.

7.2 RETScreen Software:

RETScreen software is a clean energy project analysis tool introduced by Natural Resources Canada's CANMET Energy Diversification Research Laboratory (CEDRL). It assists decision makers in calculating the feasibility of certain energy project potential for execution swiftly and cheaply. Software has integrated all different kind of energy exclusively renewable energy allied aspects. Software algorithms can compute technical, economic and environmental feasibility of dissimilar renewable energy, energy efficiency and cogeneration projects in terms of resultant solar fraction, NPV, IRR, payback periods, GHG emissions decrease and reinforcement fuel investment funds.
RETScreen software creators implanted climatic and geographical situations of almost all towns of world map affirmed by NASA. Solar irradiance is key feature between climatic states of certain site that reliably resembles to life cycle performance of PV system. That is the reason for determination of certain place for renewable energy system installation is a vital thought as far as its climatic situations and geographical data.

RETScreen software has been programmed to find out the feasibility of a system as far as its technical parameters such as number of PV units utilized and corresponding power carried to load, economic factors and environmental limitations.

RETScreen results are explained in three tactics;

- Technical Analysis
- Economic Analysis
- Emissions Analysis

1. Technical Analysis:
In financial languages, technical analysis is a security analysis procedure of

noticing the modifications in previous prices with aim of predicting upcoming price and volume.

However, in engineering standings, technical analysis deals with parameters of product upon which the efficiency and efficient application depends. For standalone PV system's technical analysis, number of PV units needed for achieving 100% power capacity and resultant total power carried to load are examined.

2. Economic Analysis:

Economics deals with manufacture of goods, their delivery and customer's reaction. Economics of a certain project can be evaluated on the foundation of economic factors like NPV, IRR, equity and simple payback periods.

3. Emissions Analysis:

GHG emissions are key drive of global warming effect that is initiating severe health problems and even deaths of thousands of thousands of individuals consistently. Main source behind GHG emissions is inadequate ignition of high carbon content fossil fuels. That is the reason the entire world is searching for clean and environment friendly energy sources and in this point of view numerous etiquettes have also been set to control emissions.

The price and life-span of apparatus are taken from the reliable sources of internet and published papers for the models and the Energy consumption calculation has been done for a basic rural need.

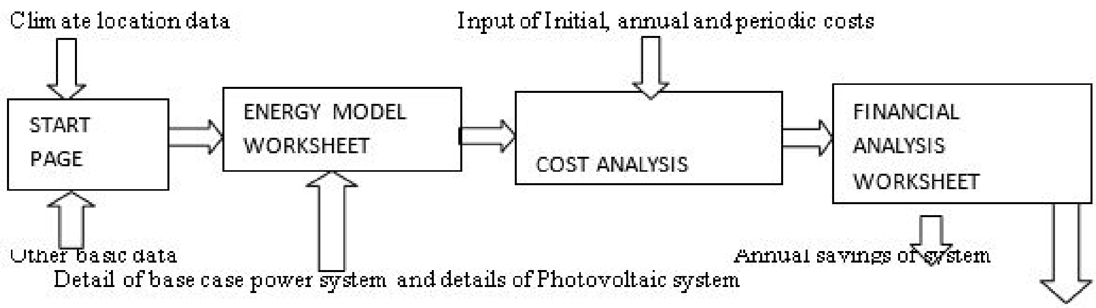


Figure 7.2: Flowchart of RETScreen

Case 1: Centralized solar mini-grid-connected home system &SecentralizedSolar Home System

Centralized solar mini-grid-connected home system:
With this system, we have considered to serve 30 households where total load is 37.5kW. Based on the calculation (included in HOMER part 1.1), we have taken 11kW PV panel, 88 lead acid battery of 12V 83.4Ah, 10kW generator to supply power to the load. Further, we have added 6kW inverter to converts DC output of PV panels into AC current.

Climate Data:
In this system we have considered Chittagong, Bangladesh as our project location. In figure 7.2.1(a) & (b) shows the climate data affirmed by NASA.

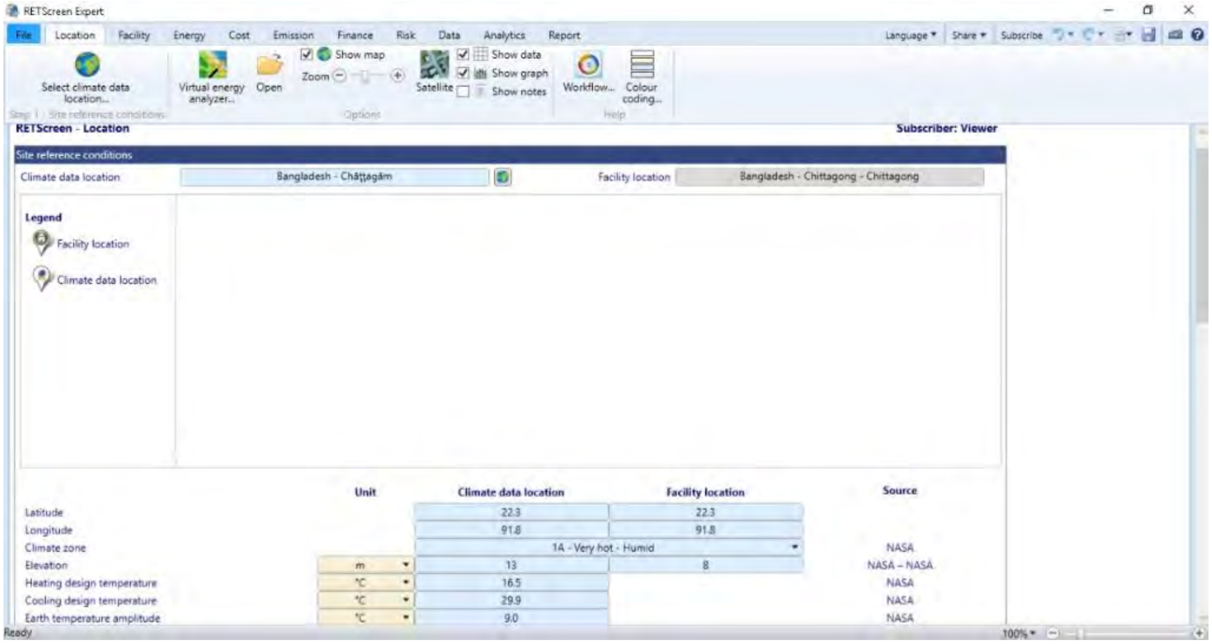
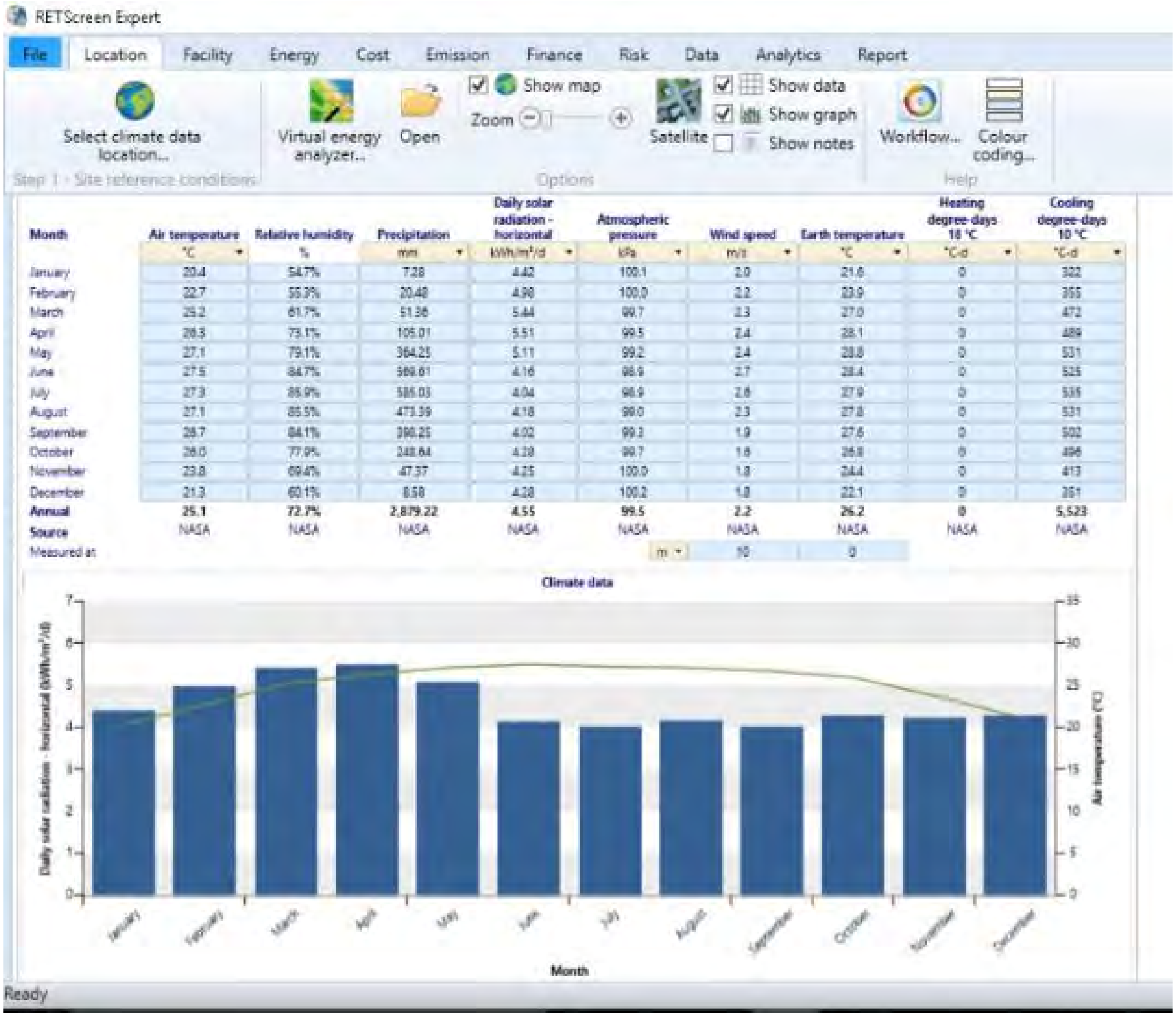


Figure 7.2.1(a): Climate Data



Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	20.4	54.7%	7.28	4.42	100.1	2.0	21.6	0	322
February	22.7	55.3%	20.48	4.98	100.0	2.2	23.9	0	355
March	25.2	61.7%	51.38	5.44	99.7	2.3	27.0	0	472
April	28.3	73.1%	105.01	5.51	99.5	2.4	28.1	0	489
May	27.1	79.1%	364.25	5.11	99.2	2.4	28.8	0	531
June	27.5	84.7%	569.61	4.16	98.9	2.7	28.4	0	525
July	27.3	85.9%	585.03	4.04	98.9	2.8	27.9	0	535
August	27.1	85.5%	473.39	4.18	99.0	2.3	27.8	0	531
September	28.7	84.1%	390.25	4.02	99.3	1.9	27.6	0	502
October	28.0	77.9%	248.64	4.28	99.7	1.8	26.8	0	498
November	23.8	69.4%	47.37	4.25	100.0	1.8	24.4	0	413
December	21.3	60.1%	8.58	4.28	100.2	1.8	22.1	0	351
Annual	25.1	72.7%	2,879.22	4.55	99.5	2.2	26.2	0	5,523
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
Measured at					m	10	0		

Figure 7.2.1(b): Climate Data

Load:

Here, we have considered,

120 Lights = 10 Watt * 120 nos. * 5 hrs. = 6,000 watt-hour;

60 Fans = 25 watt * 60 nos. * 15 hrs. = 22,500 watt-hour;

30 TV = 60 watt * 30 no. * 5 hrs. = 9,000 watt-hour;

Total is = 6000+22500+9000 = 37,500 watt = 37.5 KWh per family/day

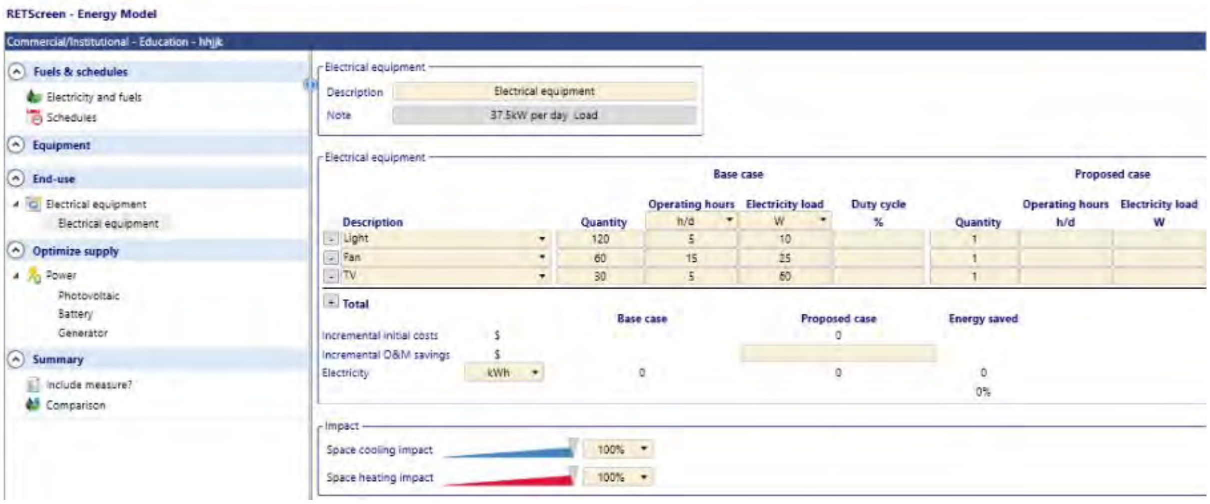


Figure 7.2.2: Load

PV Panel:

Here, we have chosen photovoltaic type mono-si and 44 no. of units of 250W PV panel to design our 11kW photovoltaic power capacity. To get batter solar radiation we have taken slope equal to 22.35 and azimuth equal to 0 (Recommended by Homer). Moreover, to keep our result more accurate, we have considered miscellaneous loss of inverter equal to 0.

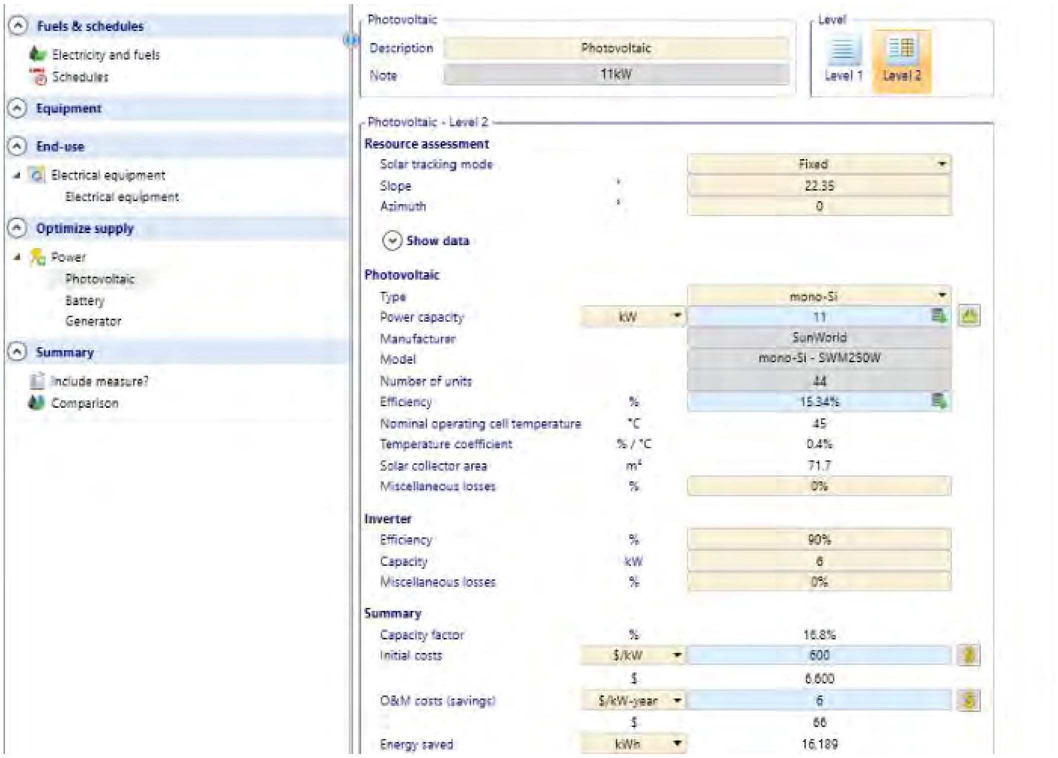


Figure 7.2.3: PV panel

Battery:

Here, we have modelled 88 lead acid batteries each one's nominal voltage 12V, maximum capacity 83.4Ah.

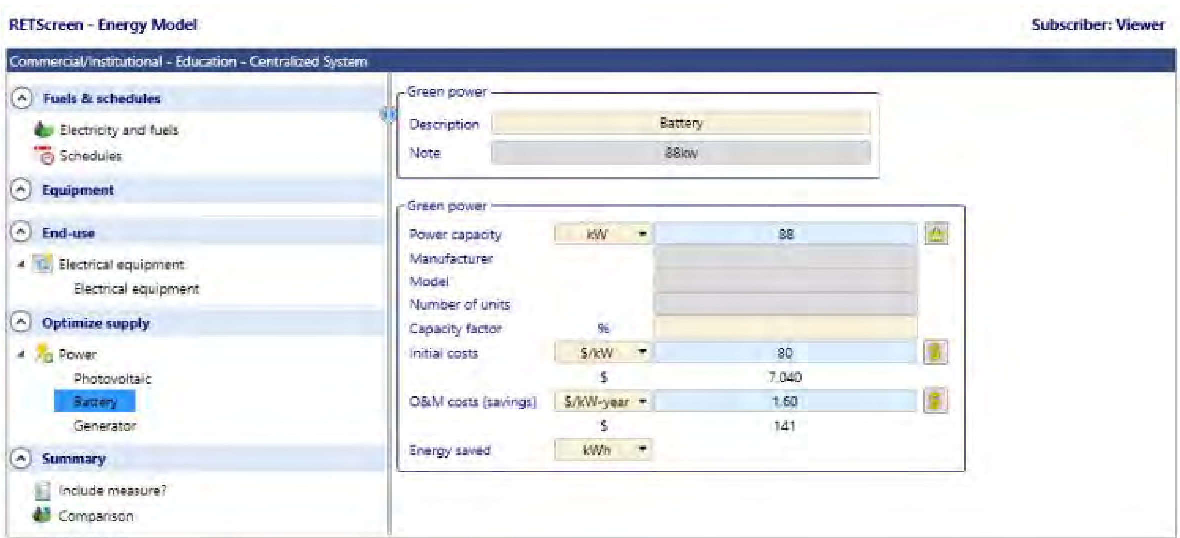


Figure 7.2.4: Battery

Fuel Cost: According to Bangladesh Petroleum Corporation, we have taken price of fuel per litre in dollar.

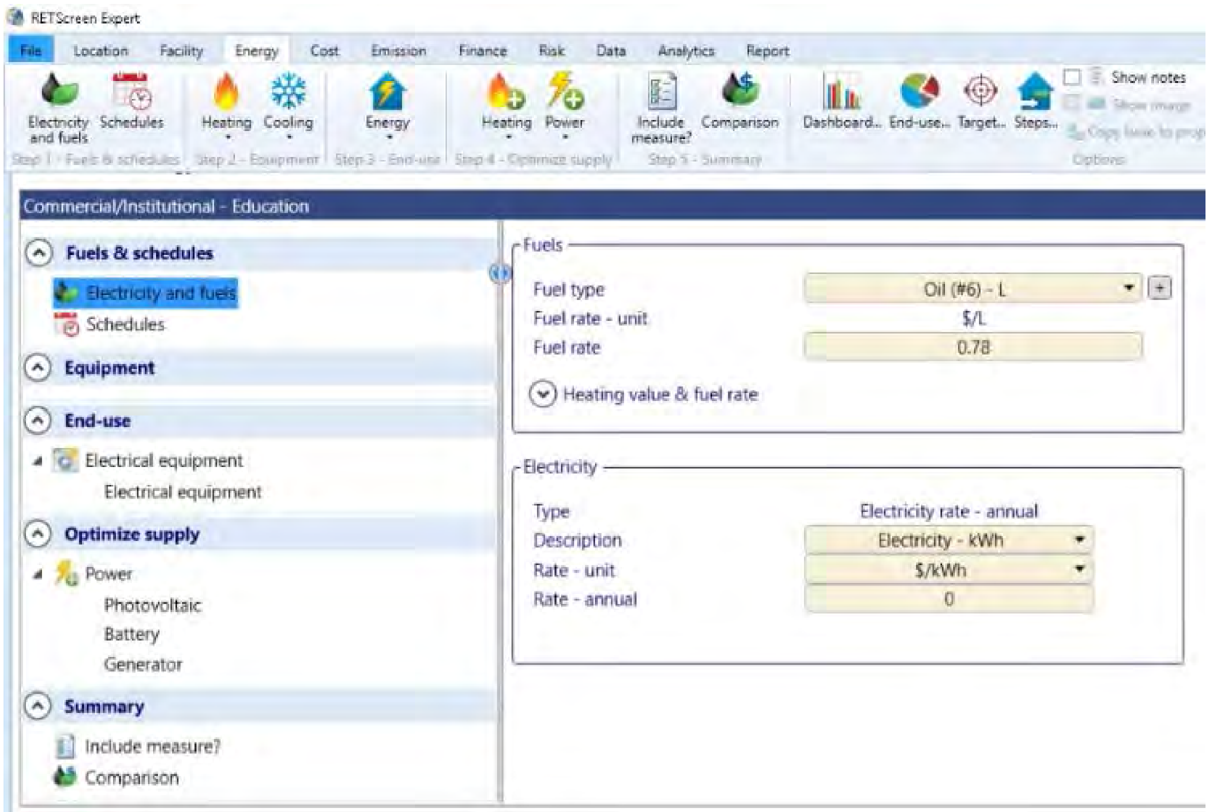


Figure 7.2.5: Fuel Cost

Generator:

We have chosen a back-up generator of 10kW which run on an existing fuel source to supply power during blackouts and power outages.

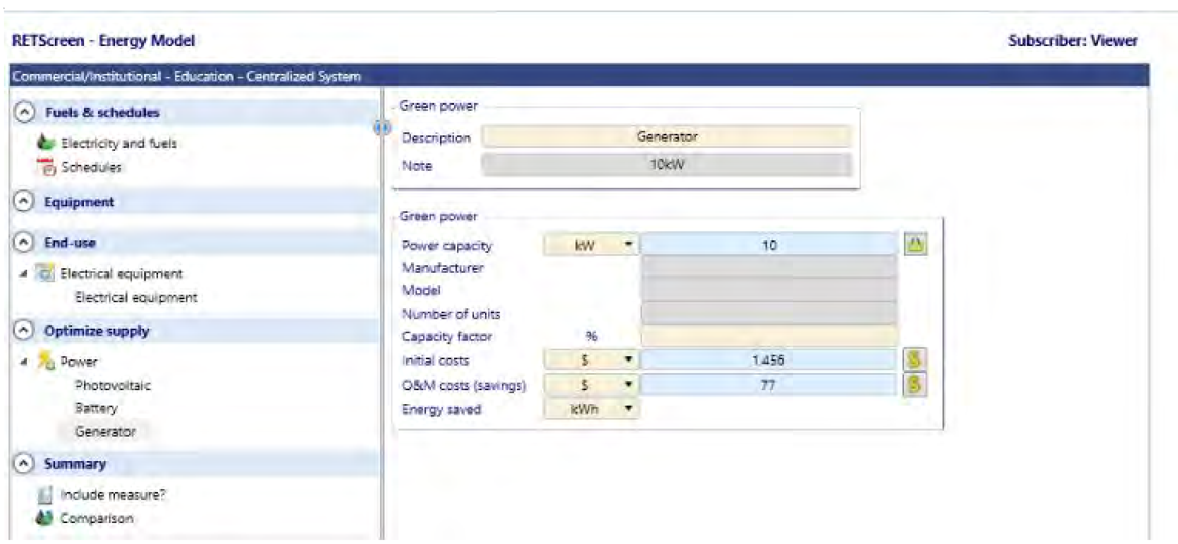


Figure 7.2.6: Generator

Annual Cost:

Here we can see total initial cost of PV panel, battery, generator, inverter and system fixed capital cost is $25,376 and operation & management cost of PV panel, battery, and generator is $468. Finally, we have compared our RETScreen annual result with Homer annual result which are exactly same.

RETScreen - Cost Analysis

Initial costs (credits)	Unit	Quantity	Unit cost	Amount
Incremental initial costs				$ 15,096
Show data				
Electrical equipment				
Electrical equipment			$ 0	Update cost
Power system				
Photovoltaic			$ 6,600	Update cost
Generator			$ 1,456	Update cost
Battery			$ 7,040	Update cost
Inverter	cost	1	$ 1,080	$ 1,080
System Fixed Capital Cost	cost	1	$ 9,200	$ 9,200
Total initial costs				**$ 25,376**
Annual costs (credits)	**Unit**	**Quantity**	**Unit cost**	**Amount**
O&M costs (savings)	project			$ 284
Show data				
Electrical equipment				
Electrical equipment			$ 0	Update cost
Power system				
Photovoltaic			$ 66	Update cost
Generator			$ 77	Update cost
Battery			$ 141	Update cost
System Fixed O&M Cost	cost	1	$ 184	$ 184
Total annual costs				**$ 468**
Annual savings	**Unit**	**Quantity**	**Unit cost**	**Amount**
User-defined	cost			$ -
Total annual savings				**$ -**

Figure 7.2.7: Annual Cost

Decentralized Solar Home System:

In decentralized solar home system, we have considered 1100 W of total load. Based on the calculation (included in HOMER part 1.2), we have taken 600W PV panel, 5 lead acid battery of 12V 83.4Ah to supply power to the load.

Climate Data:

In this system we have considered Chittagong, Bangladesh as our project location. In figure 7.2.1(a) & (b) shows the climate data affirmed by NASA.

Load:

Here, we have considered,

4 Lights = 10 Watt * 4 nos. * 5 hrs. = 200 watt-hour;

2 Fans = 20 watt * 2 nos. * 15 hrs. = 600 watt-hour;

1 TV = 60 watt * 1 nos. * 5 hrs. = 300 watt-hour;

Total is = 200+600+300 = 1,100 watt = 1.1 KWh/day

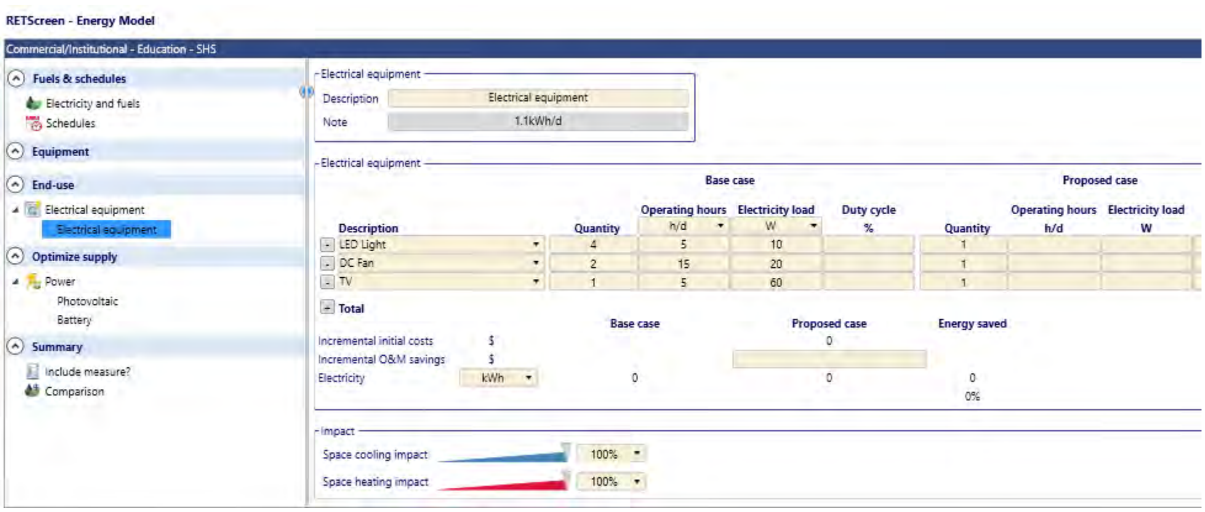


Figure 7.2.8: Load

PV Panel:

Here, we have chosen photovoltaic type mono-si and 3 no. of units of 200W PV panel to design our 0.6kW photovoltaic power capacity.

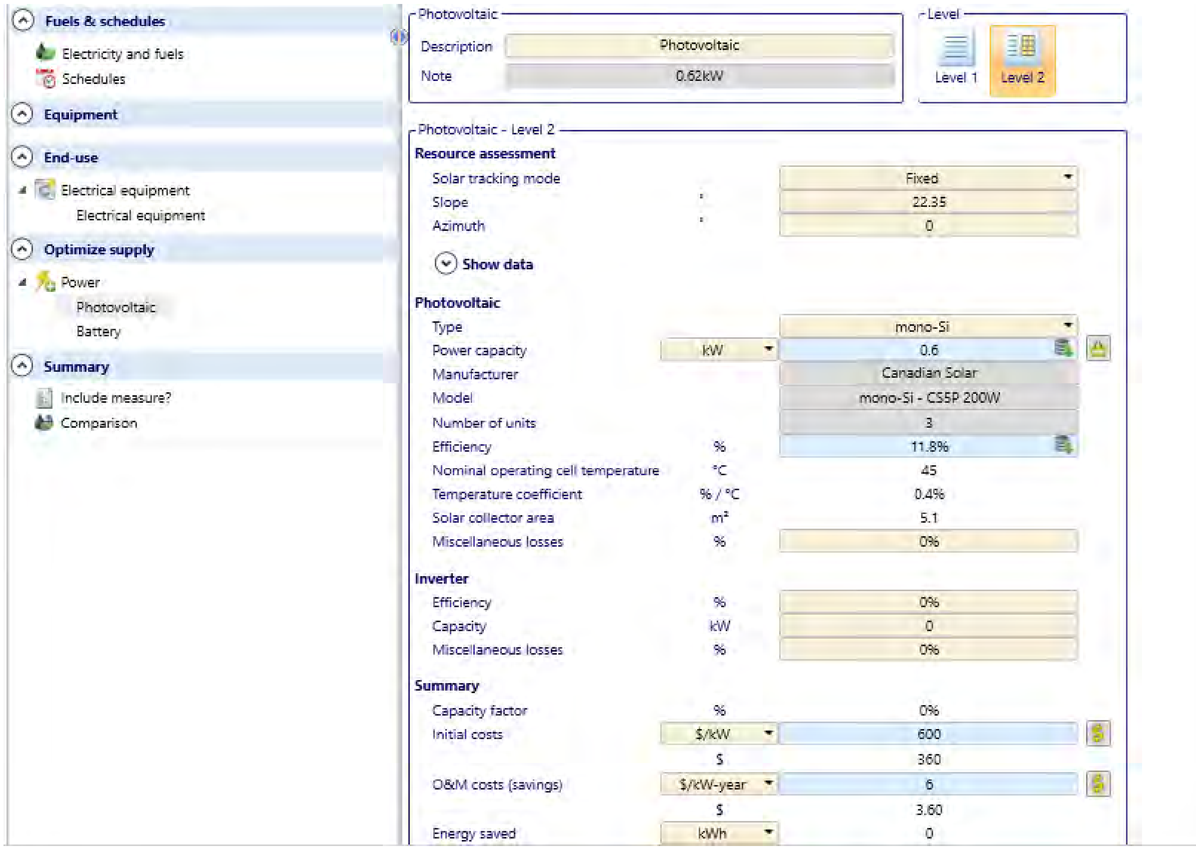


Figure 7.2.9: PV panel

Battery:

Here, we have selected 5 lead acid batteries each one's nominal voltage 12V, maximum capacity 83.4Ah.

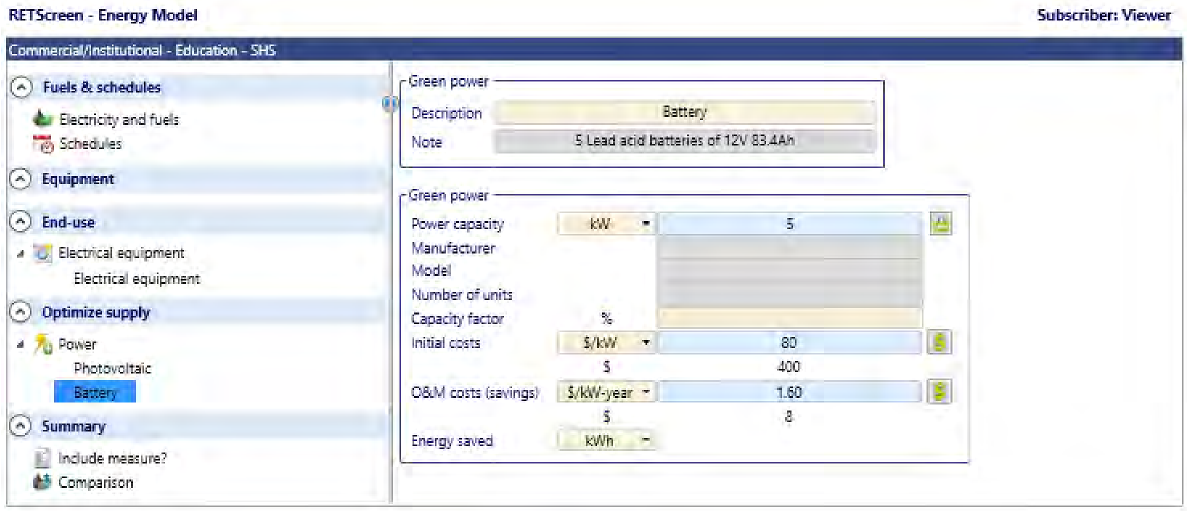


Figure 7.2.10: Battery

Annual Cost:

Now, we can see total initial cost of PV panel, battery is $760 and operation & management cost of PV panel, battery is $11.6. Finally, we have compared our RETScreen annual result with Homer annual result which are identical.

RETScreen - Cost Analysis

Initial costs (credits)	Unit	Quantity	Unit cost	Amount
Incremental initial costs				$ 760
Show data				
Electrical equipment				
Electrical equipment			$ 0	Update cost
Power system				
Photovoltaic			$ 360	Update cost
Battery			$ 400	Update cost
	cost	0	$ 0	$ 0
Total initial costs				**$ 760**
Annual costs (credits)	**Unit**	**Quantity**	**Unit cost**	**Amount**
O&M costs (savings)	project			$ 11.60
Show data				
Electrical equipment				
Electrical equipment			$ 0	Update cost
Power system				
Photovoltaic			$ 3.60	Update cost
Battery			$ 8	Update cost
Fuel cost - proposed case				$ 0
	cost	0	$ 0	$ 0
Total annual costs				**$ 11.60**
Annual savings	**Unit**	**Quantity**	**Unit cost**	**Amount**
User-defined	cost			$ -
Total annual savings				**$ -**

Figure 7.2.11: Annual Cost

Case 2: Centralized Solar Battery Charging Station & Decentralized Dedicated Solar power Charging Kit

Centralized Solar Battery Charging Station:

In this system, we have considered 28.8kW of total load. Based on the calculation (included in HOMER part 2.1), we have taken 3.5kW PV panel, 1.9kW generator to supply power to the load. In addition, we have added 2kW inverter to converts DC output of PV panels into AC current.

Climate Data:

Here, we have considered Chittagong, Bangladesh as our project location. In figure 7.2.12(a) & (b) shows the climate data affirmed by NASA.

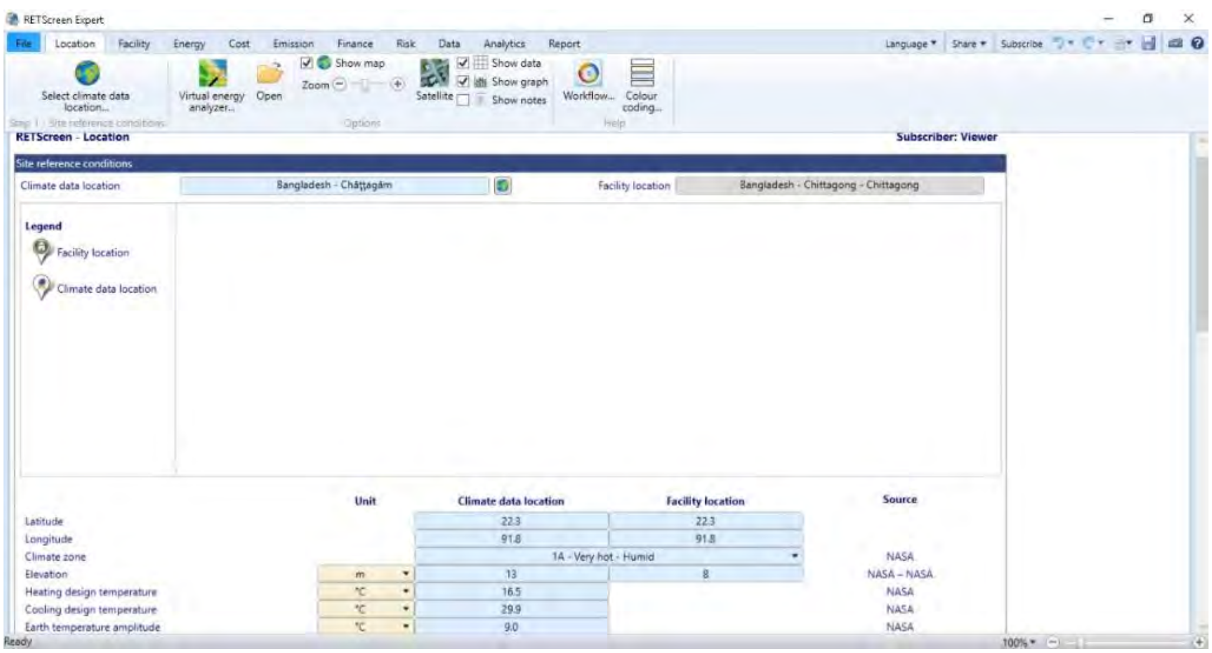
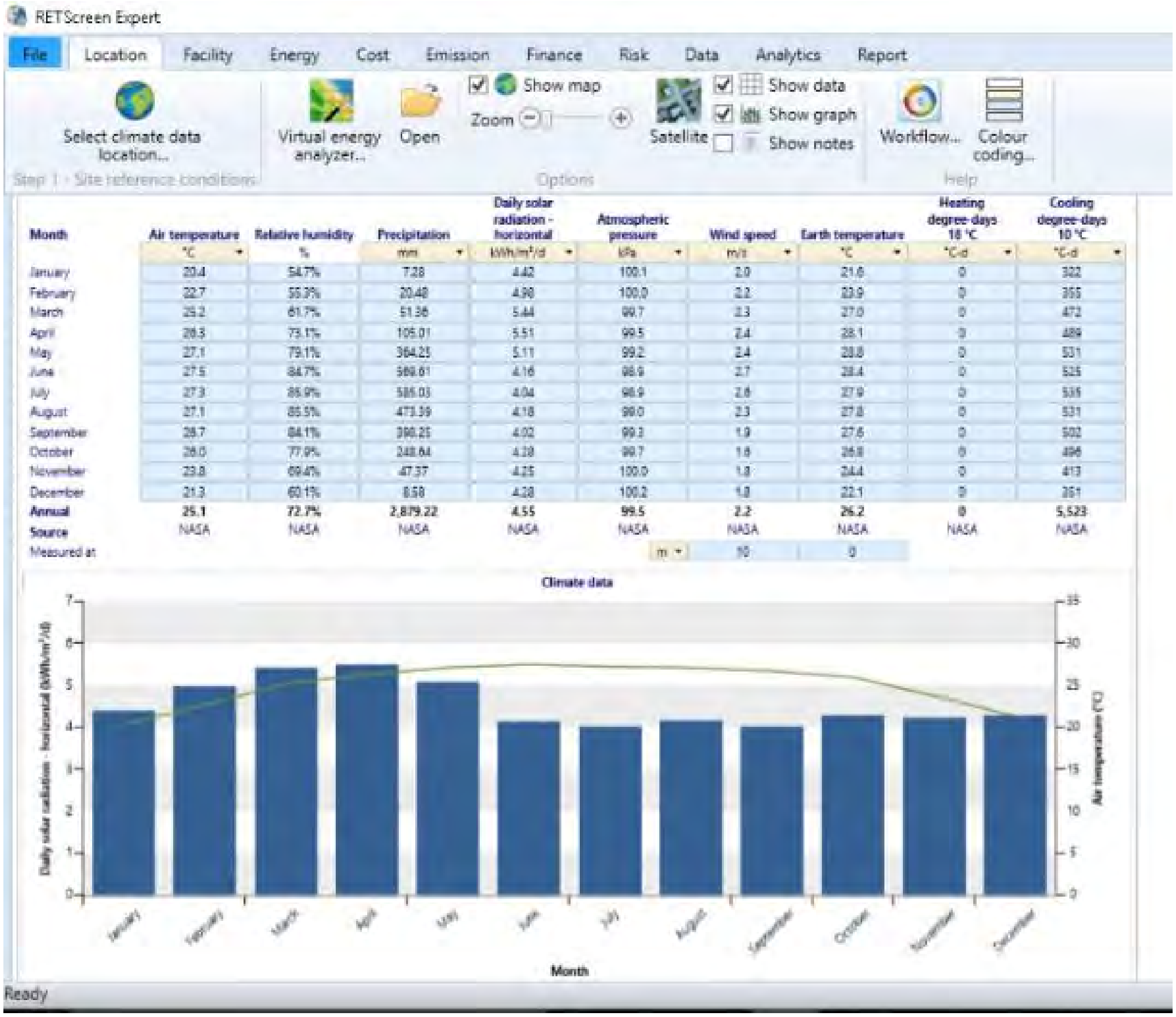


Figure 7.2.12(a): Climate Data



Month	Air temperature (°C)	Relative humidity (%)	Precipitation (mm)	Daily solar radiation - horizontal (kWh/m²/d)	Atmospheric pressure (kPa)	Wind speed (m/s)	Earth temperature (°C)	Heating degree-days 18 °C (°C-d)	Cooling degree-days 10 °C (°C-d)
January	20.4	54.7%	7.28	4.42	100.1	2.0	21.6	0	322
February	22.7	55.3%	20.48	4.98	100.0	2.2	23.9	0	355
March	25.2	61.7%	51.38	5.44	99.7	2.3	27.0	0	472
April	28.3	73.1%	105.01	5.51	99.5	2.4	28.1	0	489
May	27.1	79.1%	364.25	5.11	99.2	2.4	28.8	0	531
June	27.5	84.7%	589.61	4.16	98.9	2.7	28.4	0	525
July	27.3	85.9%	585.03	4.04	98.9	2.8	27.9	0	535
August	27.1	85.5%	473.39	4.18	99.0	2.3	27.8	0	531
September	28.7	84.1%	390.25	4.02	99.3	1.9	27.6	0	502
October	28.0	77.9%	248.84	4.28	99.7	1.6	26.8	0	496
November	23.8	69.4%	47.37	4.25	100.0	1.8	24.4	0	413
December	21.3	60.1%	8.58	4.28	100.2	1.8	22.1	0	351
Annual	**25.1**	**72.7%**	**2,879.22**	**4.55**	**99.5**	**2.2**	**26.2**	**0**	**5,523**
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
Measured at					m	10	0		

Figure 7.2.12(b): Climate Data

Load:

Here, we have considered,

10 Battery sets = 1200 Watt * 12nos. = 12,000 watt-hour;

Total is = 12,000watt = 12KWh/day

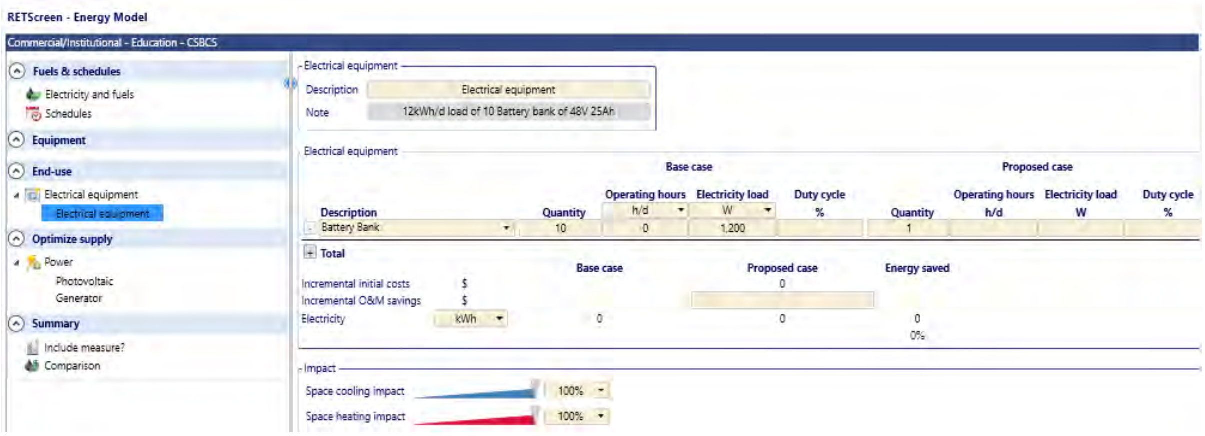


Figure 7.2.13: Load

PV panel:

Here, we have chosen photovoltaic type mono-si and 14 no. of units of 250W PV panel to design our 3.5kW photovoltaic power capacity. Moreover, to keep our result more accurate, we have considered miscellaneous loss of inverter equal to 0.

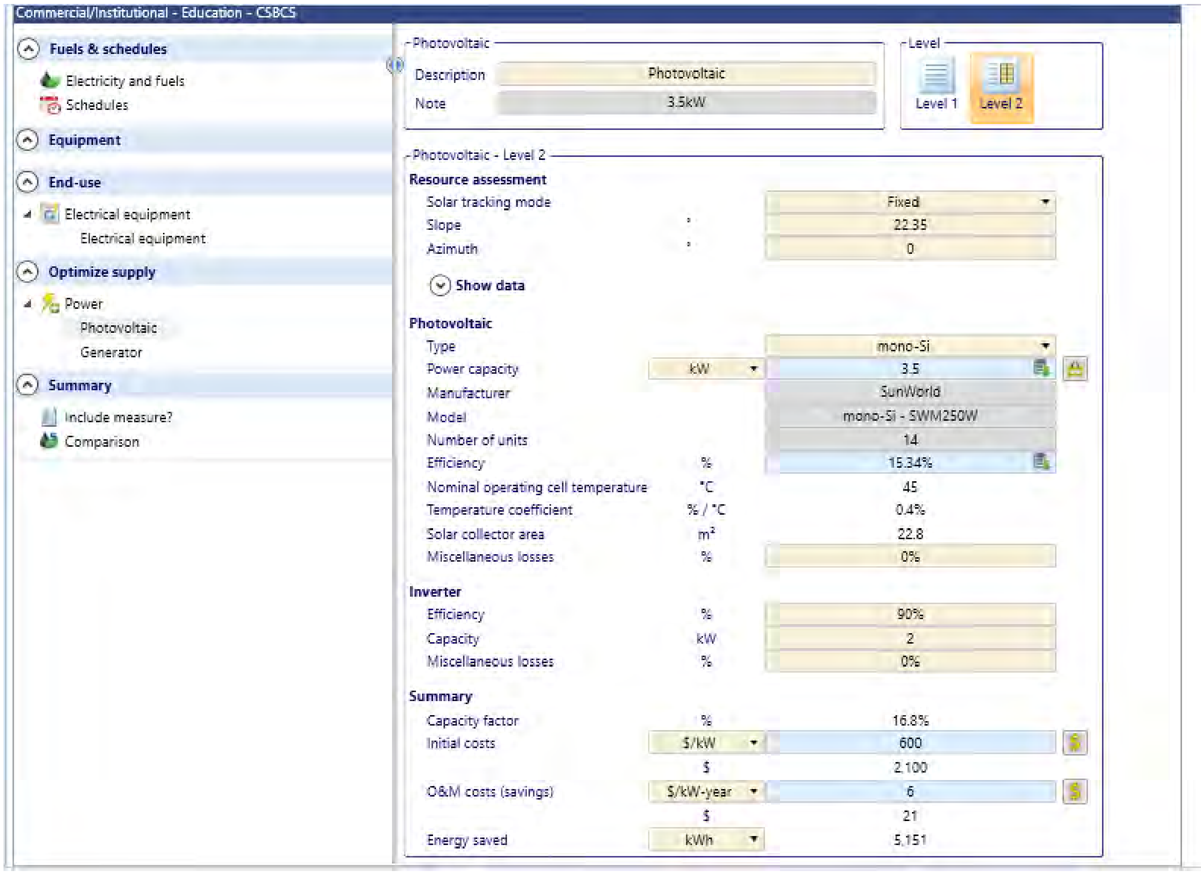


Figure 7.2.14: PV panel

Fuel Cost:

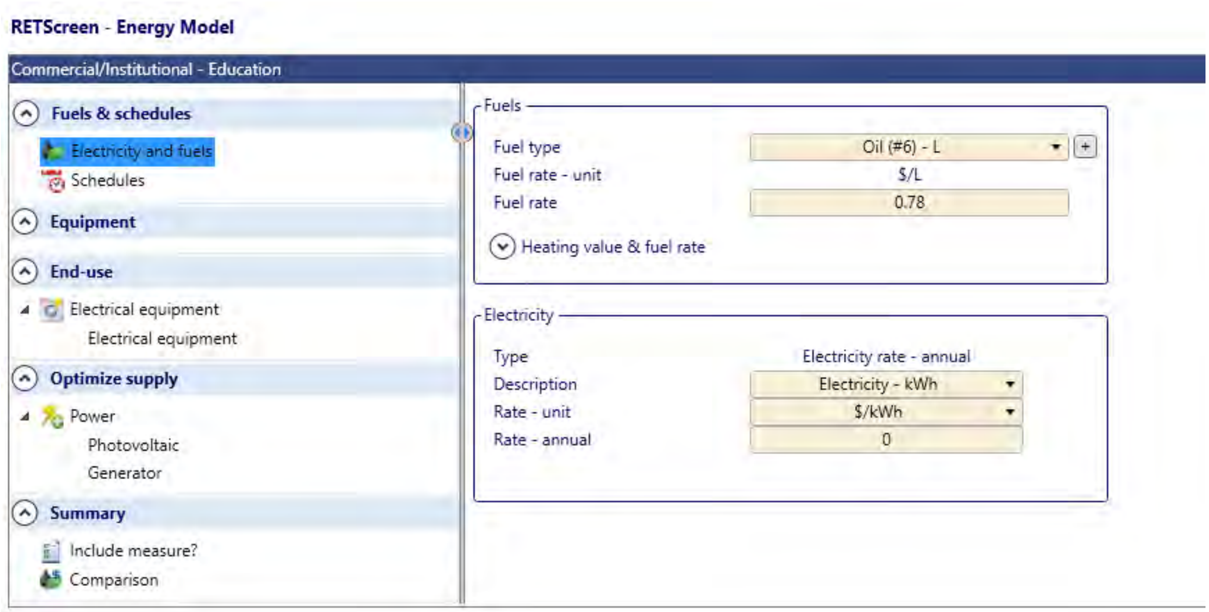


Figure 7.2.15: Fuel Cost

Generator: We have measured a back-up generator of 1.9kW which run on an existing fuel source to supply power during blackouts and power outages.

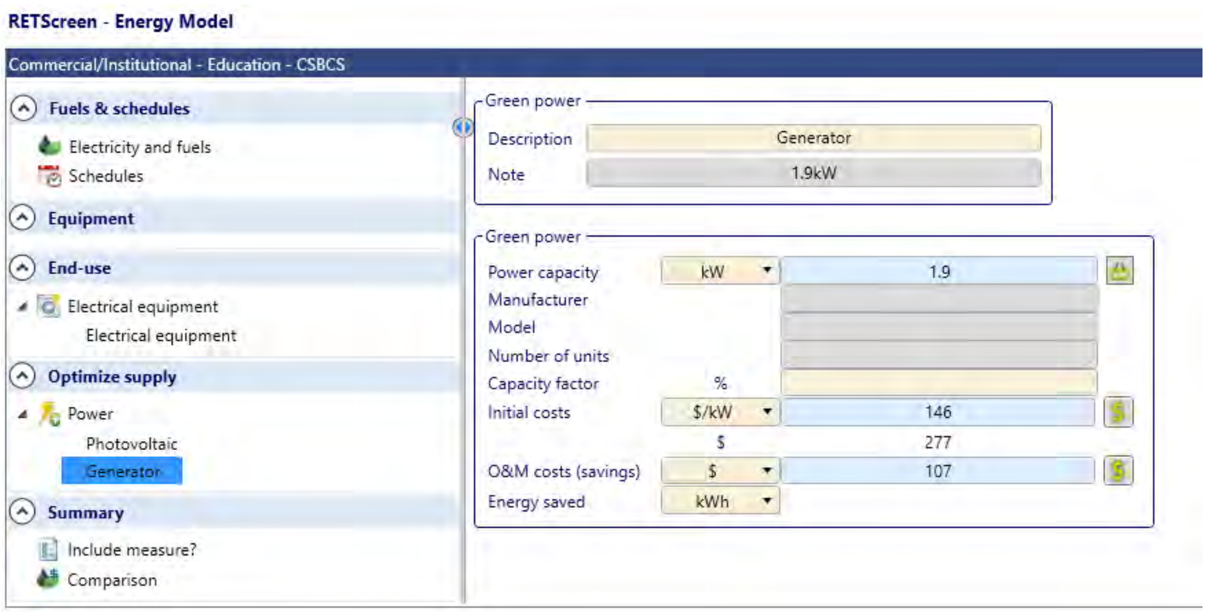


Figure 7.2.16: Generator

Annual Cost:

Here we can see total initial cost of PV panel, generator, inverter and system fixed capital cost is $5,177and operation & management cost of PV panel, generator and system fixed O&M cost is $177. Finally, we have compared our RETScreen annual result with Homer annual result which are similar.

RETScreen - Cost Analysis

Initial costs (credits)	Unit	Quantity	Unit cost	Amount
Incremental initial costs				$ 2,377
Show data				
Electrical equipment				
Electrical equipment			$ 0	Update cost
Power system				
Photovoltaic			$ 2,100	Update cost
Generator			$ 277	Update cost
Inverter	cost	1	$ 360	$ 360
System Fixed Capital Cost	cost	1	$ 2,440	$ 2,440
Total initial costs				**$ 5,177**
Annual costs (credits)	**Unit**	**Quantity**	**Unit cost**	**Amount**
O&M costs (savings)	project			$ 128
Show data				
Electrical equipment				
Electrical equipment			$ 0	Update cost
Power system				
Photovoltaic			$ 21	Update cost
Generator			$ 107	Update cost
Fuel cost - proposed case				$ 0
System Fixed O&M Cost	cost	1	$ 49	$ 49
Total annual costs				**$ 177**
Annual savings	**Unit**	**Quantity**	**Unit cost**	**Amount**
User-defined	cost			$ -
Total annual savings				**$ -**

Figure 7.2.17: Annual Cost

Decentralized Dedicated Solar power Charging Kit:

In decentralized DSPCK, we have considered 1.2kW of total load. Based on the calculation (included in HOMER part 2.2), we have taken 0.9kW PV panel, 4 lead acid Battery of 12V 83.4Ah to supply power to the load.

Climate Data:

In this system we have considered Chittagong, Bangladesh as our project location. In figure 7.2.12(a) & (b) shows the climate data affirmed by NASA.

Load:

Here, we have measured,

1 Battery sets = 1200 Watt * 1 nos. = 1,200 watt-hour;

Total is = 1,200watt = 1.2KWh/day

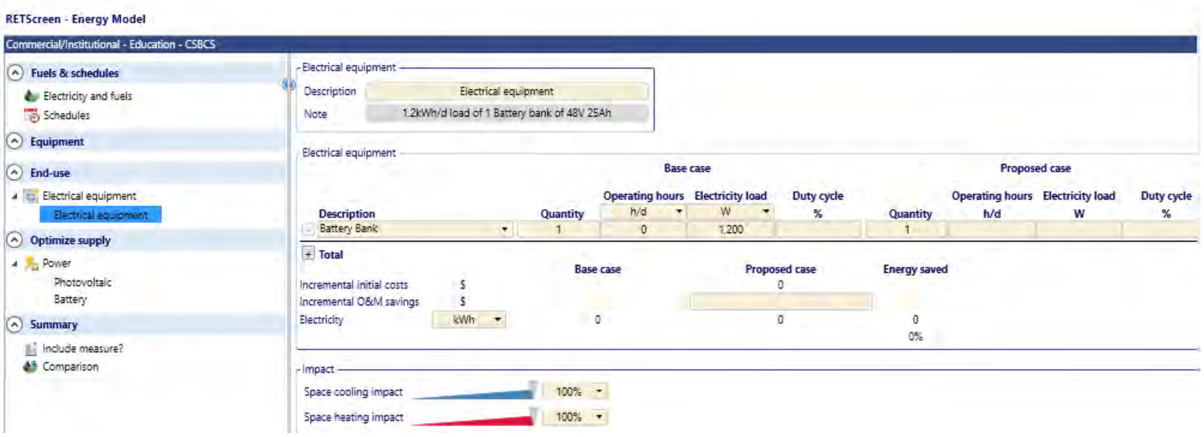


Figure 7.2.18: Load

PV panel:

Here, we have chosen photovoltaic type mono-si and 9 no. of units of 100W PV panel to design our 0.9kW photovoltaic power capacity.

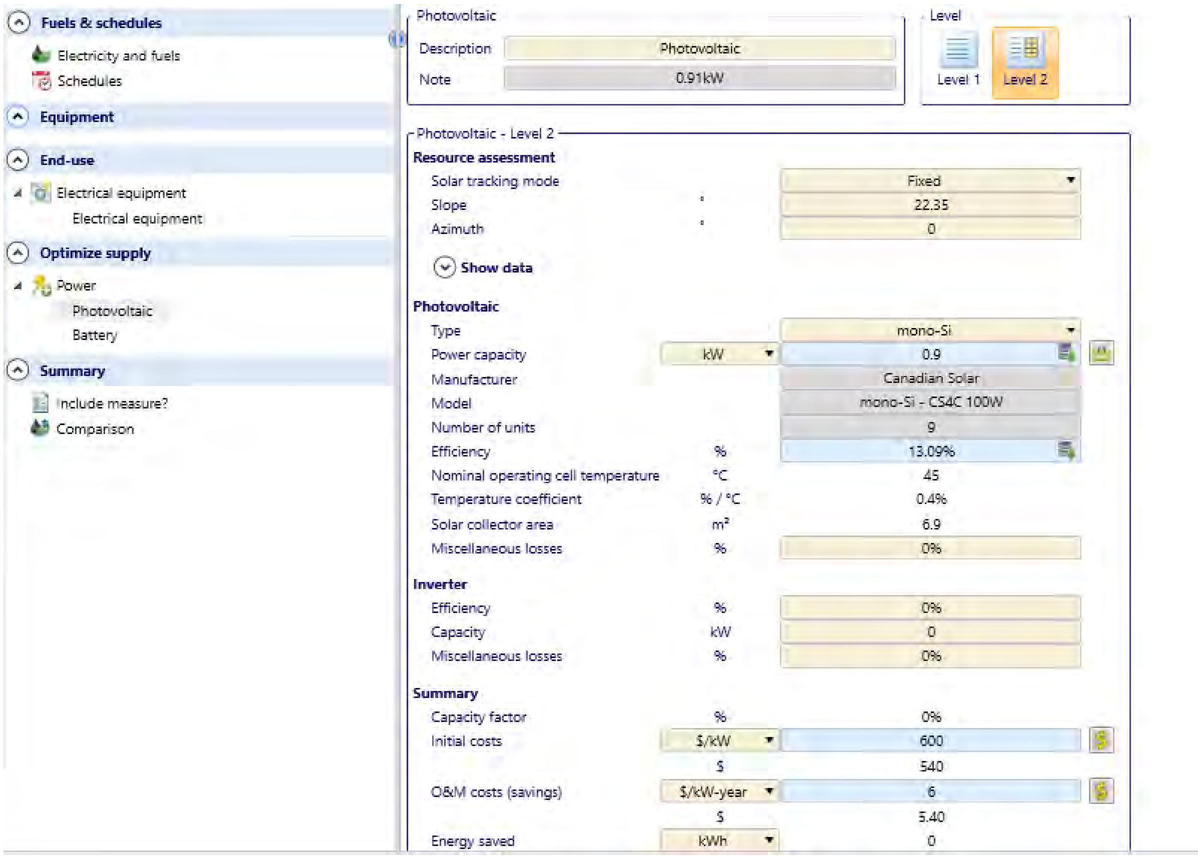


Figure 7.2.19: PV panel

Battery:

We have selected 4 lead acid batteries each one's nominal voltage 12V, maximum capacity 83.4Ah.

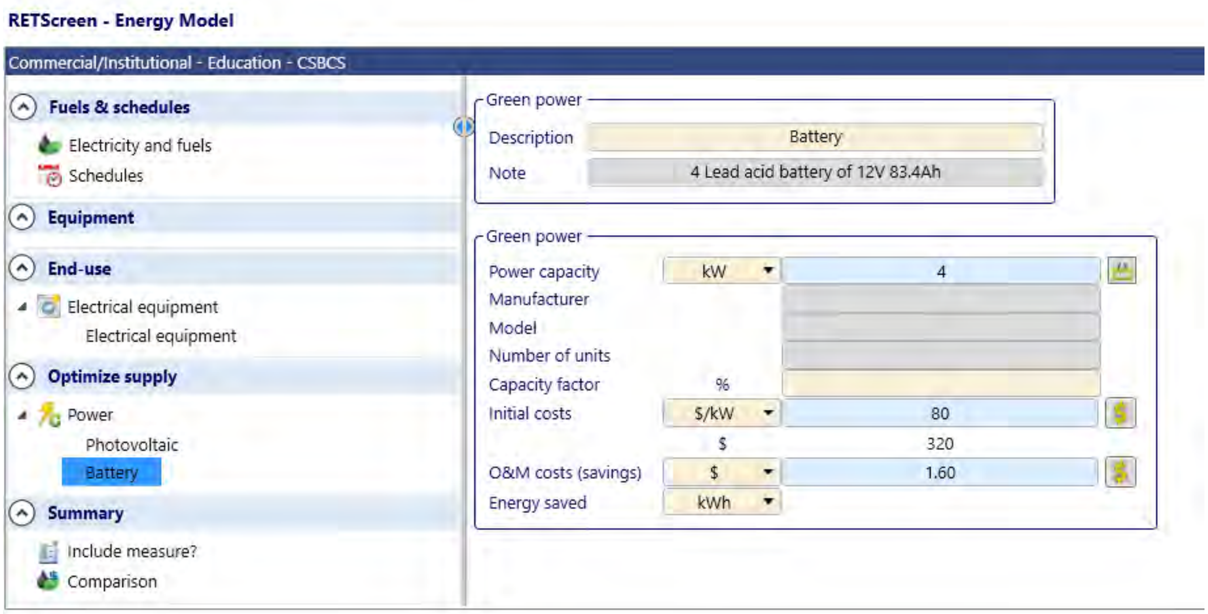


Figure 7.2.20: Battery

Annual Cost:

Here we can see total initial cost of PV panel, battery is $1,031 and operation & management cost of PV panel, battery is $10.42. Finally, we have compared our RETScreen annual result with Homer annual result which are alike.

RETScreen - Cost Analysis

Initial costs (credits)	Unit	Quantity	Unit cost	Amount	
Incremental initial costs				$ 860	
Show data					
Electrical equipment					
Electrical equipment			$ 0		Update cost
Power system					
Photovoltaic			$ 540		Update cost
Battery			$ 320		Update cost
System Fixed Capital Cost	cost	1	$ 171	$ 171	
Total initial costs				**$ 1,031**	

Annual costs (credits)	Unit	Quantity	Unit cost	Amount	
O&M costs (savings)	project			$ 7	
Show data					
Electrical equipment					
Electrical equipment			$ 0		Update cost
Power system					
Photovoltaic			$ 5.40		Update cost
Battery			$ 1.60		Update cost
Fuel cost - proposed case				$ 0	
System Fixed O&M Cost	cost	1	$ 3.42	$ 3.42	
Total annual costs				**$ 10.42**	

Annual savings	Unit	Quantity	Unit cost	Amount
User-defined	cost			$ -
Total annual savings				**$ -**

Figure 7.2.21: Annual Cost

Case 3: Centralized Solar Street Lighting System &Decentralized Solar Street Lighting System

Centralized Solar Street Lighting System:

In this system, we have considered 36kW of total load. Based on the calculation (included in HOMER part 3.1), we have taken 10kW PV panel, 10kW generator to supply power to the load. Besides, we have added 4kW inverter to converts DC output of PV panels into AC current.

Climate Data:

Here, we have considered Dhaka, Bangladesh as our project location. In figure 7.2.22(a) & (b) shows the climate data confirmed by NASA.

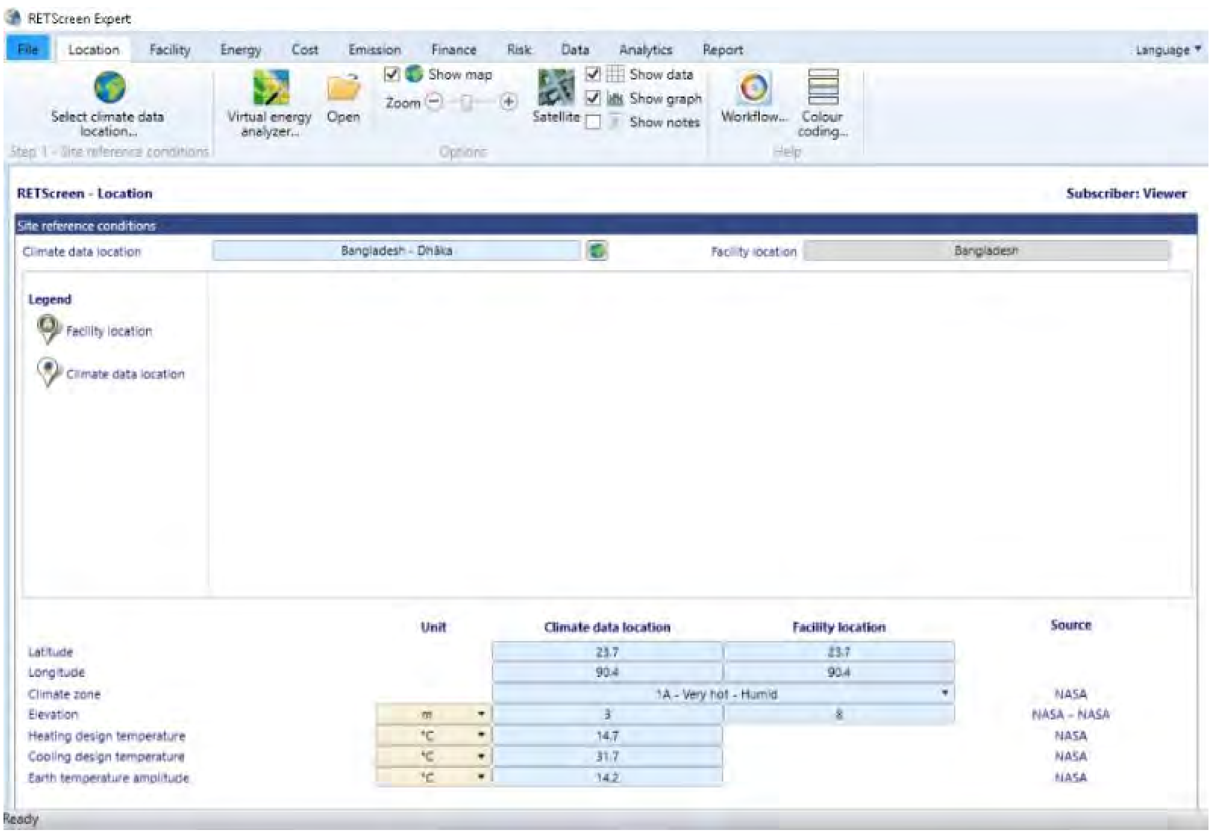
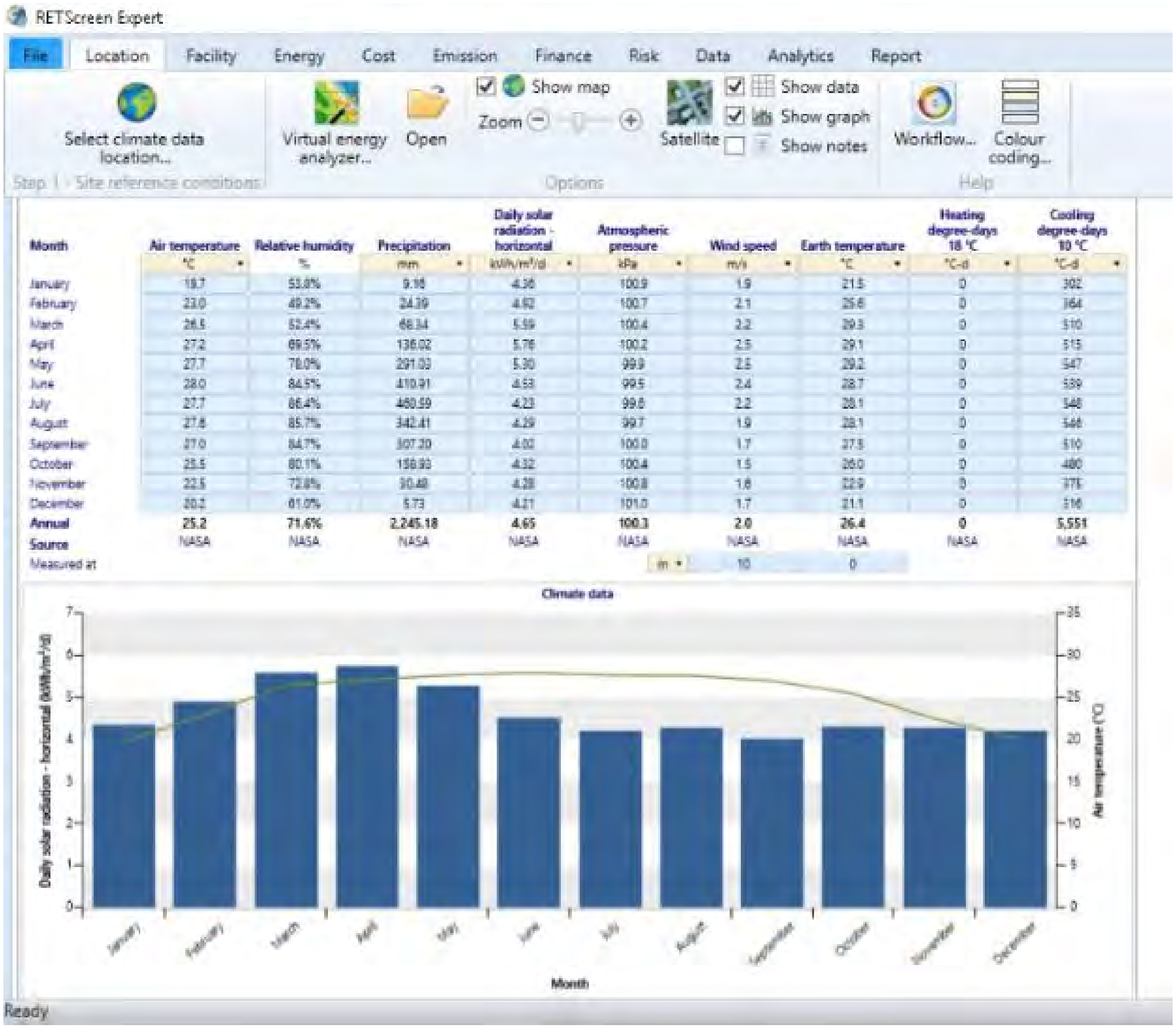


Figure 7.2.22(a): Climate Data



Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	19.7	53.0%	9.16	4.36	100.9	1.9	21.5	0	302
February	23.0	49.2%	24.39	4.92	100.7	2.1	25.6	0	364
March	26.5	52.4%	66.34	5.59	100.4	2.2	29.3	0	510
April	27.2	69.5%	138.02	5.76	100.2	2.5	29.1	0	515
May	27.7	78.0%	291.03	5.30	99.9	2.5	29.2	0	547
June	28.0	84.5%	410.91	4.53	99.5	2.4	28.7	0	539
July	27.7	86.4%	460.59	4.23	99.6	2.2	28.1	0	548
August	27.8	85.7%	342.41	4.29	99.7	1.9	28.1	0	546
September	27.0	84.7%	307.20	4.02	100.0	1.7	27.5	0	510
October	25.5	80.1%	158.93	4.32	100.4	1.5	26.0	0	480
November	22.5	72.8%	30.48	4.28	100.8	1.8	22.9	0	375
December	20.2	61.0%	5.73	4.21	101.0	1.7	21.1	0	316
Annual	25.2	71.6%	2,245.18	4.65	100.3	2.0	26.4	0	5,551
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
Measured at					m	10	0		

Figure 7.2.22(b): Climate Data

Load:

Here, we have measured,

60 Street Lights = 50 Watt * 60 nos. * 12 hrs. = 36,000 watt-hour;

Total is = 36,000watt = 36 KWh/day

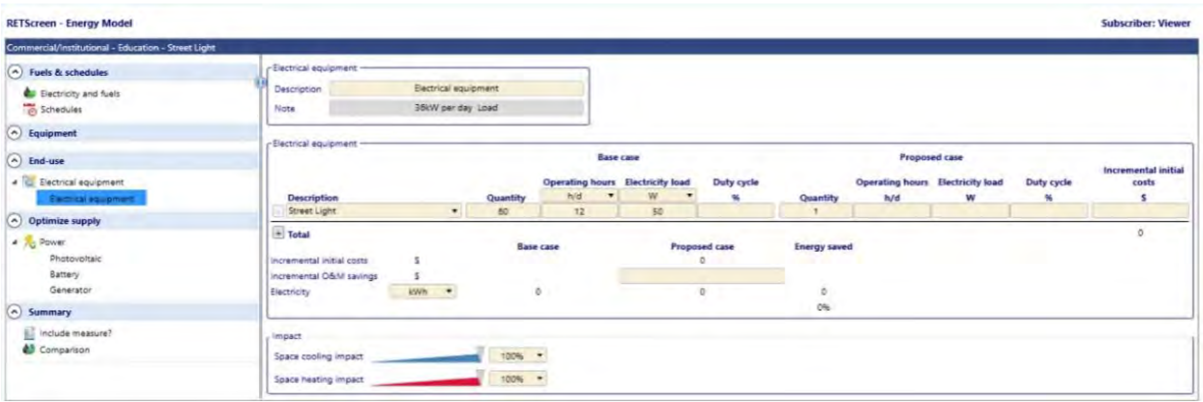


Figure 7.2.23: Load

PV panel:

Now, we have chosen photovoltaic type mono-si and 40 no. of units of 250W PV panel to design our 10kW photovoltaic power capacity. Moreover, to keep our result more accurate, we have assumed miscellaneous loss of inverter equal to 0.

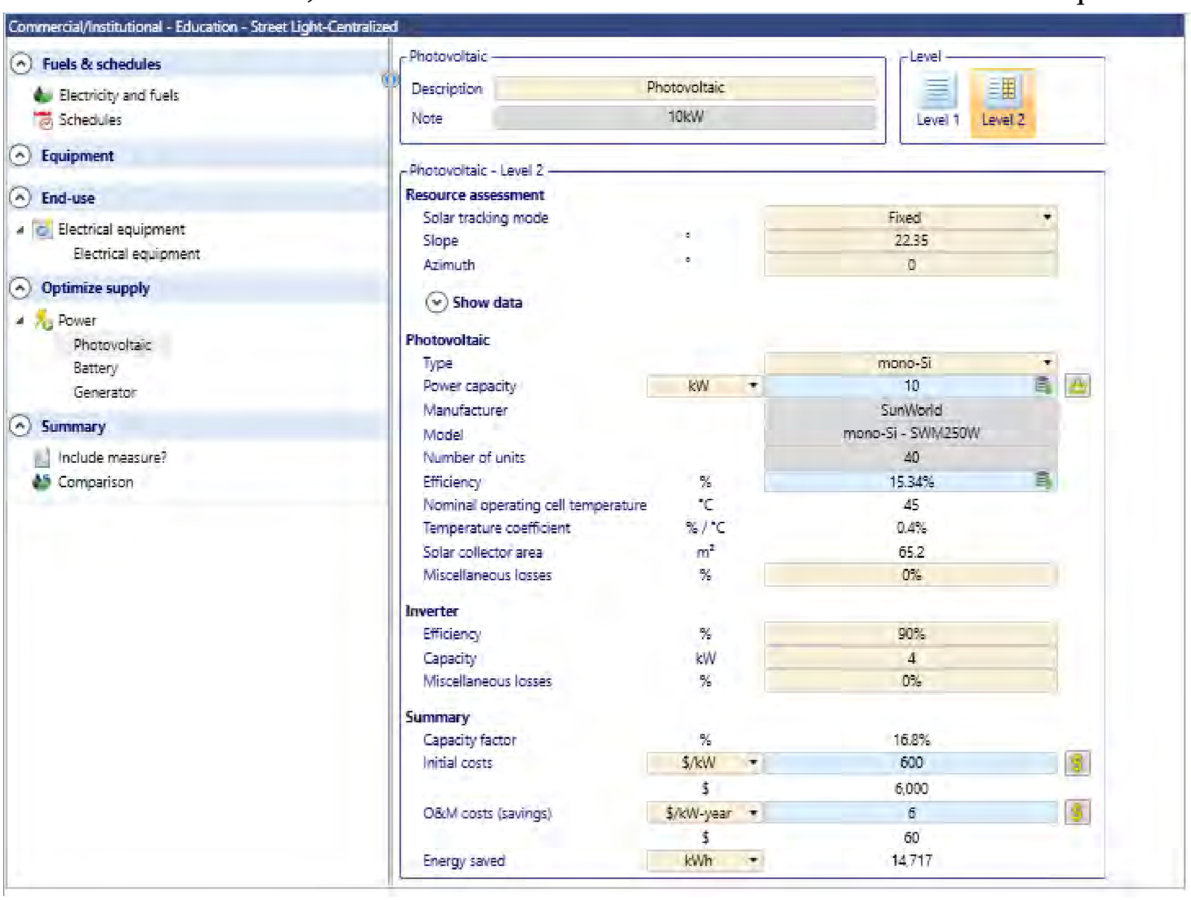


Figure 7.2.24: PV panel

Battery:

We have selected 85 batteries; each one's nominal voltage 12V, maximum capacity 83.4Ah.

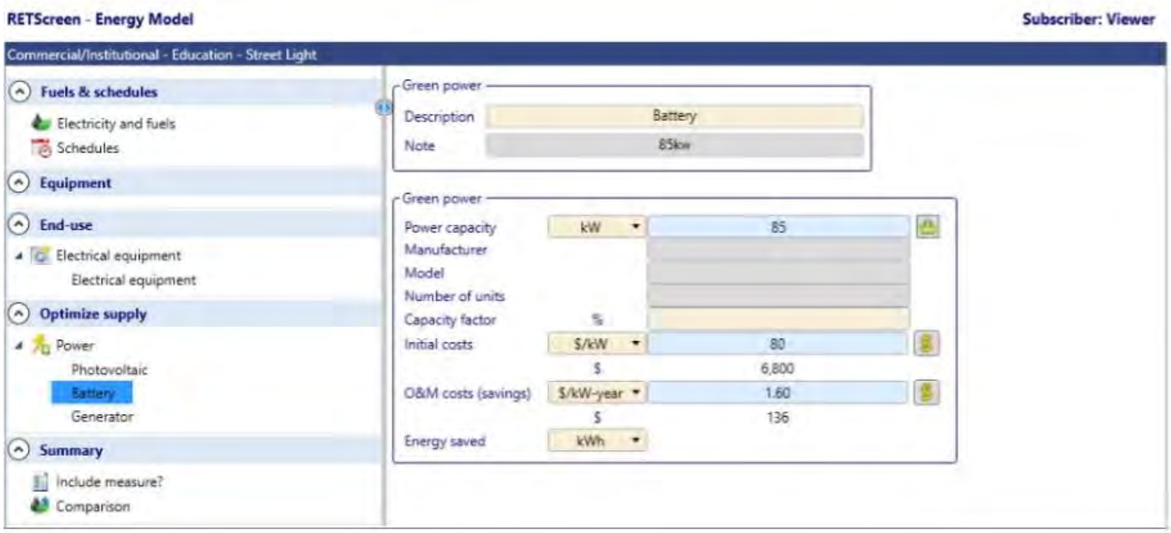


Figure 7.2.25: Battery

Fuel Cost:

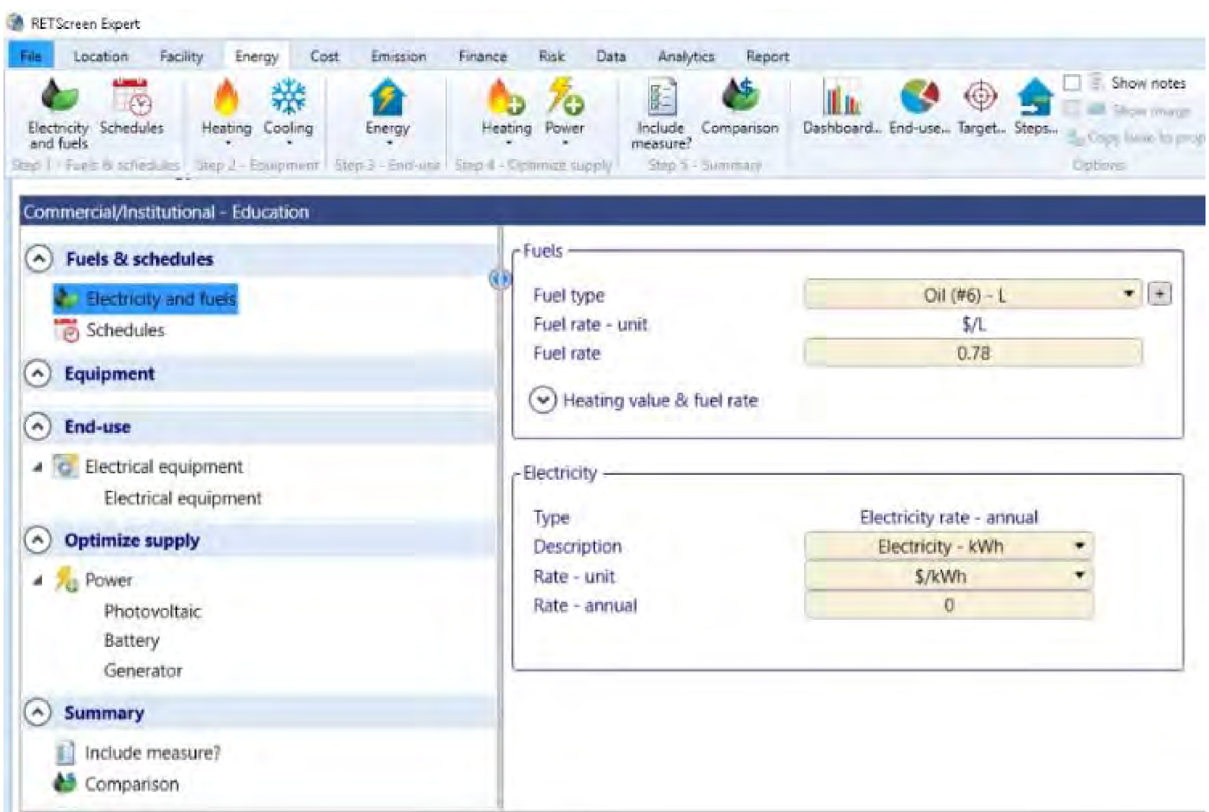


Figure 7.2.26: Fuel Cost

Generator:

We have chosen a back-up generator of 10kW which run on an existing fuel source to supply power during blackouts and power outages.

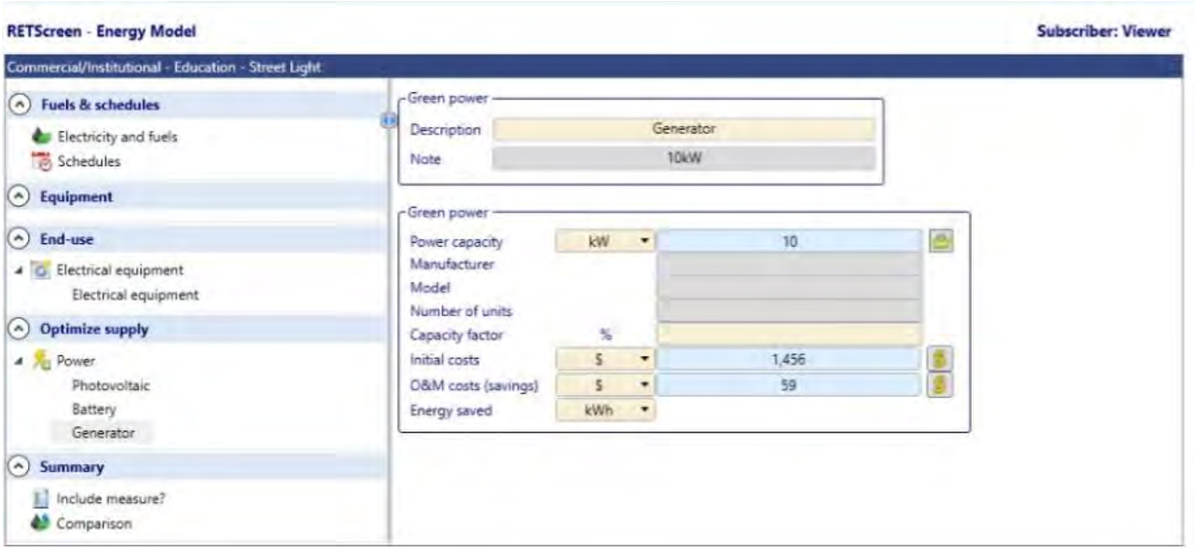


Figure 7.2.27: Generator

Annual Cost:

In brief, we can see total initial cost of PV panel, battery, generator, inverter and system fixed capital cost is $22,659 and operation & management cost of PV panel, battery, generator and system fixed O&M cost is $409. As a final point, we have compared our RETScreen annual result with Homer annual result which are equal.

RETScreen - Cost Analysis

Initial costs (credits)	Unit	Quantity	Unit cost	Amount
Incremental initial costs				$ 14,256
Show data				
Electrical equipment				
Electrical equipment			$ 0	Update cost
Power system				
Photovoltaic			$ 6,000	Update cost
Battery			$ 6,800	Update cost
Generator			$ 1,456	Update cost
Inverter	cost	1	$ 720	$ 720
System Fixed Capital Cost	cost	1	$ 7,683	$ 7,683
Total initial costs				**$ 22,659**

Annual costs (credits)	Unit	Quantity	Unit cost	Amount
O&M costs (savings)	project			$ 255
Show data				
Electrical equipment				
Electrical equipment			$ 0	Update cost
Power system				
Photovoltaic			$ 60	Update cost
Battery			$ 136	Update cost
Generator			$ 59	Update cost
System Fixed O&M Cost	cost	1	$ 153.66	$ 154
Total annual costs				**$ 409**

Annual savings	Unit	Quantity	Unit cost	Amount
User-defined	cost			$ -
Total annual savings				**$ -**

Figure 7.2.28: Annual cost

Decentralized Solar Street Lighting System:

In Decentralized Solar Street Light System, we have considered 0.6kW of total load. Based on the calculation (included in HOMER part 4.2), we have taken 0.2kW PV panel, 1.5kW Battery to supply power to the load.

Climate Data:

In this system we have considered Dhaka, Bangladesh as our project location. In figure 7.2.22(a) & (b) shows the climate data affirmed by NASA.

Load:

Here, we have measured,

1 Street Light = 50 Watt * 1 nos. * 12 hrs. = 600 watt-hour;

Total is = 600watt = 0.6 KWh/day

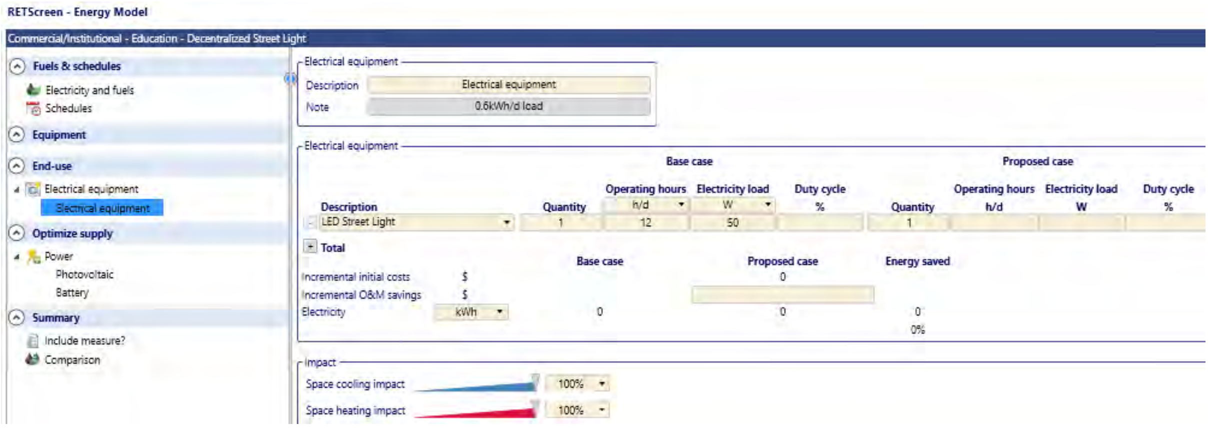


Figure 7.2.29: Load

PV panel:

Here, we have chosen photovoltaic type mono-si and 9 no. of unit of 50W PV panel to design our 0.45kW photovoltaic power capacity.

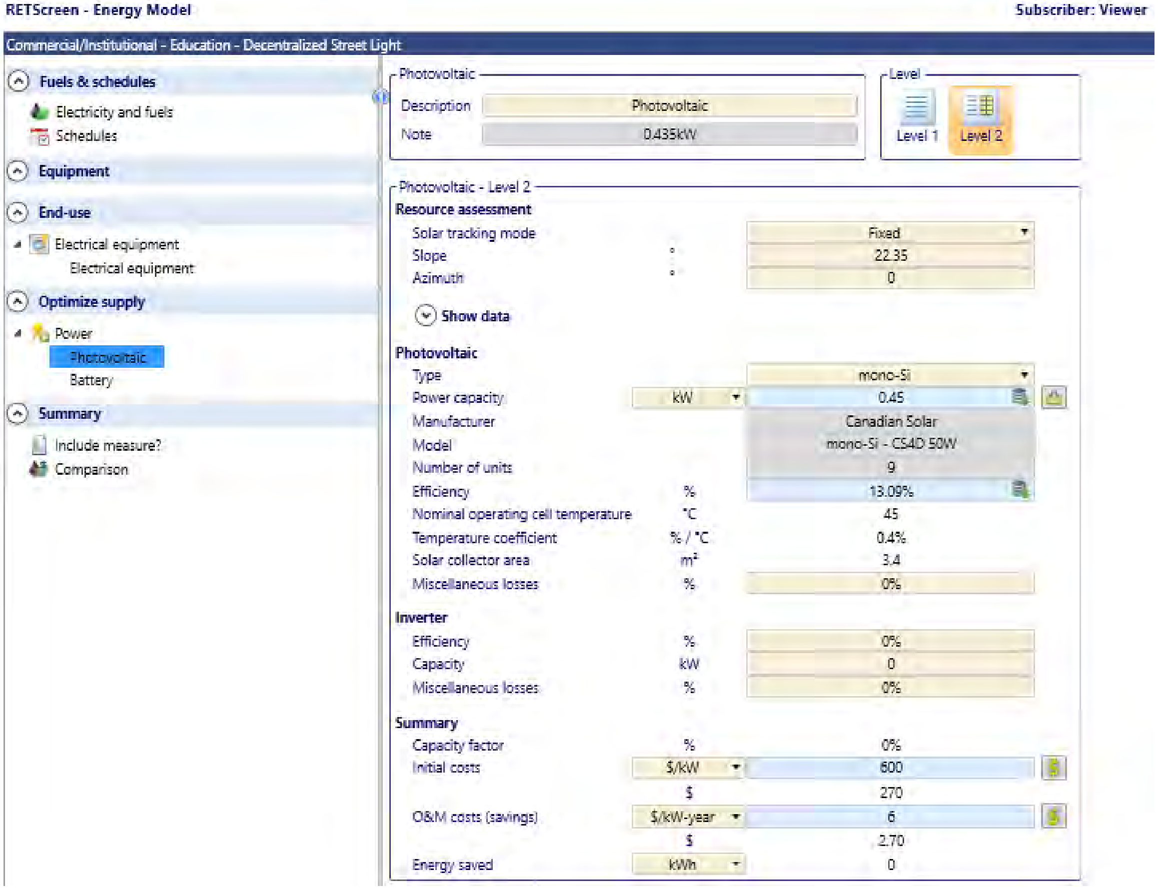


Figure 7.2.30: PV panel

Battery:

We have taken 2 lead acid battery of 12V 83.4Ah.

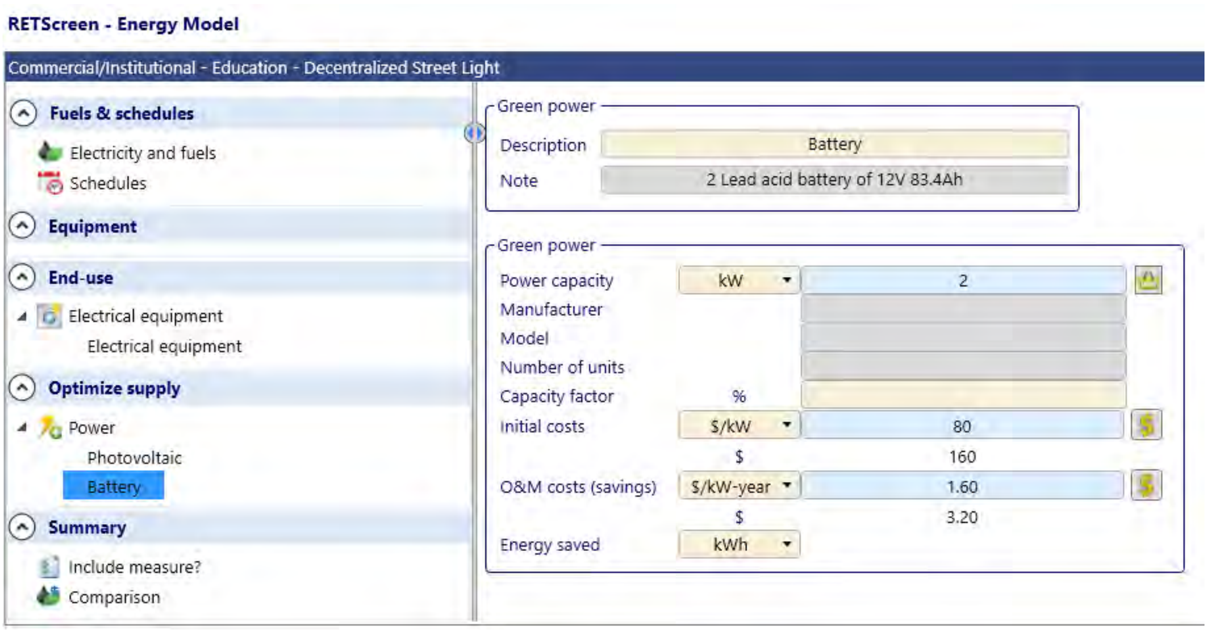


Figure 7.2.31: Battery

Annual Cost:

Here we can see total initial cost of PV panel, battery is $430 and operation & management cost of PV panel, battery is $5.9. Finally, we have compared our RETScreen annual result with Homer annual result which are similar.

RETScreen - Cost Analysis

Initial costs (credits)	Unit	Quantity	Unit cost	Amount
Incremental initial costs				$ 430
Show data				
Electrical equipment				
Electrical equipment			$ 0	Update cost
Power system				
Photovoltaic			$ 270	Update cost
Battery			$ 160	Update cost
	cost	0	$ 0	$ 0
Total initial costs				**$ 430**

Annual costs (credits)	Unit	Quantity	Unit cost	Amount
O&M costs (savings)	project			$ 5.90
Show data				
Electrical equipment				
Electrical equipment			$ 0	Update cost
Power system				
Photovoltaic			$ 2.70	Update cost
Battery			$ 3.20	Update cost
	cost	0	$ 0	$ 0
Total annual costs				**$ 5.90**

Annual savings	Unit	Quantity	Unit cost	Amount
User-defined	cost			$ -
Total annual savings				**$ -**

Figure 7.2.32: Annual Cost

Case 4: Centralized Solar Traffic Lighting System&Decentralized Solar Traffic Lighting System

Centralized Solar Traffic Lighting System:

In this system, we have considered 4.32kW of total load. Based on the calculation (included in HOMER part 4.1), we have taken 1.3kW PV panel, 0.59kW generator to supply power to the load. Besides, we have added 0.3kW inverter to converts DC output of PV panels into AC current.

Climate Data:

Here, we have considered Dhaka, Bangladesh as our project location. In figure 7.2.33(a) & (b) shows the climate data confirmed by NASA.

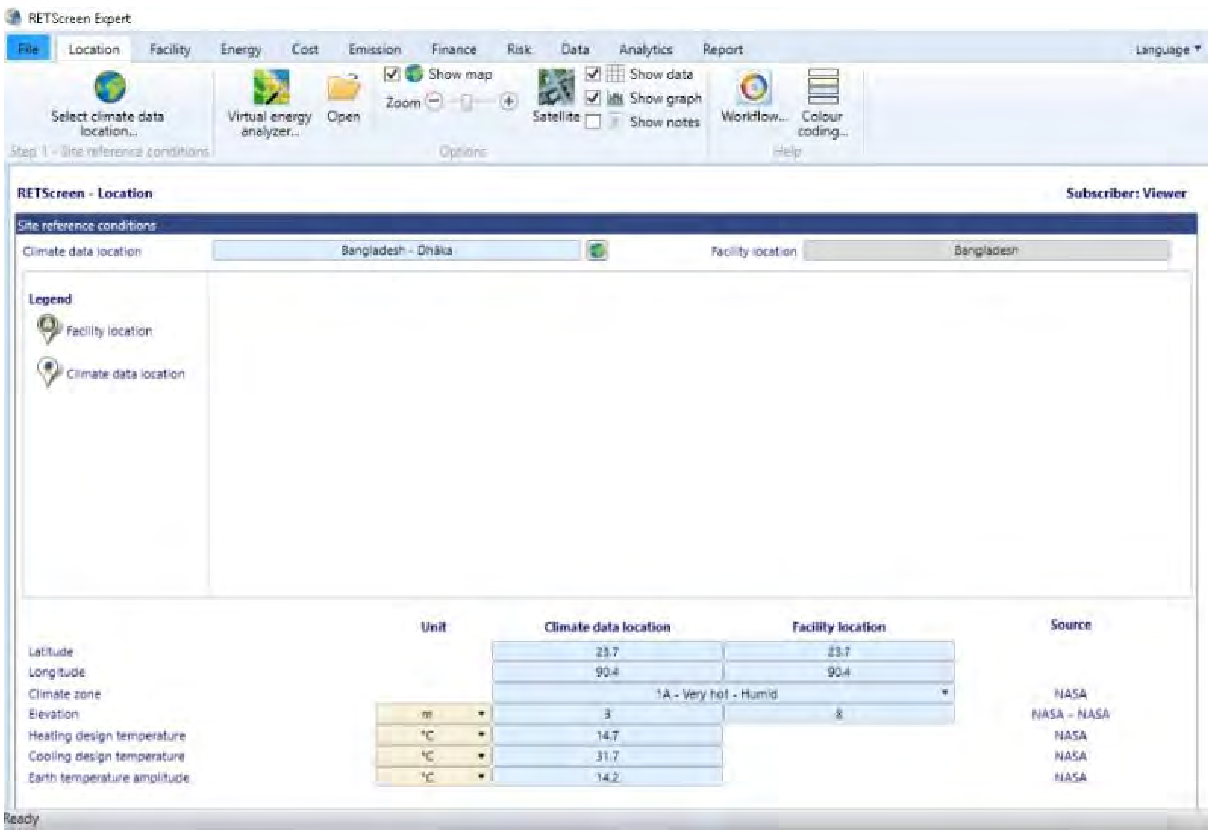
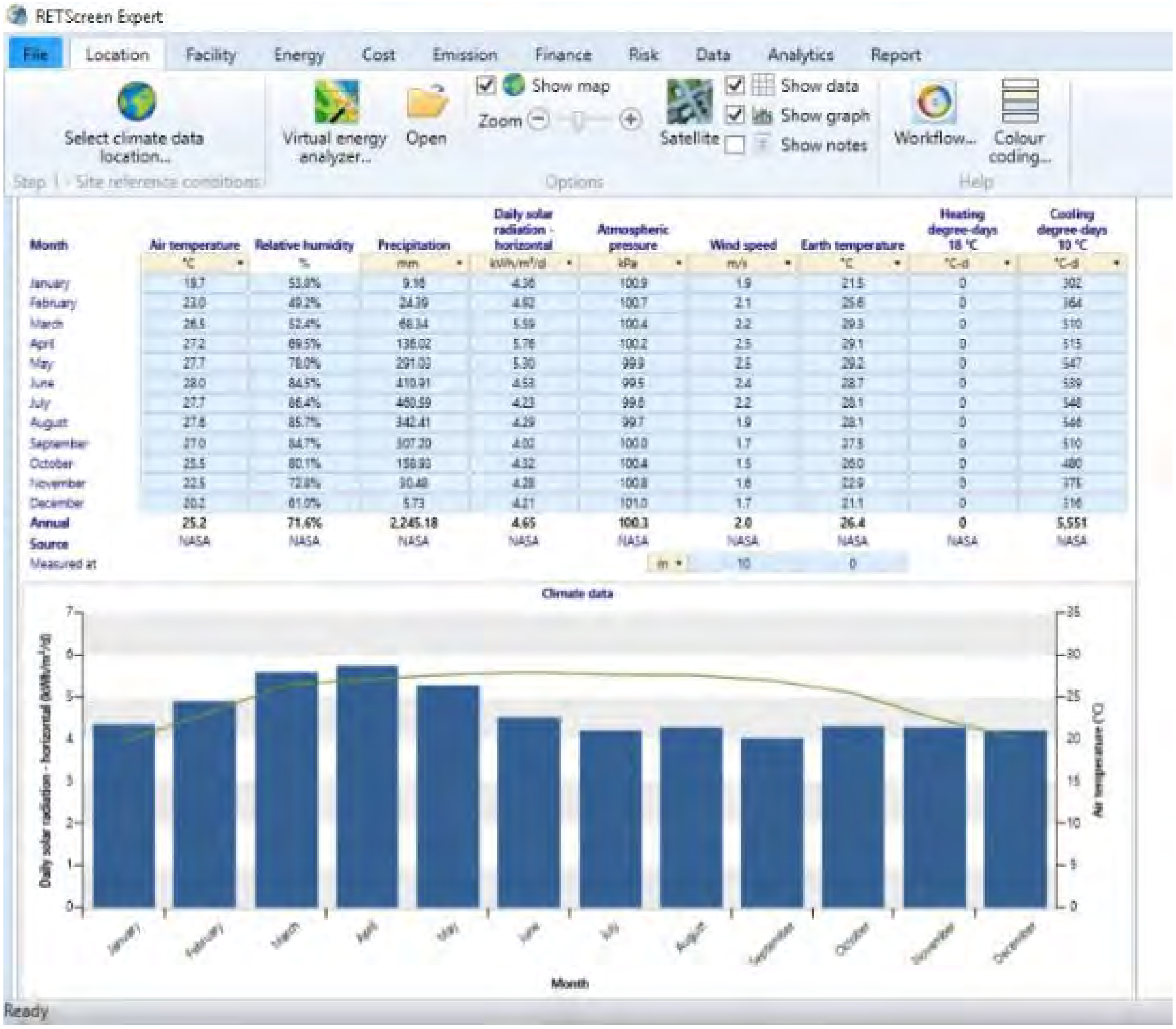


Figure 7.2.33(a): Climate Data



Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	19.7	53.0%	9.16	4.36	100.9	1.9	21.5	0	302
February	23.0	49.2%	24.39	4.92	100.7	2.1	25.6	0	364
March	26.5	52.4%	68.34	5.59	100.4	2.2	29.3	0	510
April	27.2	69.5%	138.02	5.76	100.2	2.5	29.1	0	515
May	27.7	78.0%	291.03	5.30	99.9	2.5	29.2	0	547
June	28.0	84.5%	410.91	4.53	99.5	2.4	28.7	0	539
July	27.7	86.4%	460.59	4.23	99.6	2.2	28.1	0	548
August	27.8	85.7%	342.41	4.29	99.7	1.9	28.1	0	548
September	27.0	84.7%	307.20	4.02	100.0	1.7	27.5	0	510
October	25.5	80.1%	158.93	4.32	100.4	1.5	26.0	0	480
November	22.5	72.8%	30.48	4.28	100.8	1.8	22.9	0	375
December	20.2	61.0%	5.73	4.21	101.0	1.7	21.1	0	316
Annual	25.2	71.6%	2,245.18	4.65	100.3	2.0	26.4	0	5,551
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
Measured at					m	10	0		

Figure 7.2.33(b): Climate Data

Load:

Here, we have measured,

12 Lights = 15 Watt * 12 nos. * 24 hrs. = 4,320 watt-hour;

Total is = 4,320watt = 4.32 KWh/day

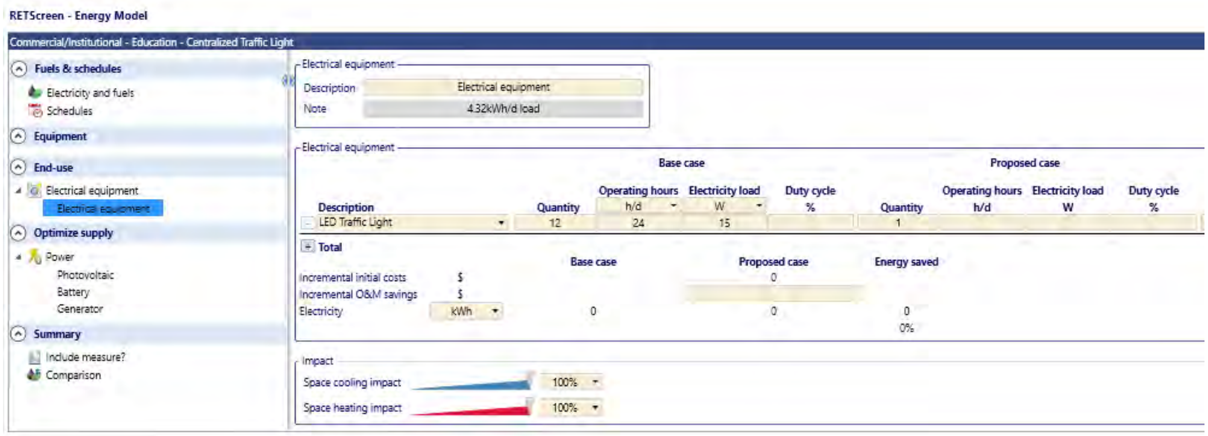


Figure 7.2.34: Load

PV panel:

Now, we have chosen photovoltaic type mono-si and 13 no. of units of 100W PV panel to design our 1.3kW photovoltaic power capacity. Moreover, to keep our result more accurate, we have assumed miscellaneous loss of inverter equal to 0.

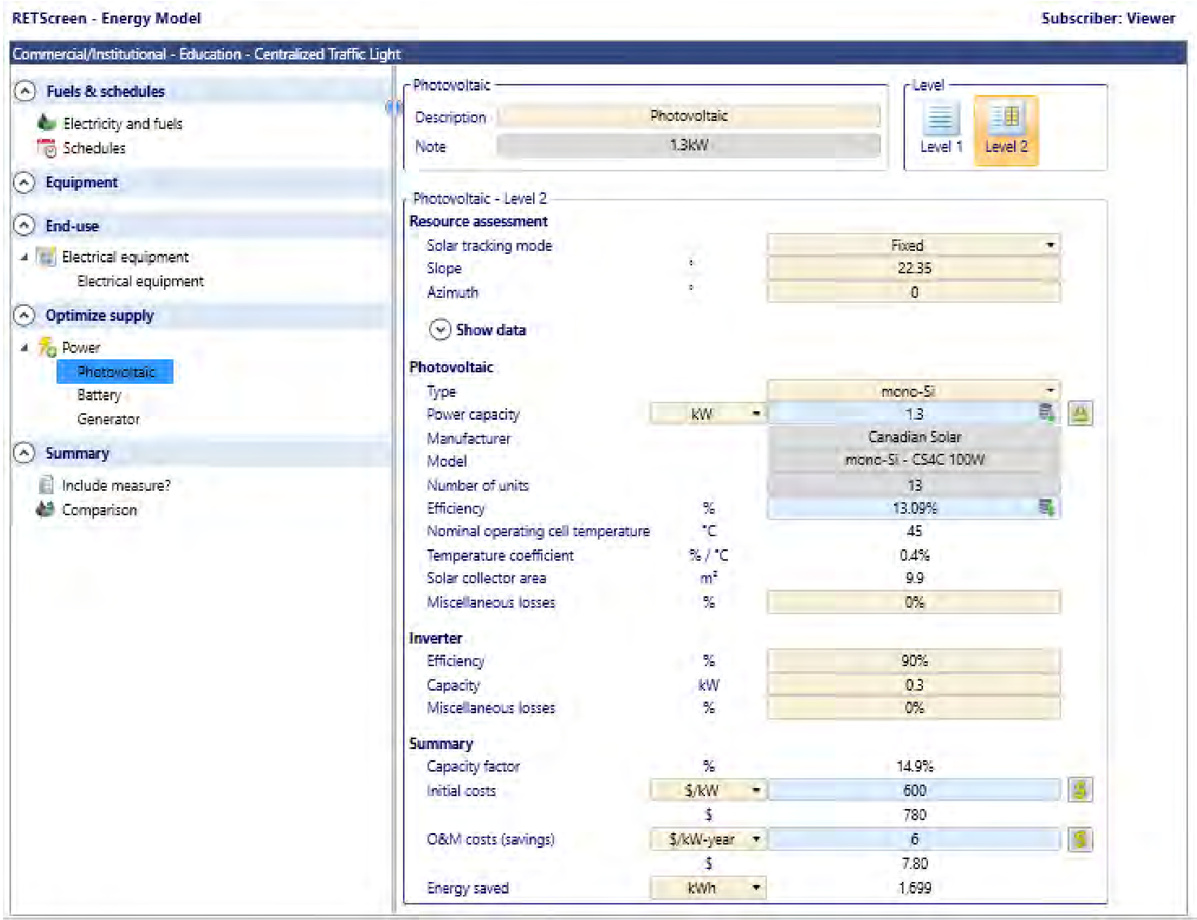


Figure 7.2.35: PV panel

Battery:

We have selected 11 lead acid batteries each one's nominal voltage 12V, maximum capacity 83.4Ah.

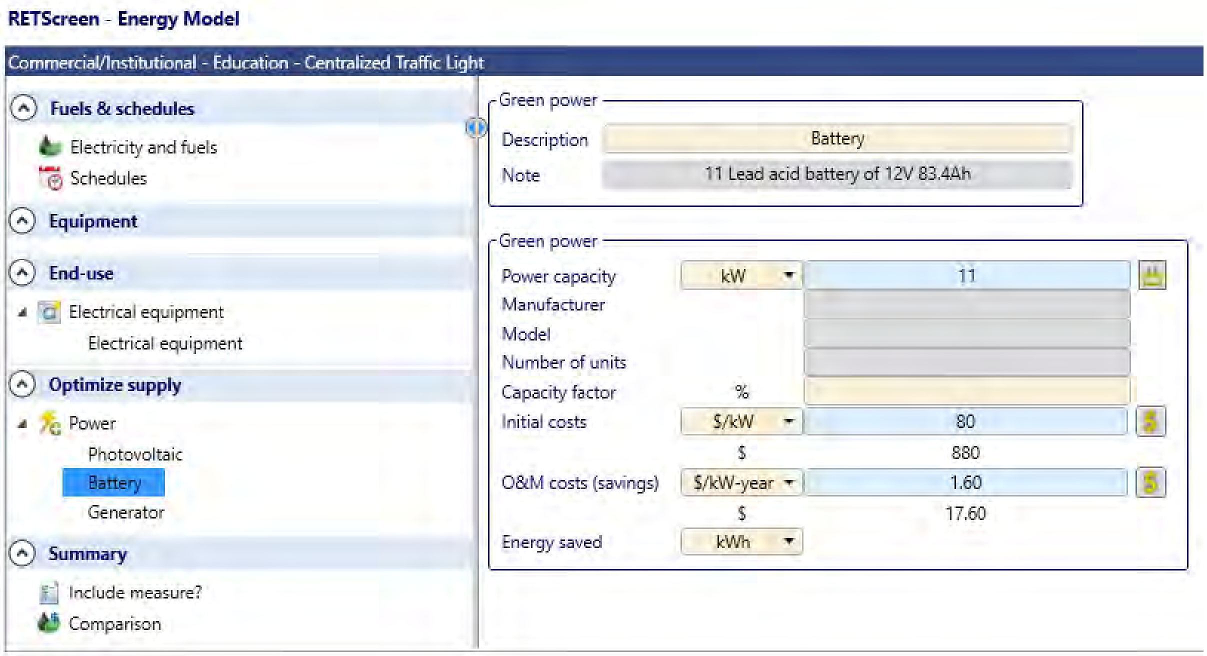


Figure 7.2.36: Battery

Fuel Cost:

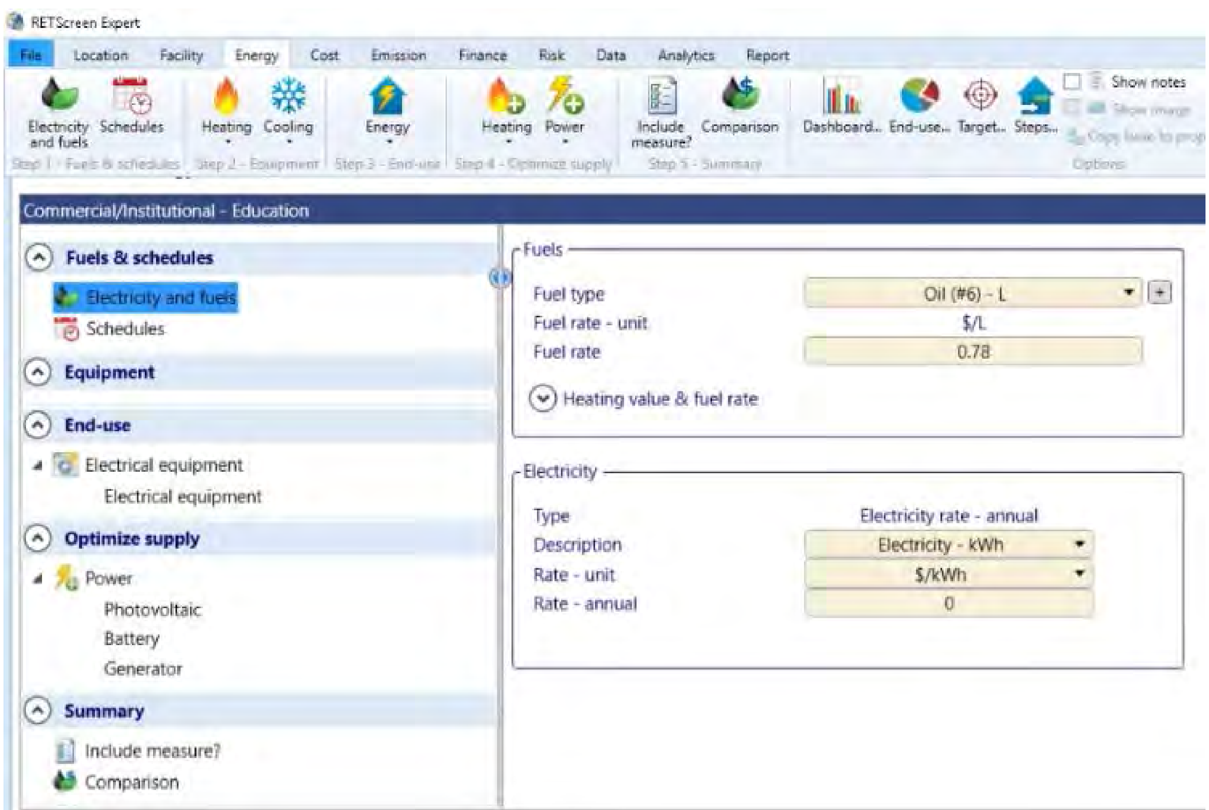


Figure 7.2.37: Fuel Cost

Generator:

We have chosen a back-up generator of 0.59kW which run on an existing fuel source to supply power during blackouts and power outages.

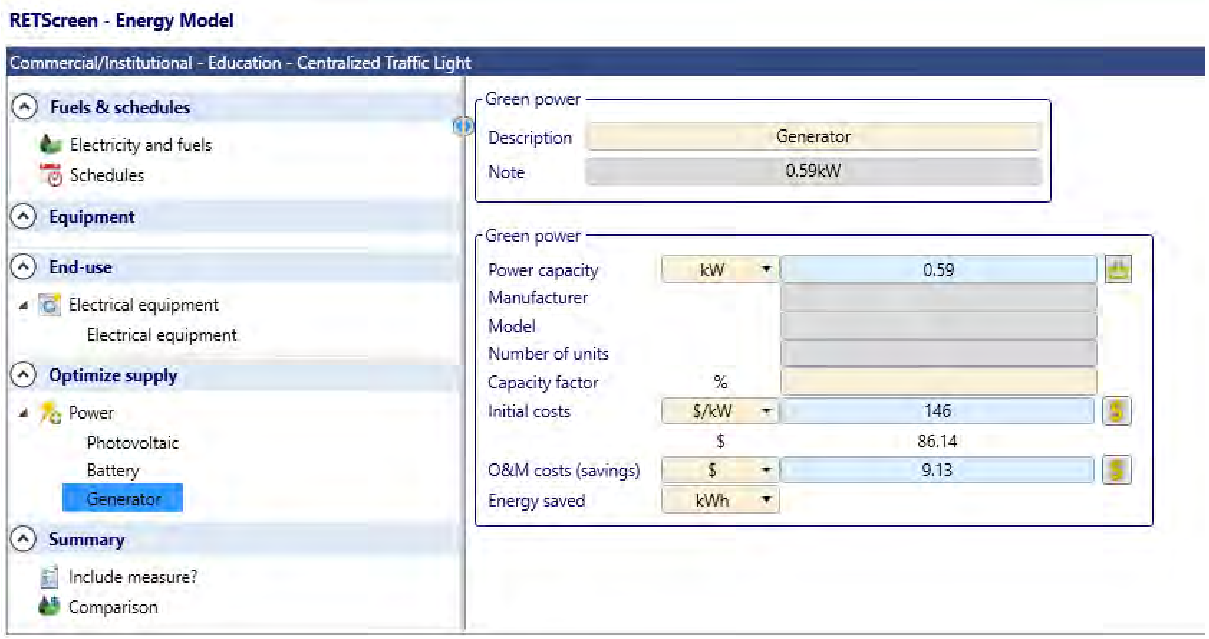


Figure 7.2.38: Generator

Annual Cost:

Now, we can see total initial cost of PV panel, battery, generator, inverter and system fixed capital cost is $3,263 and operation & management cost of PV panel, battery, generator and system fixed O&M cost is $63.53. Finally, we have compared our RETScreen annual result with Homer annual result which are equal.

RETScreen - Cost Analysis | Subscriber: Viewer

Initial costs (credits)	Unit	Quantity	Unit cost	Amount	
Incremental initial costs				$ 1,746	
Show data					
Electrical equipment					
Electrical equipment			$ 0		Update cost
Power system					
Photovoltaic			$ 780		Update cost
Battery			$ 880		Update cost
Generator			$ 86.14		Update cost
System Fixed Capital Cost	cost	1	$ 1,463	$ 1,463	
Inverter	cost	1	$ 54	$ 54	
Total initial costs				$ 3,263	

Annual costs (credits)	Unit	Quantity	Unit cost	Amount	
O&M costs (savings)	project			$ 34.53	
Show data					
Electrical equipment					
Electrical equipment			$ 0		Update cost
Power system					
Photovoltaic			$ 7.80		Update cost
Battery			$ 17.60		Update cost
Generator			$ 9.13		Update cost
Fuel cost - proposed case				$ 0	
System Fixed O&M Cost	cost	1	$ 29	$ 29	
Total annual costs				$ 63.53	

Annual savings	Unit	Quantity	Unit cost	Amount
User-defined	cost			$ -
Total annual savings				$ -

Figure 7.2.39: Annual Cost

Decentralized Solar Traffic Lighting System:

In decentralized Solar Powered Traffic Control, we have considered 0.36kW of total load. Based on the calculation (included in HOMER part 4.2), we have taken 0.154kW PV panel, 2kW Battery to supply power to the load.

Climate Data:

In this system we have considered Dhaka, Bangladesh as our project location. In figure 7.2.33(a) & (b) shows the climate data affirmed by NASA.

Load:

Here, we have measured,

1 Lights = 15 Watt * 1 nos. * 24 hrs. = 360 watt-hour;

Total is = 360watt = 0.36 KWh/day

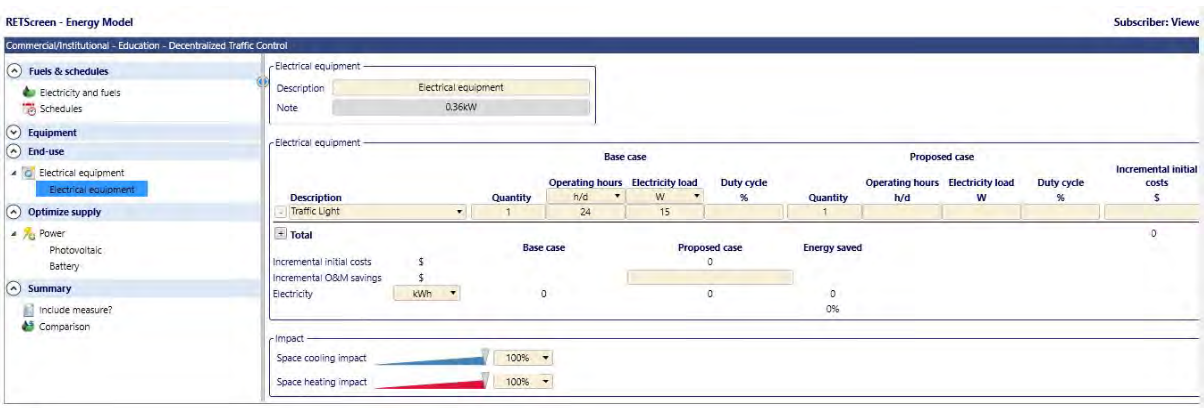


Figure 7.2.40: Load

PV panel:

Here, we have chosen photovoltaic type mono-si and 3 no. of units of 50W PV panel to design our 0.15kW photovoltaic power capacity.

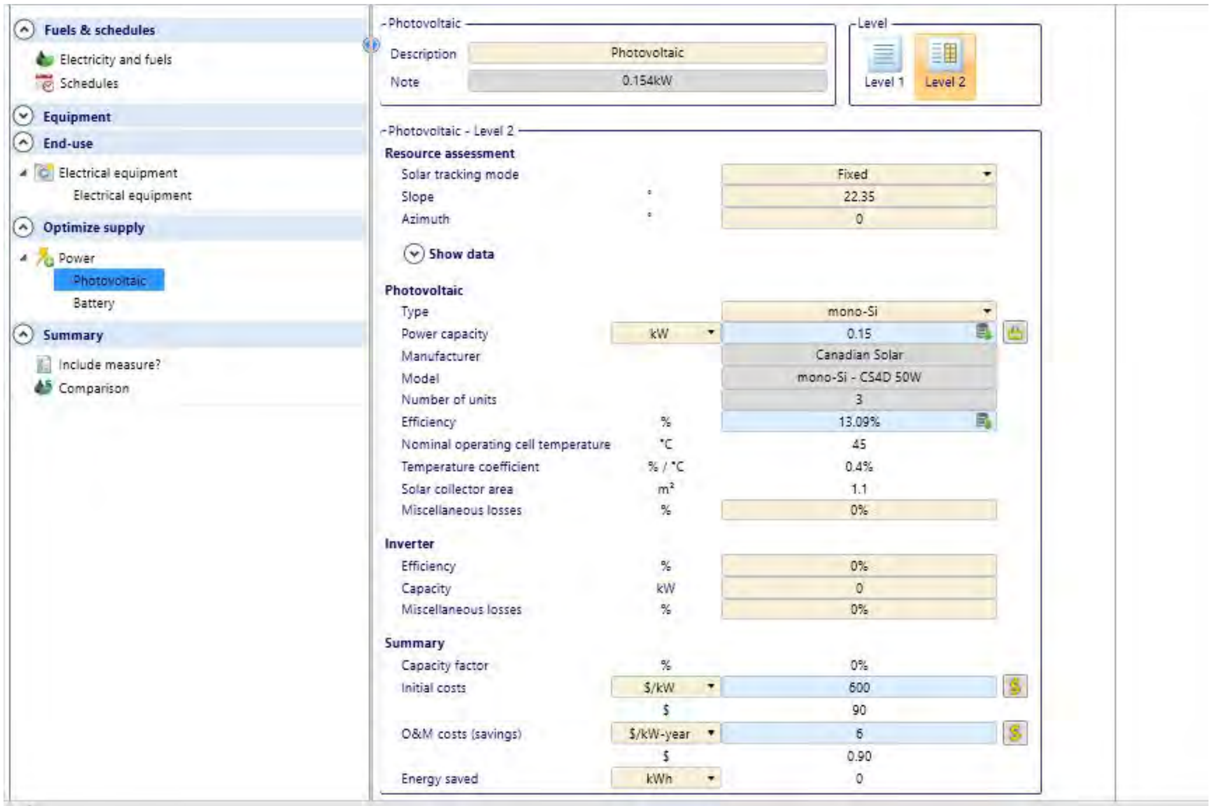


Figure 7.2.41: PV panel

Battery:

We have selected 2 batteries; each one's power capacity is 1kW and nominal voltage 12V, maximum capacity 83.4Ah.

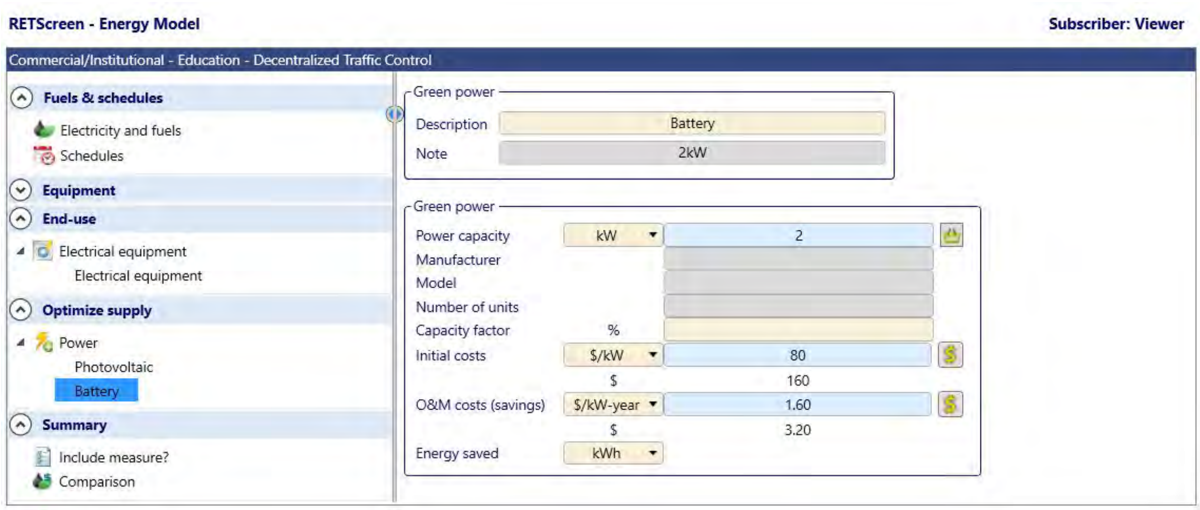


Figure 7.2.42: Battery

Annual Cost:

Here we can see total initial cost of PV panel, battery is $250 and operation & management cost of PV panel, battery is $4.1. Finally, we have compared our RETScreen annual result with Homer annual result which are identical.

RETScreen - Cost Analysis | Subscriber: Viewer

Initial costs (credits)	Unit	Quantity	Unit cost	Amount	
Incremental initial costs				$ 250	
Show data					
Electrical equipment					
Electrical equipment			$ 0		Update cost
Power system					
Photovoltaic			$ 90		Update cost
Battery			$ 160		Update cost
User-defined	cost			$ -	
Total initial costs				**$ 250**	
Annual costs (credits)	**Unit**	**Quantity**	**Unit cost**	**Amount**	
O&M costs (savings)	project			$ 4.10	
Show data					
Electrical equipment					
Electrical equipment			$ 0		Update cost
Power system					
Photovoltaic			$ 0.90		Update cost
Battery			$ 3.20		Update cost
User-defined	cost			$ -	
Total annual costs				**$ 4.10**	
Annual savings	**Unit**	**Quantity**	**Unit cost**	**Amount**	
User-defined	cost			$ -	
Total annual savings				**$ -**	

Figure 7.2.43: Annual Cost

CHAPTER 8

Conclusion and Future Works

8.1 Conclusion:

For proper utilize of solar power for reducing the dependency on national grid electricity, some initiative has taken place by our government to establish more solar power related projects throughout the country. The objective of our thesis study was to give the investors as well as the consumers a clear idea about solar power systems covering all the technical and economic parts. We considered four cases here which can go under solar power system category; centralized and decentralized home system, battery charging station and dedicated solar power charging kit, centralized and decentralized street lighting system and traffic lighting system. We have discussed elaborately the pros and cons of every case and also showed the economic analysis using Homer pro and RETScreen software. Lastly, solar power can be a viable option for electricity generation of our country if proper sizing of materials are done and also the prices of the equipment are reduced.

8.2 Challenges and Future Works:

There have been some difficulties and challenges that we faced while doing the thesis. Firstly, there did not have enough comparative analysis based papers in the internet so we had lack of ideas how we could present the cases more attractively. Secondly, we got enough information about all the decentralized cases but for the centralized systems there were lack of implementation because it is not popular yet throughout the world. Thirdly, in HOMER software there are different type of load categories i.e. residential, community, industrial etc. but there are nothing specified what kind of load would go under which category. Also Homer only counts capital, replacement, O & M costs for simulation but there are some other costs i.e. miscellaneous costs is not included which gives slightly different values from RETScreen software. Lastly, in RETScreen software there is no feasibility analysis for loads.

The thesis has a vision of improvement its analysis with more resources and more cases. The possible future works of the thesis has been discussed below:

- This thesis work was all about solar power. In our future work we can add some more renewable energy sources as power generator and check if we could get more cost effective solution from them.
- Back-up generator consumes fuel and emit harmful gases. Our future work can include the idea about how this fuel generator can be replaced by other energy sources effectively.
- Recently some more solar invention i.e. solar irrigation has taken place and successfully running in remote areas. These cases will be included with our future writing with full analysis.
- Lastly, field visits can give us actual feedback from the consumers which can be a good part of analysis and we should include them under “case study” segments.

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