A novel analysis of standalone PV mini-grid model for climate change mitigation in Myanmar's rural village

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Abstract

PV Mini-grid is becoming the feasible solution for fueling socio-economic development, of off-grid villages in Myanmar. This research work involved techno-economic analysis of five PV mini-grid models. The models were varied by having five demand scenarios (DS) as the sensitivity values. The experience of a village in Ma Gyi Pin Te is shared. The village is located in Taungtha Township, Mandalay region, in central Myanmar where there is high Solar PV potential. The village has 270 households with a population of 1,124. The electricity demand is projected to consist of primary load 1 (96.92 kWh/day, 30.94 kW peak), primary load 2 (588.10 kWh/day, 102.69 kW peak), and the deferrable load (117.53 kWh/day, 44.67 kW peak). After thousands of simulation exercises on off-grid PV mini-grid models using HOMER Pro (version 3.12.0), the optimum model was selected. This proposed model consists of PV modules of capacity of 208 kW, PV-MPPT of 150 kW, Storage Battery (Lead Acid) capacity of 800 kWh, and the Converter of 80.7 kW. Its LCOE (Levelized Cost of Energy) is 0.267 $/kWh. According to the simulation results, Diesel fuel 142,978 L/yr, and its cost 94,366 $/yr will be saved. Also, about the equivalent of CO_2 374,263 kg/yr emission will be avoided. This research work can be used for optimization studies to plan and deploy more PV mini-grids in Myanmar to achieve technical and economic efficient rural electrification in off-grid areas that also help in climate mitigation.

Keywords:

Myanmar, Taungtha, HOMER Pro, 100% renewable fraction, off-grid PV mini-grid,climate change itigation.

1. Introduction

There is no more doubt that the world is suffering impacts of climate change resulting from Greenhouse gas (GHG) emissions which mainly coming from the usages of fossil fuels. Renewable energy sources can be the alternatives to fossil fuels, as they generally emit very minimal or no GHG emissions. Renewable energy are inherently sustainable as they rely on infinitely available resources. Generally, fuel cost is zero. They are clean, green and eco-friendly energy systems. Renewable energy can help a create a e better world for next generations. Renewable energy can predominantly fuel the strategies towards a sustainable future for our mother earth, including many developing countries such as Myanmar [4].

Myanmar has tremendous renewable energy al resources so that the potentials for renewable energy applications are high. The country's energy policy encourages the development of renewable energy. Based on a 2014 analysis of Columbia University, Myanmar can reach universal access of electricity by 2030. In the long run, the extension of the Myanmar National Grid System will play a major role in meeting the 2030 target; more than 95% of the population, comprising 7.2 million households is expected to be connected. This is seen as the least-cost electrification strategy [5]. The department of rural development (DRD) under the Ministry of Agriculture, Livestock and Irrigation has the responsibility for implementing the off-grid electrification Programme of national electrification project (NEP). According to DRD data for FY 2016-2017, out of the total 63,899 villages, 22,911 have already been electrified. This result to a rural electrification rate of approximately 36 % (?)with the majority of rural electricity systems installed consisting of solar PV systems, including both Solar Home Systems (SHS) and Solar PV mini-grids [6].

1.1 Motivation

Myanmar is aiming to achieve electricity access for the whole country. Off-grid rural electrification is also the country's prioritized mission because 65.35% of the population [13] is living in the rural areas. In the medium term, SHS and mini-grids will be the key components of the pre-electrification process of the NEP to provide power for rural development. In this pre-electrification process, solar-powered mini-grids will play an important role for villages that require more capacity that what SHS can provide. The feasibility studies of these grids are needed to help ensure their successful implementation.

This research study is therefore being done in support of the e NEP Pre-Electrification process, as well as rural development of the country. Also, it support the country's environmental conservation agenda.

1.2 Research methodology: State-of-the-art

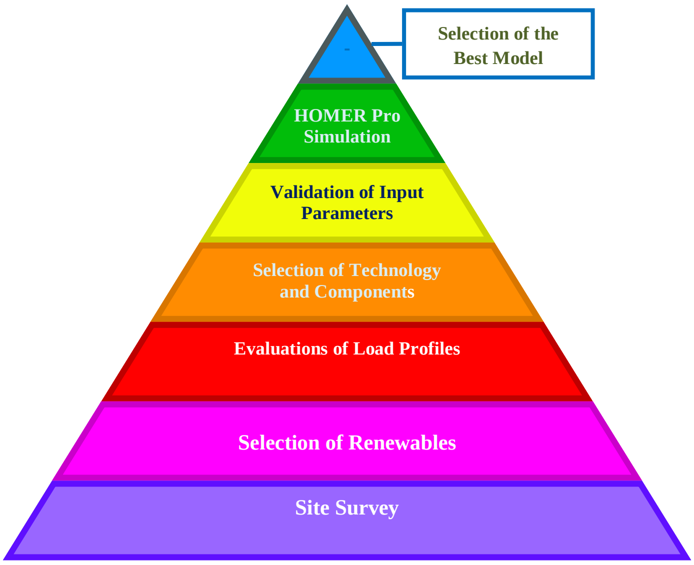


Fig. 1 Hierarchical methodology [2].

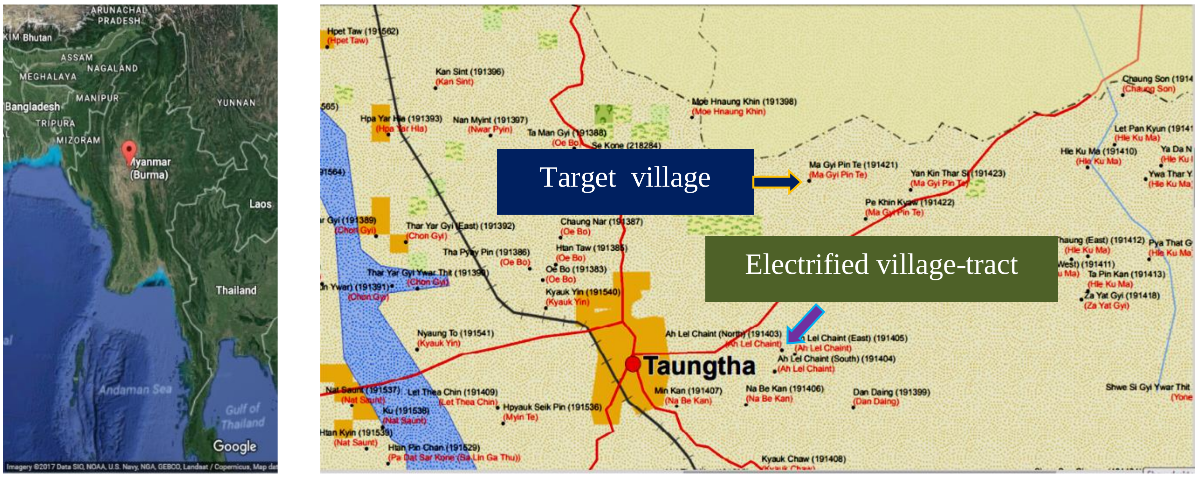
The research methodology hierarchical, a comprehensive process that involves seven pyramidal steps shown in Fig. 1. The first step is the site survey which is the foundation of the study; it aims to study and understand the real ground situation. The problems of and constraints to energy access are identified. The second step is the selection of appropriate energy supply based on the potential energy resources in the sites and what are the energy priority targets of the country. the third step involves the selection of relevant energy technologies and the determination of the main components of the mini-grid systems. The fourth step is the projection of the load profiles. This is followed, by the fifth step, which is the validation of the input parameters. The sixth and principal work in this process is the Techno-Economic Optimization of different mini-grid models performed using the well-proven tool, HOMER Pro (version 3.12). The final step is the selection of the best model [2].

2. Case study on Village Ma Gyi Pin Te: energy scenarios and problem statement

One of un-electrified villages in Mandalay region was selected as case study for this research. The region is located in the center of the country and plays important role in the national economy. It is one of three most populated rural regions the country. These were the factors considered in the selection of this area for the study.

2.1 Location of the village

Fig. 2 (a) shows the location of the targeted village, which is situated in Taungtha Township, Myingyan district, Mandalay region. It is included in the village-tract of Ma Gyi Pin Te, located North-East of Taungtha city, and approximately five km away from the electrified village-tract called Ah Lel Chaint, as shown in Fig. 2 (b).



(a) (b)

Fig. 2 Location of target d village: (a) Countrywide map showing the location is in central Myanmar; (b) Village-tract map showing village Ma Gyi Pin Te.

2.2 Diesel mini-grid system

On October 15, 2011, 183 houses in that village was electrifed with an off-grid 20 kW Diesel mini-grid system [7]. The electricity charges were 2000 Myanmar Kyats/month for each lighting device, 1000 Myanmar Kyats/month for charging each mobile phone and 3000 Myanmar Kyats/month for each TV appliance. By January, 2014, the number of electrified houses were also 183 and electrification rate is 80% [8]. The diesel genset operated between 18 to 21 hrs/day and the villagers, on the average, used electricity for a total of only about 3 hours/day day. This limited the time of use of the mini-grid. Besides, there were frequent needs for maintenance and repair because only a second-hand diesel generator wass used. Furthermore, the diesel fuel prices were increasing year by year.

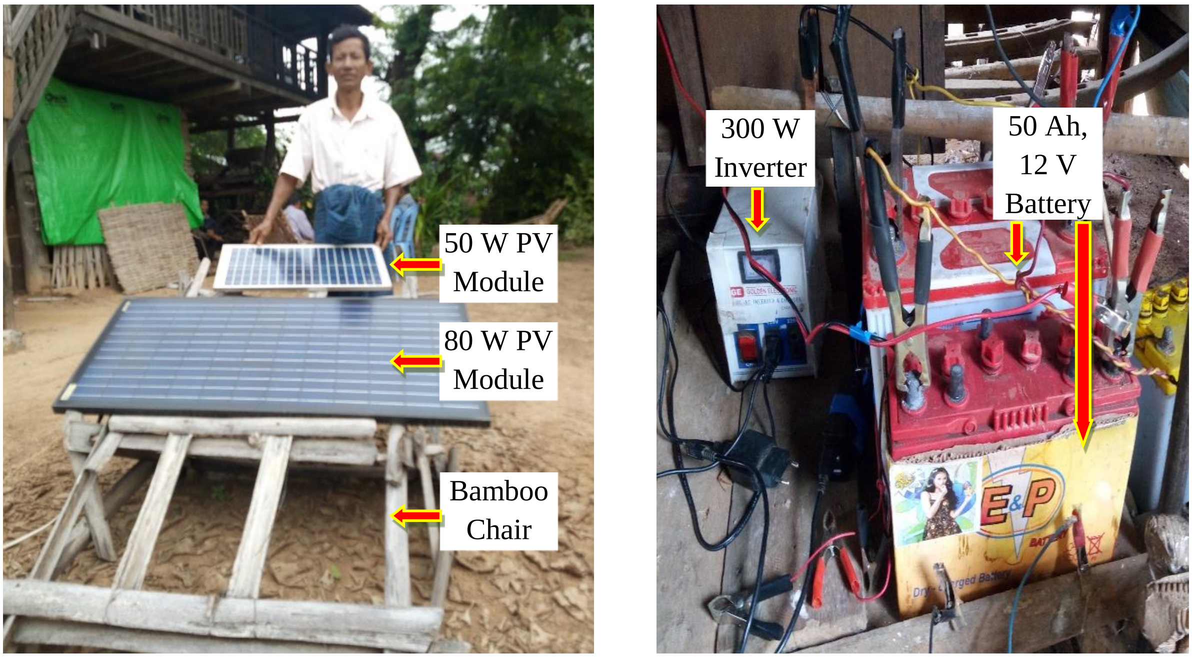
On the other hand, the cost was decreasing and supply has become easier for solar PV products, that can be found in the local markets of Taungtha and Myingyan cities. Tthe villagers increased their use and applications of SHS. As a result, the owner of the diesel mini-grid system stopped its operation in 2015.

2.3 The existing SHS

When the village was visited at that in November 2017, it has 270 households with a population of 1,124. About 100 households are using SHS. Some SHS deployers are using two to four modules to supply the different electricity applications in their home compounds. About 100 villagers were interviewed.

One of the homes visited is shown in Fig. 3 (a). It has a large 80 W PV module is 80 W and ae small 50 W module. However, the owner installed for both modules the same capacity of battery (50 Ah, 12 V) to charge, but without installing proper charge controllers (shown on Fig. 3 (b)).

There weree other technical errors in the design that resulted to inefficient applicatinos ation as well as failures of batteries and inverters. It has also not considered the inclination angle, shading effects and the design of proper mounting stand for these modules. Other SHS users in the area have similar low awareness and lack of understanding on how to improve the effectiveness of solar home PV systems.



(a) (b)

Fig. 3 (a) Villager and his PV modules; (b) Direct charging without using charge controllers.

2.4 Problem statement

2.4.1 Problems tree analysis of existing SHS

Based on the site visits, the problems of most of the SHS installations in the studied village [1] can be illustrated in Fig. 4.

Fig. 4 Problem tree of the existing SHS [1].

2.4.2 Problems of existing diesel genset systems

On the other hand, there are also problems in the use of diesel gensets. They include loud noise from its operation, and the need for careful storage of diesel fuel due to fire hazards because of the hot weather and careless use of firewood by villagers. There is also the global environmental concern about greenhouse gas emissions from use of diesel that the country has started to recognize. These problems are shown in Fig. 5.

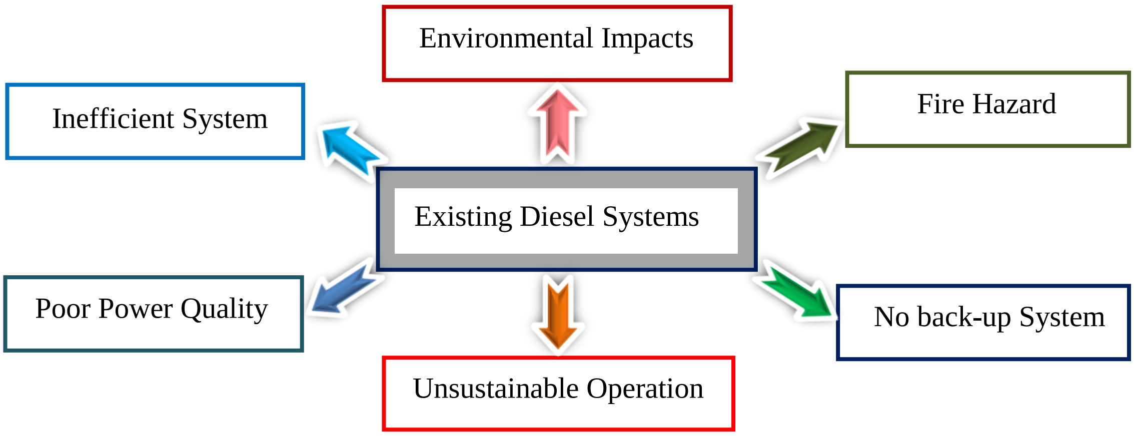


Fig. 5 Problem tree of the existing diesel systems for water pumping and industrial loads [1].

There are curretly two oil mills and eight water pumping systems in the village Ma Gyi Pin Te. The oil mills are operated with 25 hp diesel engines. The water pumping systems are operated with 12 hp diesel engines.

The diesel fuel consumption of the whole village is about 27 gallons per day in the hot season (March, April and May), 8 gallons per day in the rainy season (June, July, August, September, October), and 16 gallons per day in the cold season (November, December, January, February). Besides, there may be more diesel fuel consumption in May, October and November due to more works after the harvesting period of the crops.

Annually, diesel fuel consumption is 5460 gallons/yr (21349.72 L/yr) and this is getting unsustainable. Diesel fuel costs are increasing year by year. In addition, there is also e transportation cost. Diesel genset has also higher operation cost, maintenance cost, repair cost and replacement cost of its components. Thus, it is e uneconomical for in the long run.

During repair and replacement of parts, the machine cannot be operated. There is also no backup system, thus electricity supply is interrupted. This of course has negative impacts to the businesses, also the villagers who are dependent on the diesel genset for their electricity supply.

There is also lack of local knowhow in the operation of diesel gensets. The villagers do not know how to effectively use the diesel genset for water pumping and powering the village industrial loads. They do not know how to decrease the couple-losses from belt-drive and other speed changers. Some villagers inappropriately matched the sizes of diesel engine and the generators. These all contribute more to the inefficiency of diesel engine operations resulting to problems of poor power quality.

2.4.3 Problems from the cooking by fuelwood

The fuelwood is used for the cooking and the consequent problems as considered in [3].

(1) Deforestation towards climate change

The average fuelwood consumption per household is 7 tons per year. The total fuelwood consumption for the whole village is nearly 1,900 tons per year. That amount can cause the significant deforestation, and then, the landscape changes and reduce the absorbing capacity of the forests. As a consequence, the climate change will contribute form it.

(2) GHG emissions towards global warming

Wood is heterogeneous and exact amount of carbon in 1 kg of dry wood will vary depending on the species of wood, age of wood etc. 1 kg of wood contains about 450 to 500 gm of carbon. This means 1 kg of wood is holding about 1.65 to 1.80 kg of CO_2. This is how wood or forest act as carbon sink

[11]. CO_2 emissions from the burning wood is 109.6 kg CO_2 per GJ [9]. Other chemicals are produced, including nitrogen dioxide; 200 g of CO_2 equivalent per kg of wood burnt, the gas is 300 times more potent as a greenhouse gas than CO_2 and lasts 120 years in the atmosphere. Methane produced (70 g of CO_2 equivalent per kg of wood) 21 times more potent than CO_2. Carbon monoxide is also in large amounts. Overall, although figures vary depending on a multitude of factors, there is no doubt that wood burning is contributing to global warming [10]. Based on the study in [11], the Emissions from fuelwood consumption for that village calculated as 3,102,572 kg CO_2/year.

(3) Health problems from burning of the fuelwood

The health implications of wood burning derive from the emissions which contain carbon monoxide, nitrogen dioxide, and particulates, as well as other noxious gases [20]. More than four million people die each year from illnesses attributable to indoor air pollution from cooking with traditional biomass and inefficient cook-stoves. For the one billion people who depend on health facilities in remote and rural areas that presently lack electricity [12, 14].

(4) Cost for fuelwood

According to the interviews' results, the monthly fuelwood per household is about 4 $. Then, the total cost for the whole village is about 1,080 $ per year. It is sure that there is more cost of the fuelwood combination with the fuelwood cost for the donation ceremonies.

(5) High possibility of fire hazard

According to the site study, there is easy to be fire hazard from the combinational effects of the cooking by the fuelwood, the constructional materials of the rural house, the hot weather condition of the Central Dry Zone Area, the diesel fuel storage for the applications of the diesel systems.

3. Development of a 100% renewable energy standalone PV mini-grid model

3.1 Selection of green energy for electrification at the focused village

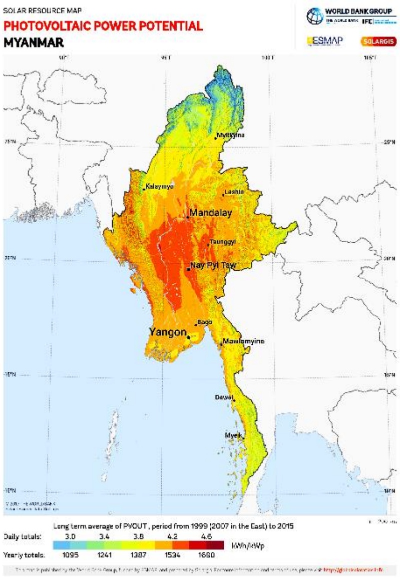


Fig. 6 Photovoltaic power potential of Myanmar [16].

Myanmar has a strong solar radiation level as reflected in Fig. 6 [16]. The central dry zone area of Myanmar consisting of Magway, Mandalay, and Sagaing regions with an average radiation of more than 5 kWh/ m²/ day and limited variation in radiation during the rainy season is highly suitable for solar PV applications [15]. Therefore, the proposed project located in Mandalay region is very feasible for implementation of a PV mini-grid system.

Based on the field surveys during the site visit, there is no hydro potential and biomass resources is insufficient in the village. Therefore, power generating systems based on these renewable energy resources are not feasible to install.

Wind power systems were also considered. However, the average wind speed required for modern wind turbines is at least 6 meters per second; most of Myanmar is considered unattractive as average wind speeds are below 4 meters per second, except for coastline and mountain ranges such as Shan and Chin states [15]. The target village is not located in these states. Only solar PV mini-grid remains as an option to implement an GHG emission-less power generation system.

3.2 General design of 100% renewable energy, standalone PV mini-grid

the main components of the proposed 100% renewable energy power system, based on a standalone PV mini-grid are PV array, PV MPPT charge controller, storage battery bank, direct current (DC) bus, bi-directional converter, and alternative current (AC) bus. The solar PV mini-grid systems is shown in Fig. 7.

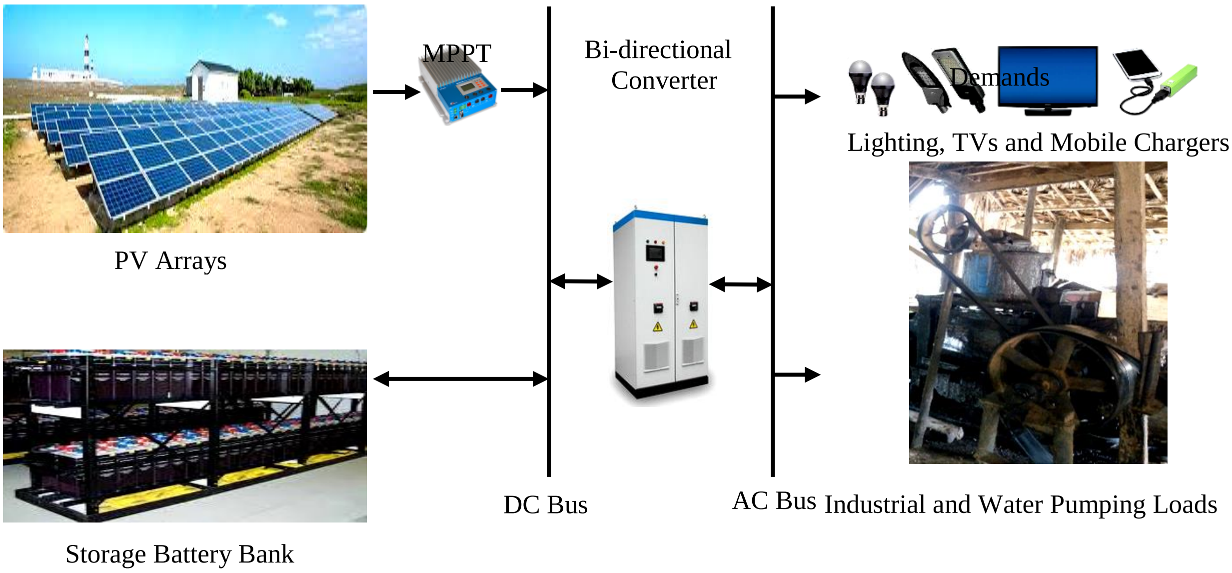


Fig. 7 General design of proposed 100 % renewable energy standalone PV mini-grid system.

Actually, PV has intermittent and non-dispatchable characteristics. Thus, its output needs to be controlled at a desired state through a DC-DC converter (Maximum Power Point Tracker, MPPT charge controller). Again, the output of the controller need to be kept at a capacity appropriate to the capacity of storage battery bank to obtain a 24-hour power supply, especially for autonomous (off-grid), PV mini-grid system.

The bi-directional converter is the important control component between two different buses. The other primary components are PV array racks, system housing, data logging system, grounding system, DC wires and BOS (balance of systems) components such as power limiters, pre-payment meters, wires, lamps, power sockets and others are needed for internal installations.

3.3 Solar radiation resources

GHI (Global Horizon Irradiation) is the key parameter for designing of PV power generation system. The highest GHI can be found in the central lowland areas of Myanmar where average daily totals reach yearly total of 1900 kWh/m^2 (average daily total up to 5.2 kWh/m^2) or higher [15]. In this modeling, GHI data was downloaded from NREL (National Renewable Energy Lab) database in HOMER Pro as reflected in Fig. 8. The GHI data need the relevant map data [16]. The required temperature data was also downloaded from NREL database in HOMER Pro.

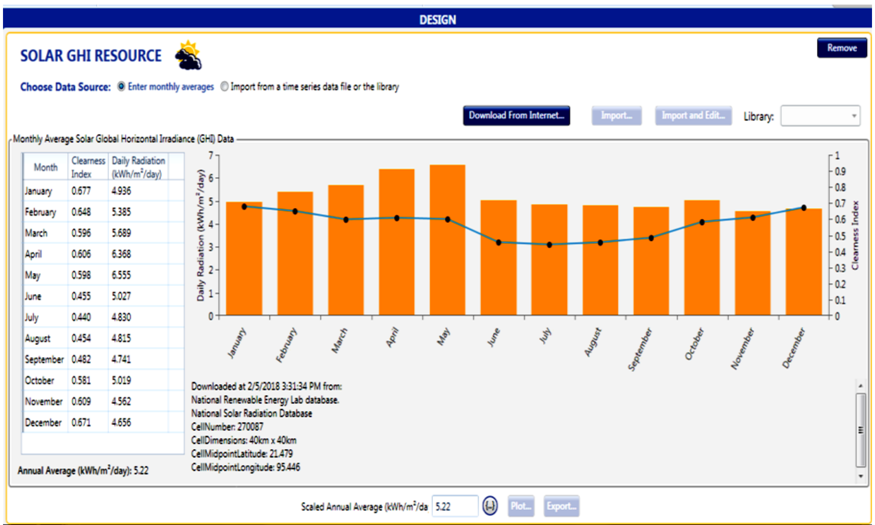


Fig. 8 Downloaded GHI Data of Project Location in HOMER Pro from NREL.

3.4 Inputs of the PV mini-grid system with the sensitivity values

The economics and technical constraints are the key parameters for the optimization, as well for energy planning. The nominal discount rate and the expected inflation rate set are set [17] with the sensitivity values for the analysis. The annual capacity shortage is set as 15% and 20%.

The selected PV Module consists of 72 poly-crystalline silicon cells. The cost per kW of PV inputted consists of the capital cost of 1000 $, replacement cost of 0 $, operational and maintenance cost of 10 $/year. Its lifetime is set as 20 years, the de-rating factor set as 90% and the electric bus set as DC. The MPPT (Maximum Power Point Tracker) inputs are: capital cost of 200 $, replacement cost of 150 $, operational and maintenance cost of 5 $/year. Its lifetime is 15 years and its search space is 29, 30, 50, 100, 120, 150, 200, and 250.

The advanced input parameters were set as: ground reflectance of 20 %, no tracking system, the panel slope at 21.29º, and the azimuth at default. The temperature effect, were obtained from the PV specifications and were set with the sensitivity values as follows: the efficiency at standard test condition at 15.5%; the temperature effect on power (%/ºC) operating cell temperature -0.45; -0.4495, and -0.4505; and nominal operating cell temperatures (ºC) 43, 45 and 47.

The economic data for the 1 kWh battery's are: Capital cost of 200 $; replacement cost of 180 $; operation and maintenance cost of 20 $/year; lifetime of 10 years; throughput of 800 kWh; initial state of large at 100%; minimum state of charge at 30%; minimum storage life of 5 years; and string size of 120 V. The converter inputs for 1-kW capacity are: capital cost of 300 $; replacement cost of 280 $; operation and maintenance cost of 5 $/year; and lifetime of 15 years.

3.5 Demand Scenarios

Different electricity demand profile were considered for the pagoda, monastery, households, street lights, mills, workshops and water wells. The projections were aimed to satisfy l the electricity needs of the village and address the problems presented in 2.4. It is also targeted to contribute to promoting the quality of life of the local community through the use of electricity generated from the proposed PV mini-grid system.

There are 270 households and around 80% (216 households) desired to take the power supply from proposed PV mini-grid. The remaining 20% desired to use their own SHS. The loads and times of the demand side were determined based on the observation on the daily normal routine and lifestyle of the village.

Based on the ratings of electrical power consumption, the households are generally classified into three groups: 56 households are low-power consumption group (type 1), 80 households are medium-power consumption group (type 2) and 80 households are high-power consumption group (type 3).

According to the simulation features of HOMER Pro, the electricity load types are inherently distinguished into two groups; as primary electric load and deferrable load. The objective of this load divisions is to know how the PV Mini-grid Model could be changed by changing the different load scenarios.

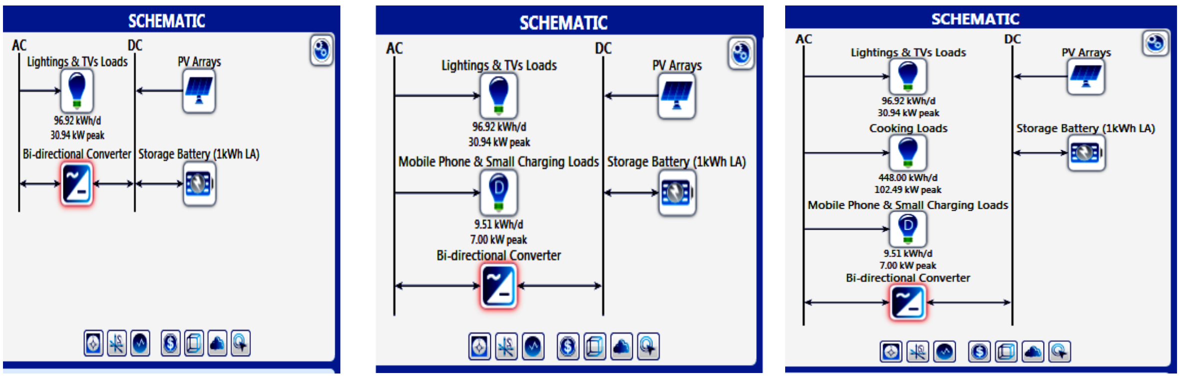
3.6 100% renewable energy, standalone PV mini-grid models with five demand scenarios

Five PV Mini-grid models (Model 1 to Model 5) with five demand scenarios (DS1 to DS5) were considered according to electricity demand priorities. Lighting is the first priority, while the second and the third are the mobile phone charging and the us of TVs, respectively. The small industrial machines and the water pumping systems are the fourth prioritized loads. The last one is the cooking loads. The five Demand Scenarios (DS) are connected with the general design (Fig. 7).

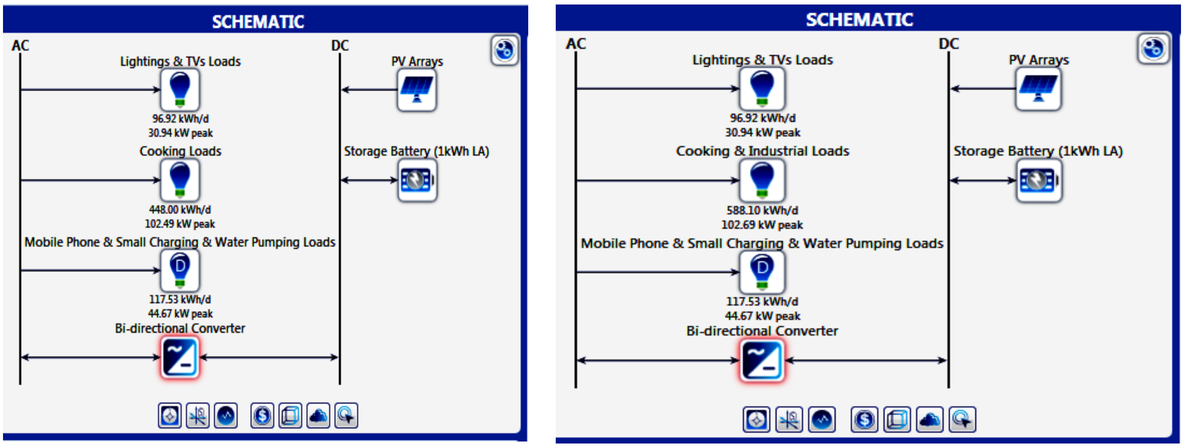
Table 1 shows the different DS of the different models. Based on the demand surveys, the capacities of these DS were evaluated and inputted with the corresponding times. Fig. 9 reveals the significant differences of the various DS in each 100% renewable energy, PV-based mini-grid models.

Table 1 100% renewable energy, five PV mini-gird models and their demand scenarios.

PV Mini-grid Model	DS	Primary Load 1	Primary Load 2		Deferrable Load	
		Lightings & TVs	Cooking Loads	Industrial Loads	Phone & Small Charging Loads	Water Pumping
M1	DS1	96.92 kWh/day 30.94 kW peak	-	-	-	-
M2	DS2	96.92 kWh/day 30.94 kW peak	-	-	9.51 kWh/day 7 kW peak	-
M3	DS3	96.92 kWh/day 30.94 kW peak	448 kWh/ day 102.49 kW peak	-	9.51 kWh/day 7 kW peak	-
M4	DS4	96.92 kWh/day 30.94 kW peak	448 kWh/ day 102.49 kW peak	-	117.53 kWh/day 44.67 kW peak	
M5	DS5	96.92 kWh/day 30.94 kW peak	588.10 kWh/ day 102.69 kW peak		117.53 kWh/day 44.67 kW peak	



(a) (b) (c)



(d) (e)

Fig. 9 Five PV mini-grid models in HOMER Pro: (a) M1, (b) M2, (c) M3, (d) M4 and (e) M5.

4. Simulation results and performance evaluation

The five PV Mini-grid models were simulated and optimized using HOMER Pro. The results of thousands of simulations were tabularized. The main tabular results of the optimization of the 100% renewable energy models are shown on Table 2.

4.1 Comparison of 100% renewable energy, five PV mini-gird models

Table 2 Comparison of the results from the simulation of five PV mini-gird models.

Particulars	**M1**	**M2**	**M3**	**M4**	**M5**
PV (kW)	25.9	31.9	164	177	208
PV-MPPT (kW)	29	30	80	110	150
Storage Battery (1 kWh LA)	190	200	920	870	800
Converter (kW)	16.7	17.5	113	95.3	80.7
Cost of Energy (COE, $/kWh)	0.483	0.448	0.385	0.335	0.267
Net Present Cost ($)	230,573	246,953	1.08 M	1.13 M	1.10 M
Operating Cost ($/yr)	9,702	10,205	42,974	45,156	42,132
Initial Cost ($)	75,766	84,116	389,602	407,361	423,075

It shows the impacts of electricity demand on the capacity (sizing) of the various components of the PV mini-grid and the result of the financial analysis. The stakeholders of the off-grid, mini-grid PV system (government organizations, authorities, local community, donors, project developers, and others) can select the preferred model based on the budget, financial factors, capacity of the PV mini-grid and the projected demand.

4.2 Selection of the model 5 (M5)

This study selected M5 as the proposed model of due to the following reasons s:

- The design capacity of M5 is the largest. It allows larger contribution of solar power generation to the country's energy supply.
- The COE of M5 is the cheapest. Thus, making electricity cost affordable to the poor villagers
- M5 can achieve the maximum GHG emissions reduction. Hence, M5 has the largest contribution to the green growth objectives.
- Only M5 can supply all the demands of the village.
- Due to its large capacity, M5 can have excess electricity production that can temporary supply o the neighboring villages.
- M5 considered supplying the industrial loads. Hence, village-based small enterprises can be energized by implementing M5.

- To implement M5, distribution lines need to be installed to connect all load centers. This will develop the grid network, making it ready to be connected to - the national grid system comes to the village. There will be less delay to develop a grid-connected PV mini-grid.

4.3 Detail results of M5 and remarks

Fig. 10 shows the tabular results for M5 based on HOMER Pro analysis. The upper table is an evaluation using e different sensitivity values. The lower table is the Optimization results. The PV power output from the proposed model (M5) is shown on Fig. 11.

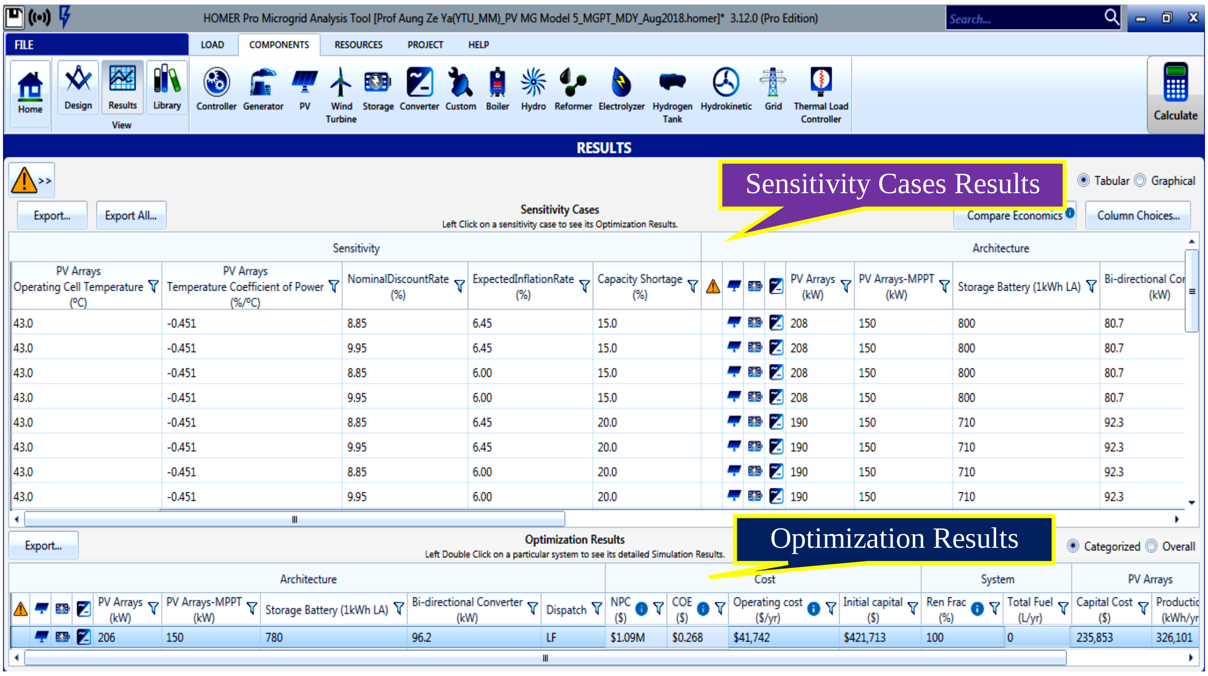


Fig. 10 Tabular simulation results of proposed 100% renewable energy model in HOMER Pro.

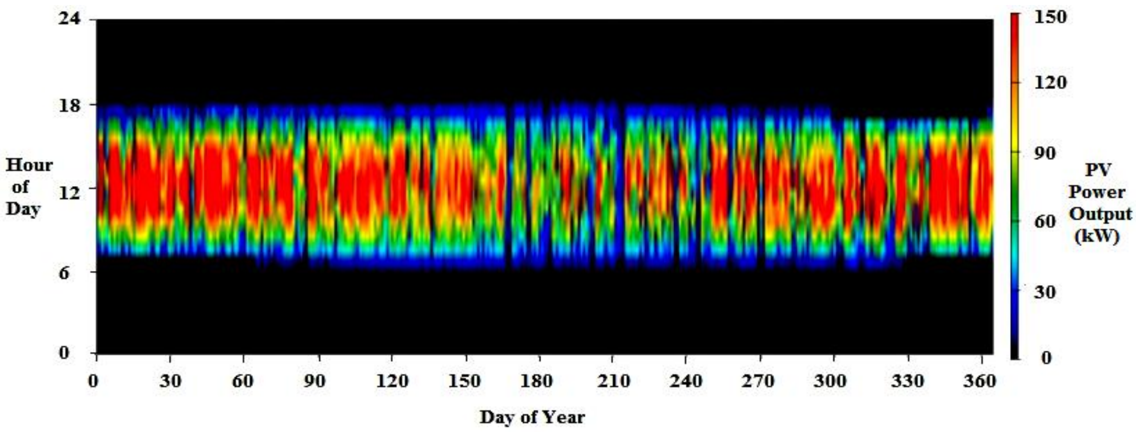


Fig. 11 PV power output of proposed 100% renewable energy, standalone model in HOMER Pro.

The simulation results for M5 is shown on Table 3. Fig. 12 shows the state of charge of 1 kWh lead acid battery and Fig. 13 shows the inverter power output of the proposed M5.

Table 3 Simulation results of proposed 100% renewable energy, standalone PV mini-grid model.

Particulars	Value	Value (with %)
Electrical Results		
PV Production	330,399 kWh/yr	100 %
AC Primary Load Consumption	214,785 kWh/yr	83.7 %
Deferrable Load Consumption	41,929 kWh/yr	16.3 %
Excess Electricity	32,391 kWh/yr	9.8%
Capacity Shortage	43528 kWh/yr	14.9 %
PV		
Rated Capacity	208 kW	-
Mean Output	905 kWh/day	-
Capacity Factor	-	18.1 %
Maximum Output	150 kW	-
Hours of Operation	4353 hrs/yr	-
Storage Battery (1 kWh LA)		
Nominal Capacity	800 kWh	-
Bus Voltage	120 V	-
Annual Throughput	126,192 kWh/yr	-
Lifetime Throughput	640,000 kWh/yr	
Energy Input	140,652 kWh/yr	-
Energy Output	112,869 kWh/yr	-
Autonomy	16.8 hrs	-
Usable Nominal Capacity	560 kWh	-
Expected Lifetime	5.07 yrs	-
Bi-directional Converter		
Capacity	80.7 kW	-
Hours of Operation	8,479 hrs/yr	-
Energy Input	270,225 kWh/yr	-
Energy Output	256,714 kWh/yr	-
Capacity Factor	-	36.3 %

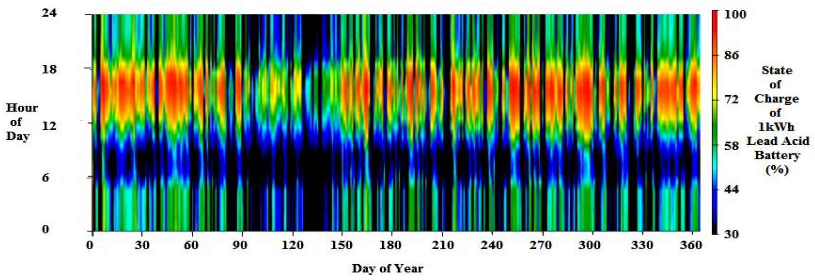


Fig. 12 State of charge (%) of 1kWh lead acid battery of proposed model (M5) in HOMER Pro.

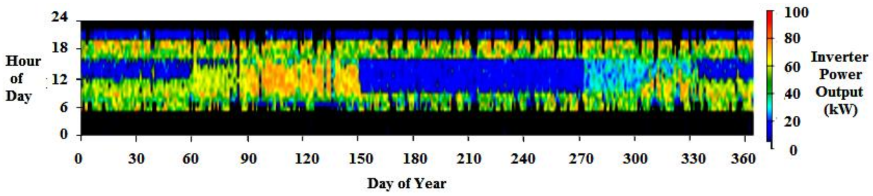


Fig. 13 Inverter power output of proposed standalone PV mini-grid model (M5) in HOMER Pro.

4.4 Simulation of renewable fraction 0, standalone diesel mini-grid model

The proposed model is also compared with the diesel mini-grid to evaluate the comparative benefits of M5. The simulation, showed the following result: for a diesel generator with capacity of 170 kW: net present cost is 3.71 M$, COE is 0.793 $, operating cost is 228, 980 $/yr, initial capital is 52,000 $, renewable fraction is zero, total fuel consumption is 142,978 L/yr, annual electricity production is

427,003 kWh, operation and maintenance cost is 111,690 $/yr, and fuel cost is 94,366 $/yr. The estimation of greenhouse gas (GHG) emissions is shown on Fig. 14.

A comparison h Table 2 will show obvious both economic and environmental benefits of deploying the proposed 100% renewable energy model 5, the PV-powered mini-grid.

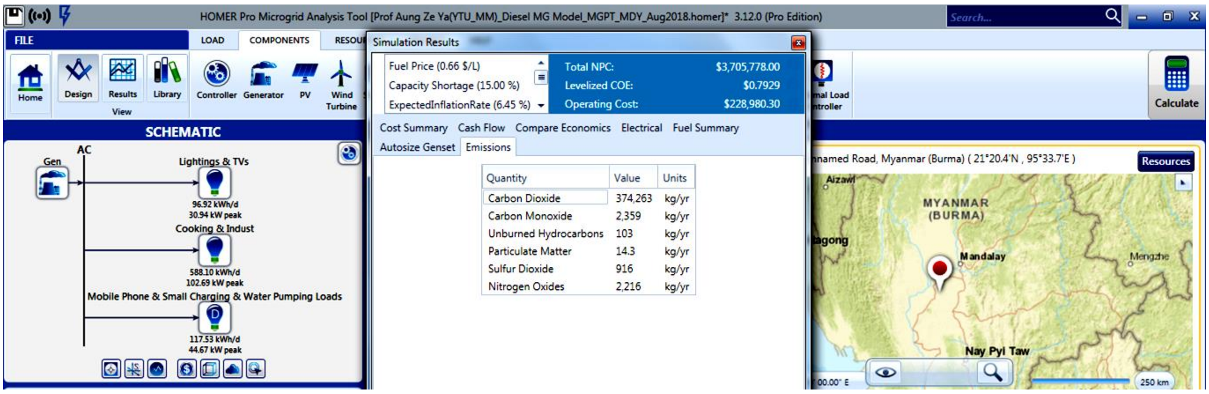


Fig. 14 GHG emissions from standalone diesel mini-grid model for same DS as M5 in HOMER Pro.

4.5 Climate change mitigation

The proposed model (M5) can contribute to climate change mitigation as it does not emit GHG. On the other hand the standalone diesel mini-grid model will generate greenhouse gases. The amount of GHG emissions is shown on Table 4.

Table 4 Diesel fuel cost saving and emissions reductions.

Particulars	For One Year	For 20 Years
Diesel Fuel		
Total Fuel	142,978 L/yr	2,859,560
Fuel Cost	94,366 $/yr	1,887,320
GHG Emissions		
Carbon Dioxide	374,263 kg/yr	7,485,260
Carbon Monoxide	2,359 kg/yr	47,180
Unburned Hydrocarbons	103 kg/yr	2,060
Particular Matter	14.3 kg/yr	286
Sulfur Dioxide	916 kg/yr	18,320
Nitrogen Oxides	2,216 kg/yr	44,320

The proposed model M5 is again GHG emission neutral compared with using fuelwood cookstoves. The amount GHG emissions from fuelwood cookstoves (assuming fuelwood is not harvested sustainably) is shown on Table 5.

Table 5 Reduction and saving by deploying (M5).

Particulars	For One Year	For 20 Years
CO_2 Emissions by the fuelwood	3,102,572 kg CO_2/yr	62,051,440 kg CO_2
Fuelwood consumption	1,900 tons/yr	38,000 tons
The cost of the fuelwood	1,080 $/yr	21,600 $
Diesel fuel consumption	21,349.72 L/yr	426,994.4 L

5. Conclusion

This study shows that cheapest COE is from the largest size of PV mini-grid model. This study considered five demand scenarios consisting of various combination of primary load 1, primary load 2, and the deferrable load. As explained in section 4.2, M5 was selected as the proposed model. Its main components are: PV module capacity of 208 kW, MPPT of 150 kW, storage battery of 800 kWh, and converter of 80.7 kW. Its annual electricity production is 330,399 kWh/yr, while the total load consumption is 256,714 kWh/yr, and the battery throughput is 126,192 kWh/yr. The cost of energy production is 0.267 $/kWh, which is considered as an acceptable value.

The benefits of the proposed model are; saving in of diesel fuel of 142,978 L/yr, saving in diesel fuel cost of 94,366 $/yr. There is also savings in fuelwood consumption. Finally there is GHG the emissions reduction of about 3,102,572 kg CO_2/yr.

The proposed standalone PV mini-grid model (M5) can contribute in climate change mitigation. It can also help conserve forests and tree-based ecosystems in Myanmar's rural villages.

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