Optimum planning of a renewable energy based hybrid mini-grid system for embracing the sustainability benefits in southern Myanmar

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Abstract. This article reveals the Optimization of the Renewable Energy based Hybrid Mini-grid system to energize a village Kyein Ne Taung with 645 households. The feasibility of the project is analysed in HOMER (Hybrid Optimization of Multiple Energy Resources) Pro. The site visit is carried out in July, 2019. The architecture of the proposed model comprises 160 kW PV System, 160 kW Wind System, 1320 kWh Battery Storage System, and 123 kW Converter. Regarding the current situation, the proposed Hybrid system can terminate 4500 tons per year and 2600 $ per year for Fuel wood cooking as well as 7000 litres per year and 8000 $ per year for Diesel fuel applications. By comparing with the Diesel Mini-grid to electrify the desired scenario, the proposed planning can save Diesel fuel 132,567 liters per year, Diesel fuel cost 132,567 $ per year, as well as reduce the GHG (Greenhouse Gas) emissions, including Carbon Dioxide 347,009 kg per year, Carbon Monoxide 2,187 kg per year, Unburned Hydrocarbons 95.4 kg per year, Particular Matter 13.3 kg per year, Sulfur Dioxide 850 kg per year, and Nitrogen Oxides 2,055 kg per year. Therefore, simulated results prove the available Sustainability benefits, and the reliable performance of the proposed system. This research can be useful as the reference of the affordable and modern Energy planning for other Coastal villages in Southern Myanmar.

Keywords: Myanmar, RE based Hybrid Mini-grid, village Kyein Ne Taung, HOMER Pro, Sustainability benefits

1. 1. Introduction
Today, the world is suffering Climate Crisis, which is the negative impact from previous Green House Gas (GHG) emissions. To create the sustainable world, the harvesting of the Renewables is the important foundation of all strategies towards Sustainable Future of the world [1].

1.1. Background
Myanmar is blessed with tremendous natural resources and potentials of Renewables [3]. It is situated in the northwestern-most country on the mainland of South East Asia and near to the Equator and along the belt of the sun’s radiation. Also, Myanmar enriches the Wind Power resources especially in three coasts, Rakhine coast, Ayeyarwady Delta coast, and Tanintharyi coast which is the longest with bounded by the Andaman Sea in the West. It scopes South of the Gulf of Mottama up to the mouth of
Pakchan River [6]. Hence, the focused village of this study is selected in the one island of the Tanintharyi coast. Department of Rural Development (DRD) is the main actor of the implementation of Off-Grid systems of the NEP (National Electrification Project). Due to the first five year (FY 2016-2021) programme of NEP (off-grid) of DRD, it is targeted to electrify 9,874 villages with the Mini-grids [8].

1.2. Motivation
Myanmar is very susceptible to extreme weather risks, and predicted future climate change. Unsustainable development can exacerbate the rural poverty in the coastal areas, and cause to leave the native villagers and weaken the majority of the population. Rural poverty remains the problem, and ever growing importance issue is Coastal resilience [7]. The country is prioritizing to conserve the Coastal Eco-System [4]. Based on the research studies in [3-5], there are significant negative impacts from the current Fuel wood cooking, and the Diesel generators for the small industries. Therefore, this work is performed to mitigate the current impacts, to conserve the Eco-system of the Coastal village, to support the technical needs of the NEP’s Mini-grid options with the Renewables.

2. State-of-the-art

2.1. Supportive tool: HOMER
The HOMER (Hybrid Optimization of Multiple Energy Resources) software is the global standard, very convenient, commonly used worldwide, world’s leading, and very powerful tool to investigate the Mini/Microgrids. It was originally created by Dr. Peter Lilienthal at US Department of Energy’s National Renewable Energy Laboratory (NREL) in 1993. The conceptual relationship between energy balance, simulation, optimization, and sensitivity analysis of HOMER is shown in Figure 1. HOMER is different from others in its focus on hybrid microgrids; those combine multiple energy and storage sources. It is a chronological simulation, optimization and decision analysis tool. It examines all possible combinations of thousands of system types in a single run, and then sorts the systems according to the optimization variable of choice. HOMER Pro features new optimization algorithm that significantly simplifies the design process for identifying least-cost options for microgrids or other distributed generation electrical power systems [9, 10].

![Figure 1. Conceptual relationship of analysis in HOMER [9]](image)

2.2. Hierarchical methodology
Seven steps are composed in the hierarchical methodology which is the pyramid shape. The most important work to know the real situation is the ground survey. The appropriate Renewables are selected based on the available resources of the site. As the third step, the load profiles are determined. The next step is the selection of the relevant technology and the main components of the proposed Mini-grid system. The input parameters validated as the fifth step. The principal work is the Techno-Economic Optimization of different models in HOMER Pro. As shown in Figure 2, the final step is the selection of the Best Model [4].
3. Development of the models in HOMER Pro

3.1. Project location in Tanintharyi coast
The project location, village Kyein Ne Taung is placed in the mapbox of HOMER Pro as reflected in Figure 3. Its geographical coordinates are latitude 11°04'12.6"N and longitude 98°37'05.9"E. It is situated in the one of the islands of the Bokpyin Township in Kawthaung District of Tanintharyi coast as shown in Figure 4.

3.2. Renewables resources
To design PV power generation system, GHI (Global Horizon Irradiation) is one of the essential parameters. In this study, GHI is downloaded from NREL (National Renewable Energy Lab) database in HOMER Pro. The scaled annual average GHI is 5.2 kWh per m² per day that is reasonable to the described data in [11, 12]. The temperature data (scaled annual average 26.54°C) and the wind speed data are also downloaded from NREL in HOMER Pro. The scaled annual average Wind Speed of the village Kyein Ne Taung is 4.9 m/s.

3.3. Project parameters
The Economics and the Constraints are the key portions for the optimization process [4]. From [13], the discount rate and the inflation rate are considered. To access the electricity for all hours of the year, the annual capacity shortage is inserted as 0% and the project lifetime is 15 years.
3.4. Controller set up
The controller is set up with the HOMER Cycle Charging (CC), HOMER Load Following (LF), and HOMER Combined Dispatch (CD). Under the CC strategy, whenever a generator has to operate, it operates at full capacity with surplus power going to charge the battery bank. Under the LF strategy, whenever a generator is needed it produces only enough power to meet the demand. CD uses the CC when the net load is low and the LF when the net load is high [9].

3.5. Load profiles
Load profiles are divided into two groups and denoted as the Electric Load 1 and Electric Load 2. These are evaluated according to the collected site visit data and inputted in HOMER Pro model. Electric Load 1 (643.91 kWh per day and 120.62 kW peak) consists of the total demands of the 645 households and the public utility demands including the street lighting, two schools, the monastery, the mosque, and the clinic. The villagers are using the Fuel wood for cooking and total Fuel wood consumption is about 4500 tons per year and its cost is about 2600 $ per year. To eliminate these, Electric cooking is considered in Electric Load 1. For industrial loads, Diesel generators are used and the estimated consumption is about 7000 liters per year. Currently, about 9000 $ per year are used for the Diesel applications. To solve these, Electric Load 2 is considered for the combined demand of the industrial loads. Its rating is 81.18 kWh per day and 26.53 kW peak and is extensively evaluated with the seasonal variation.

3.6. Main components
PV input values for 1 kW are: Capital cost is 1080 $; Replacement cost is 0 $; Operation and maintenance cost is 10 $ per year, and lifetime is 25 years. The advanced PV inputs are: the ground reflectance is 20 %, and the array (panel) slope is 10°. Temperature inputs are: PV Array temperature coefficient is -0.38 % per °C, and PV Array operating cell temperature is 47°C; and efficiency of the standard test condition is 19.1%. The battery set values for 1 kWh are: Capital cost is 200 $; Replacement cost is 180 $; Operation and maintenance cost is 10 $ per year; lifetime is ten years. The converter input values for 1 kW are: Capital cost is 300 $; Replacement cost is 250 $; Operation and maintenance cost is 0 $ per year and lifetime is 15 years. The costs for 10 kW Wind Generator are: Capital cost is 8,000 $; Replacement cost is 7,500 $; Operation and maintenance cost is 50 $ per year, and the lifetime is 20 years. To specifically know the benefits of the Renewables based Mini-Grid (Figure 5), the Diesel Mini-Grid is also modeled in this study (Figure 6). The autosize genset is modeled with Initial Capital 390 $ per kW, Replacement 360 $ per kW, Operation and Maintenance 0.03 $ per hr, and Diesel cost 1 $ per L.

4. Simulation Results and Analysis
In HOMER Pro, the thousands of Mini-Grid models simulated with the mix-analysis of Techno-Economic feasibilities [2] due to the developed models of the previous section.

4.1. Tabular results
After simulation, the Sensitivity and the Optimization Results are listed with the two separate parts of the tabular results as mentioned in Figure 7 and Figure 8. These results are trended for the models from
the top to bottom of the best to the least cost-effective options [2, 4]. The simulation results of the different Mini-grid Systems are compared in Table A.1. According to that comparison, it is obvious that the Renewable Energy based Mini-grid system is more cost-effective than the Diesel Mini-grid system. Moreover, other benefits, the significant saving of the Diesel fuel and the reducing of the negative impacts, can be achieved by implementing the proposed PV-Wind Mini-Grid System.

4.2. Generation capacities
PV System generates 217,771 kWh per year and shares 25 % of the total generation. Wind System generates more than PV with 652,701 kWh per year.

4.3. Power outputs
Power outputs of the Renewables are highlighted in Figure 9 and Figure 10. The maximum power output of the PV System is 129 kW. Its hours of operation is 4,456 hours per year and its levelized cost is 0.0621 $ per kWh. The capacity factor of Wind System is 46.6 % with the more operation hours than PV (6756 hours per year). Its maximum power output is 177 kW and its levelized cost is cheaper than PV with 0.0124 $ per kWh. The large generation from Wind System is harvested in the rainy season and cold season. Hence, it can compensate the less generation from PV system around the middle of the year.
4.4. Times series detail analysis

Time series data of the whole year can be deeply analyzed as reflected in the following Figures.

Figure 11. Scenario on April 10th

Figure 12. Scenario on October 10th

5. Conclusion

The optimal planning of RE based Hybrid Mini-grid systems is crucially important to implement Sustainable rural electrification with the least-cost options. Then, the enhancement of knowledge transfers either emerging RE technologies or Hybrid Mini-grid simulation by applying the reliable supportive tool is needed. Therefore, this work is performed for the contribution in Myanmar’s off-grid Mission, and the priority of the conservation of Coastal Eco-System. It observed that the 160 kW PV-160 kW Wind Mini-Grid System is relevant to implement at the island village in Tanintharyi coast. COE (Cost of Energy), 0.244 $ per kWh, and the other economic results are acceptable. This work can be regarded as the effective reference for the Renewables Mini-Grid planning in the coastal areas. According to the comparison of Table A.1, the proposed planning can save Diesel fuel 132,567 liters per year, Diesel fuel cost 132,567 $ per year, as well as reduce the emissions, including Carbon Dioxide 347,009 kg per year, Carbon Monoxide 2,187 kg per year, Unburned Hydrocarbons 95.4 kg per year, Particular Matter 13.3 kg per year, Sulfur Dioxide 850 kg per year, and Nitrogen Oxides 2,055 kg per year. Also, the emissions and costs (fuel and the transportation) for the current Diesel System applications can be terminated. The health and fire hazard problems, the negative outcomes from the Fuel wood, and the current Diesel fuel applications (including the emissions from the transportation of the fuel and 8000 $ per year) are eliminated. Furthermore, about 4500 tons per year of the fuel wood can be saved. Thus, the obvious rate of the deforestation is reduced. All in all, the proposed system can fulfil the Energy dream of the local community with embracing the Sustainability benefits in Southern Myanmar.

6. Recommendations

The recommendations from this research study are addressed as the following:

- The site survey is very important to evaluate the detailed load profiles and current Energy uses.
- Wind System can be more effectively harvested than PV System in Tanintharyi coast.
- Diesel Mini-Grids can be retired by the Renewables Mini-Grid projects.
- Climate Change and the other negative impacts can be mitigated by the implementation of the Renewables Mini-Grids.

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Appendices

Appendix A

Table A.1. Comparison of the simulation results of PV-Wind Mini-grid and Diesel Mini-grid

| Particulars                  | PV-Wind Mini-grid | Diesel Mini-grid |
|------------------------------|-------------------|------------------|
| Net Present Cost ($)         | 900,061           | 2.81 M           |
| Cost of Energy ($)           | 0.244             | 0.761            |
| Operating cost ($/yr)        | 20,243            | 197,090          |
| Initial Capital ($)          | 627,313           | 58,500           |
| Renewable Fraction           | 100%              | 0                |
| Total Fuel (L/yr)            | 0                 | 132,567          |
| Fuel Cost ($/yr)             | 0                 | 132,567          |
| Emissions (kg/yr)            | 0                 | Carbon Dioxide 347,009 |
|                              |                   | Carbon Monoxide 2,187 |
|                              |                   | Unburned Hydrocarbons 95.4 |
|                              |                   | Particulate Matter 13.3 |
|                              |                   | Sulfur Dioxide 850 |
|                              |                   | Nitrogen Oxides 2,055 |

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