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An Innovative Zero-Emission Energy Model for a Coastal Village in Southern Myanmar

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Keywords: southern Myanmar, Tanintharyi coast, village lel hpet, HOMER Pro, zero-emission energy model, simulation, standalone PV-wind-battery hybrid mini-grid.

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An Innovative Zero-Emission Energy Model for a Coastal Village in Southern Myanmar

Aung Ze Ya

Abstract- Myanmar boosts the Renewables harvesting with On-Grid and Off-Grid options to implement 2030 Agenda. Reversing the degradation of the Coastal Eco-System is also the prioritized Agenda. The research and deployment of Photovoltaic (PV), Wind, and Hybrid Mini-Grids are at the initial state and separated. This work imagined for supporting and bridging these. Thus, a village Lel Hpet, located in Palaw Township, Tanintharyi Region chose due to its blessings of PV and Wind resources. The villagers currently use the Diesel Generators for the industrial loads and the fuelwood for the cooking. These cause the negative impacts. Hence, Zero-Emission Energy Model analyzed. The total demand separated into Primary and Deferrable Loads. The simulation innovated with four Models on the excellent platform for Energy Planning, HOMER (Hybrid Optimization of Multiple Energy Resources) Pro (version 3.11.5). Then, the Best Model is selected. Its simulative results proved Wind is more feasible than PV on the Tanintharyi Coast, PV and Wind can compensate each other during their less generation months, and the larger Off-Grid Mini-gird is more cost-effective. The savings of the Diesel fuel usage and its costs, and the reduction of GHG (greenhouse gas) Emissions predicted. The proposed Climate-friendly, standalone PV-Wind-Battery Hybrid Mini-Grid can improves the Green penetration in Southern Myanmar.

Keywords- southern Myanmar, Tanintharyi coast, village lel hpet, HOMER Pro, zero-emission energy model, simulation, standalone PV-wind-battery hybrid mini-grid.

I. Introduction

Myanmar, 40^{th} largest nation in the world, geographically located between 9° 32' and 28° 31' N latitude; and 92° 10' and 101° 11' E. It situated as the strategic link of South Asia and South East Asia. It covers a land area of over 676,577 square kilometers and stretches over 2280 kilometers [3].

a) *Myanmar's Three Coasts*

Myanmar is very susceptible to extreme weather risks, landslides, sea-level rise related to air-current, and predicted future climate change. Coastal erosion and flooding are further risks which are predicted to grow. Tropical storms, occasional cyclones suffer regularly. The coastline is nearly 3000 km, extending about 1900 km from 10° to 21° North of the Equator, and 93° to 97° East of Greenwich [4].

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Fig. 1 shows Myanmar's three Coasts, Rakhine Coast, Ayeyarwady Delta Coast, and Tanintharyi Coast. Mayu and Kaladan rivers flow into the Rakhine Coast. Ayeyarwady, Sittaung and Thanlwin rivers flow into Ayeyarwady Delta Coast, and Ye, Dawai, Tanintharyi, Lenya rivers flow into the Tanintharyi Coast [3].

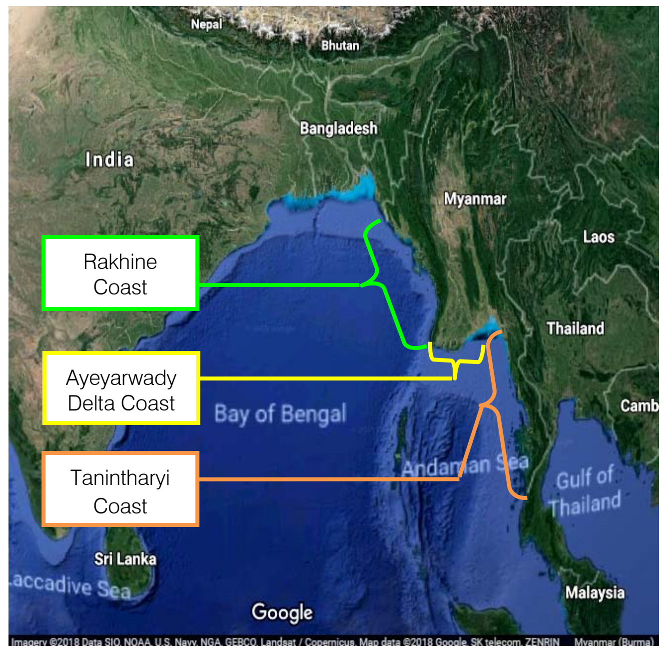


Fig. 1: Myanmar's Three Coasts [6]

Tanintharyi Coast is the longest among three. It bounded by the Andaman Sea in the West. It scopes South of the Gulf of Mottama up to the mouth of Pakchan River. It also included Myeik Archipelago, and Andaman Sea [3]. The Coasts are abundant with the coral reefs, mangroves, seagrass beds, mudflats, estuaries, and the dunes. These all play the role to uplift the quality of life of local community, and the environmental diversity. Also, these are paramount for the development of the agricultural, forestry, fishery and the tourism sectors [5].

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. Consequently, the rural population is behind the urban populations grow and prosper. Rural poverty remains the problem, and in the context of rising sea levels, and increasingly unstable weather. Coastal resilience is an issue of ever growing importance [4].

b) Standalone Mini-Grids in Myanmar

National Electrification Planning (NEP) of Myanmar Agenda 2030 aimed to electrify 7.2 million households, and achieve universal access to electricity by 2030. In the long term, the least cost extension of the National Grid System (NGS) included. For pre-electrification, the standalone Mini-Grids and Solar Home Systems (SHS) are the options for the rural areas far from that National Grid will take many years to reach [13]. The criteria to implement the standalone Mini-Grid are the village can't electrify by the NGS in the next five to ten years, its location is at least 10 kilometers from the NGS, the sufficient demand for Mini-Grid scale, and the number of households should be 150 to 200 with the concentrated group. Large villages with high demands are preferable as a high possibility of the stronger revenue streams to achieve Sustainable Mini-Grids [9].

c) Motivation

The motivation of this work is to energize the village with the Innovative Hybrid System to conserve the Coastal Eco-System. Also, it targeted to promote the Rural Electrification rate by improving the Green Growth.

d) Hierarchical Methodology

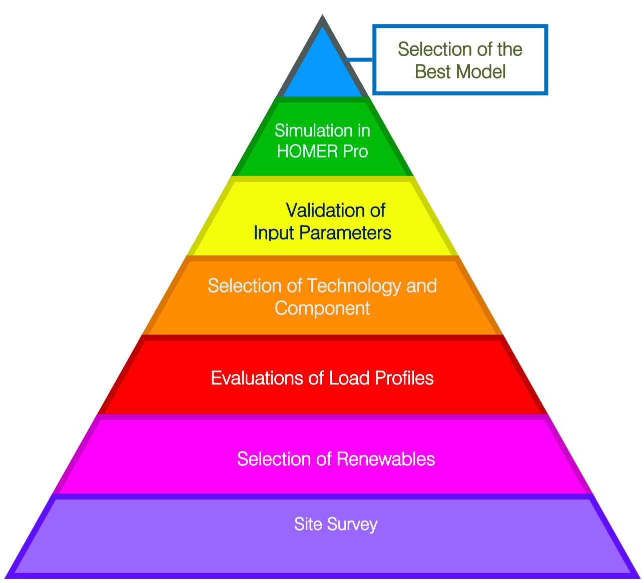


Fig. 2: The Pyramid of the Hierarchical Methodology

The hierarchical methodology is comprehensive process that involved the seven steps depicted as the pyramid in Fig. 2. The site survey is the fountain and essential work to know the real ground situation. The problems of the existing Energy access identified. Then, the appropriate Energies selected due to the potentials of the site and the priorities of the country. As the third step, the relevant technology and components chose. The load profiles predicted. The input parameters validated as the fifth step. The principal work is the Techno-Economic Optimizations of different models performed in the well-proven tool, HOMER Pro (version 3.11.5). The final step is the selection of the Best Model.

e) Identification of the Problems

The inhabitants are commonly using the small Diesel Generators for the water pumping and the industrial loads. All the houses apply the Compact Fluorescent Lamps (CFL) for the lightings and the fuelwood for the cookings. The identified problems are:

1) Contribution to the Global Warming due to the GHG Emissions from the burning of the Diesel fuels and the fuelwood [15-18],
2) Deforestation and Climate Change from the application of the fuelwood for the cooking,
3) Degradation of the bio-diverse eco-systems in the Coastal Region,
4) Health problems from the burning of the Diesel fuels and the fuelwood [20-22],
5) Easy to be fire hazards from the applications of the Diesel Generators and the firewood,
6) Insufficient and the limited supply from the existing SHS and the Diesel Generators, and
7) Environmental (Negative) impacts from the usages of the Fluorescent Lamps [19-21].

II. Zero-Emission Energy (Standalone PV-Wind- Battery Hybrid) Model in HOMER Pro

To solve above problems, the Standalone PVWind-Battery Hybrid Mini-Grid modeled in HOMER Pro.

a) Project Location in Tanintharyi Coast

Fig. 3 mentions the project location in the map-box of HOMER Pro. The village Lel Hpet in Tanintharyi Coast placed according to its geographical coordinates (13.10019806ºN and 98.60114288ºE). Also, Time Zone adjusted due to Myanmar Standard Time: six hours and thirty minutes ahead of GMT (Greenwich Mean Time).

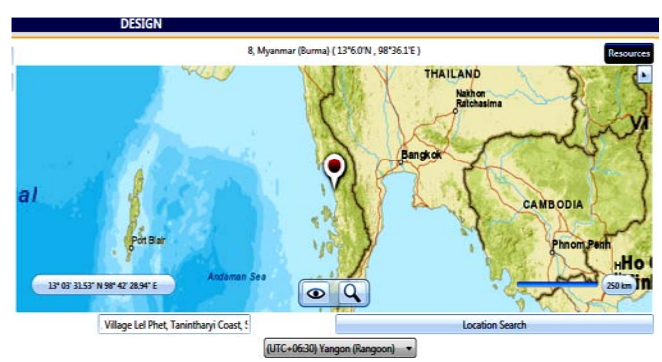


Fig. 3: Project Location (Village Lel Hpet)

b) Selection and Inputs of the Resources

Due to the geographical location, Myanmar has a rich Solar potential, and 60% of the land area appears suitable for PV deployments [10]. Fig. 4 [11] illustrates GHI (Global Horizon Irradiation) of Myanmar. From it, it is clear that the project location has the potential of Solar PV Energy. There are a few months (June, July, and August), which cannot favor for the PV generation. Hence, PV Energy is firstly selected to harvest.

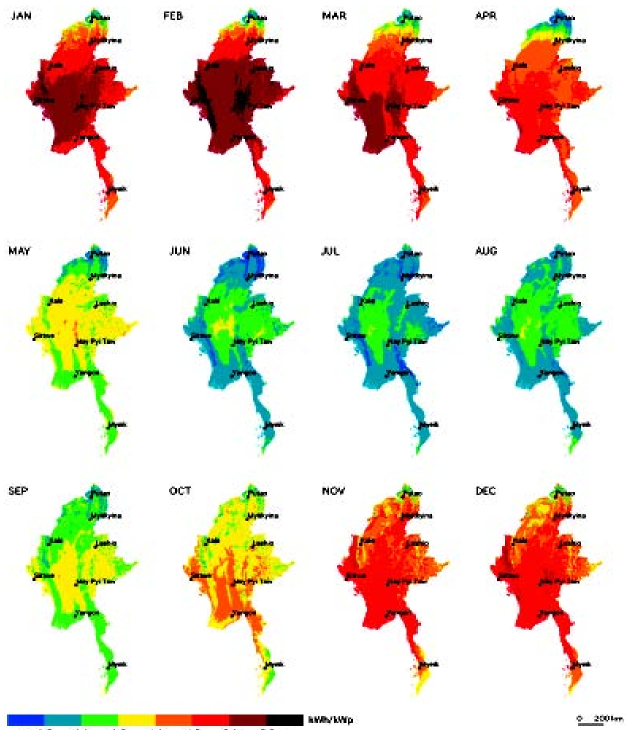


Fig. 4: GHI of Myanmar [11]

Fig. 5: GHI of a Village Lel Hpet

The input resources data of GHI downloaded from NREL (National Renewable Energy Lab) database in HOMER Pro highlighted in Fig. 5. Also, the required temperature data and Wind resources data downloaded from NREL in HOMER Pro.

According to the research of New Energy and Industrial Technology Development Organization (NEDO) in 1997, Myanmar has the strong potential of Wind Energy, with an estimated potential of 365 terawatt-hours (TWh) per year, especially abundant in the Chin and Shan states, and along the Coast [14]. Therefore, Wind Energy selected for the proposed project. To conserve the Eco-System of the Coast, and to protect from the Social Impacts, Hydropower did not consider in this study.

The strong winds can damage not only PV modules but also the construction components. However, the positive impacts can cause the low and medium speed winds. These winds create the cooling effects on PV modules and increase the power generation [11]. Hence, the Wind potential showed in Fig. 6 is not high, but, it can be beneficial for PV system. In June, July, and August, Wind has the high potentials. Thus, Wind System can compensate the less generation of PV System in these months. This point is the advantage of PV-Wind Hybrid System.

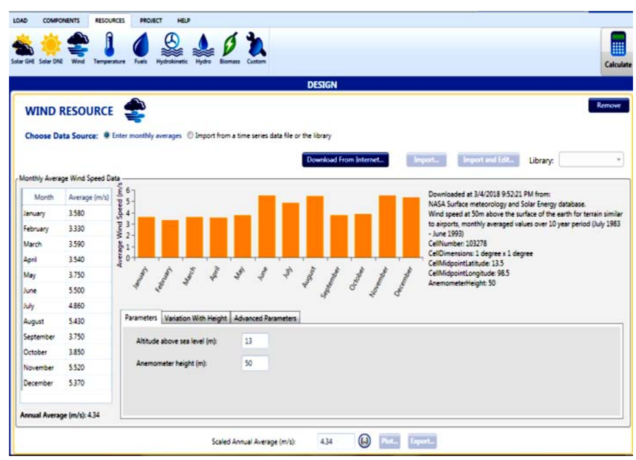


Fig. 6: Wind Resources Data of a Village Lel Hpet

c) Load Profiles

The Eco-friendly and the Energy Efficient loads are considered. To apply the effective simulation-features of HOMER Pro, the total demand divided into two main types, Primary Load (PL) and Deferrable Load (DL) as depicted in Fig.7.

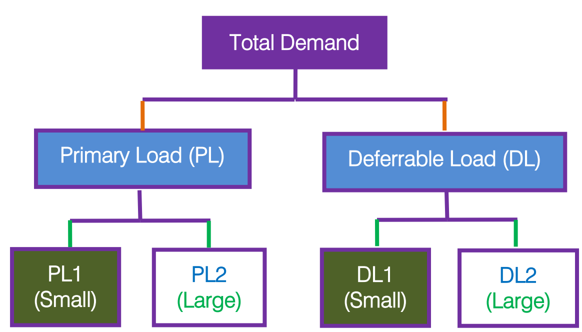


Fig. 7: The Composition of the Total Demand

PL is sub-divided into two types. PL1 (small) includes the LED lamps, flat TVs, and other small loads. PL2 (large) consists of the kitchen loads (the rice-cookers, the cooking pots), the cooling loads (the fans, the air-coolers, and the water-coolers) and the small industrial loads listed in Table 1. DL composed of two categories. DL1 (small) contains the mobile chargers, the power banks, and the rechargeable LEDs. DL2 (large) involves the fifteen 1.5 kW water pumping loads.

Table 1: Small Industrial Loads of PL2 and DL2

Load Type	Description	Power (kW)	Amount
PL2	Carpentry Workshop	1000	8
	Cold Storage	140	20
DL2	Water Pumping	1500	15

Based on the collected data from a site visit in January 2018, the load profiles predicted for a one Pagoda, a one Monastery, 250 households (HH), and the school, the street lightings, the water pumping loads, and the small industrial loads. The households (HH) are classified as the three groups depending on the demands. The low and high demand groups have 25 and 50 households. The medium demand group has 175 households. Table 2 listed the total demands of each HH group. Figs.8 to 10 described the inputs of the Primary Loads (PL1, PL2) and Deferrable Load (DL).

Table 2: Total Demands of Each HH Group

Group	Primary Load 1 (kilowatt, kW)	Primary Load 2 (kW)	Small Deferrable Loads (kilowatt hour, kWh)
Low	1.320	22.5	1.305
Medium	13.833	192.5	13.020
High	11.600	60	4.350

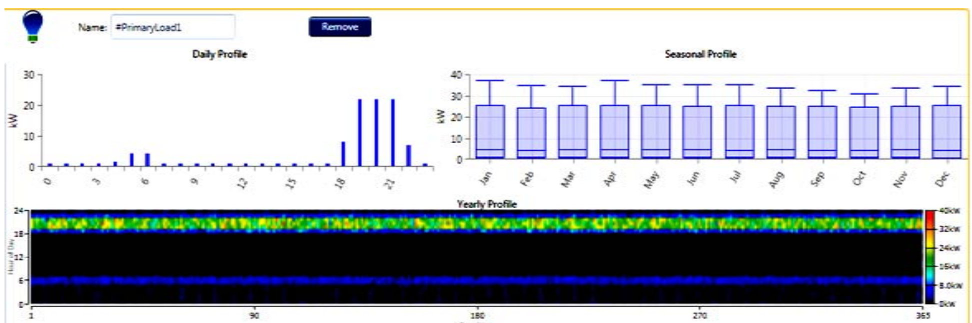


Fig. 8: PL1 Input in HOMER Pro

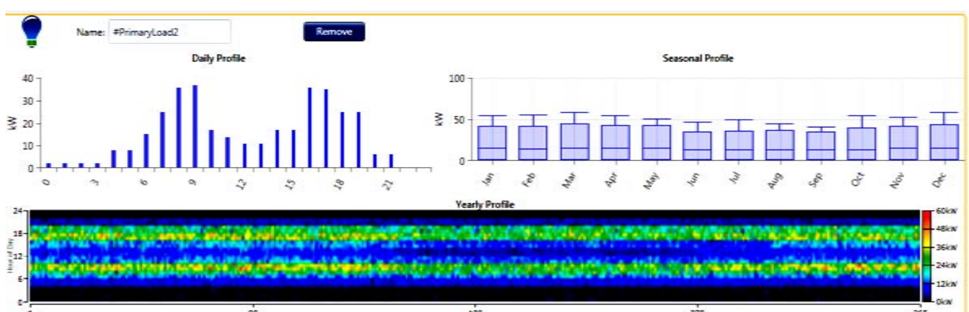


Fig. 9: PL2 Input in HOMER Pro

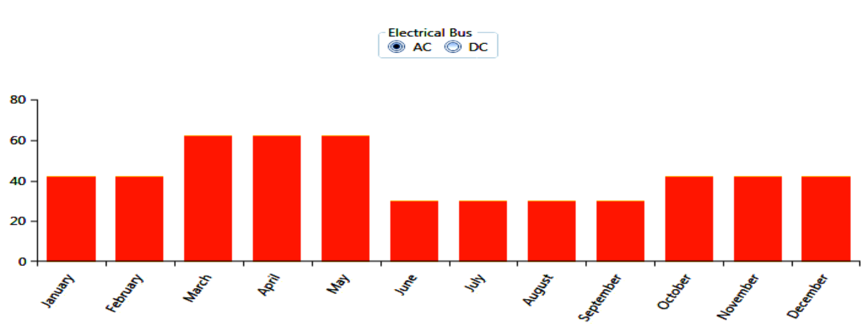


Fig.10: DL Input in HOMER Pro

d) Different Models in HOMER Pro

The modeling and the simulation are innovative. The different Models analyzed in HOMER Pro as shown in Table 3. HOMER performs the energy balance predictions, and then determines the feasible configurations to meet the demands under the specified conditions [1].

Table 3: Different Models

Model	Components	Demands
Model1 (M1)	PV-Wind-Battery Hybrid	PL1 and DL
Model2 (M2)	PV-Wind-Battery Hybrid	PL1 and PL2
Model3 (M3)	PV-Wind-Battery Hybrid	PL1, PL2,and DL
Model4 (M4)	Diesel Generators (50 kW & 25 kW)	PL1, PL2,and DL

The four Off-Grid Models explored in Figs.11 to 14. Models 1 to 3 investigated to know how the influence of the demands on the technological designs, and the economical aspects. Thus, their generating, the storage, and the converting components are the same with the different demand scenarios. Single-phase, 20 kW Wind Turbine is connected to AC (Alternating Current) Bus. The DC (Direct Current) outputs of the PV Arrays are stored into the Battery, and then converted into AC. All loads are connected to the AC Bus.

All demands (PL1, PL2 and DL) connected in the M3 and M4. PL1 is 108.6 kWh per day and 37.34 kW peak. PL2 is 336.14 kWh per day and 59.28 kW peak. Deferrable Load is 43 kWh per day and 28.75 kW peak.

Globally, the largest amount of GHG is significantly emitted from the fossil fuels utilizations for Electricity Generations [23]. Hence, the notable point is Diesel Mini-Grid (M4) modeled with the same demands as M3 to determine the specific amount of GHG Emissions, also, the fuel usage and the fuel cost from it.

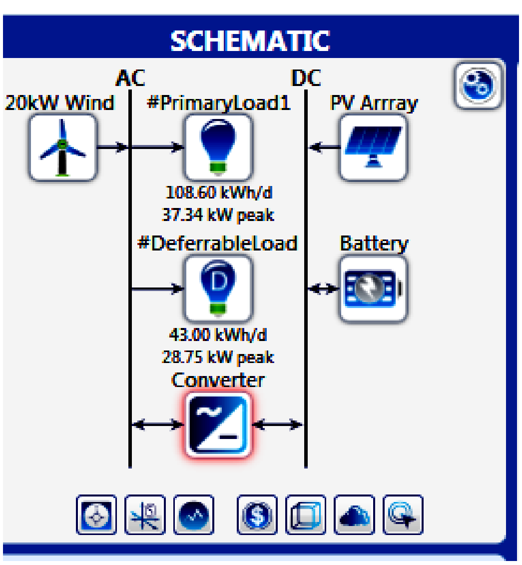


Fig.11: M1

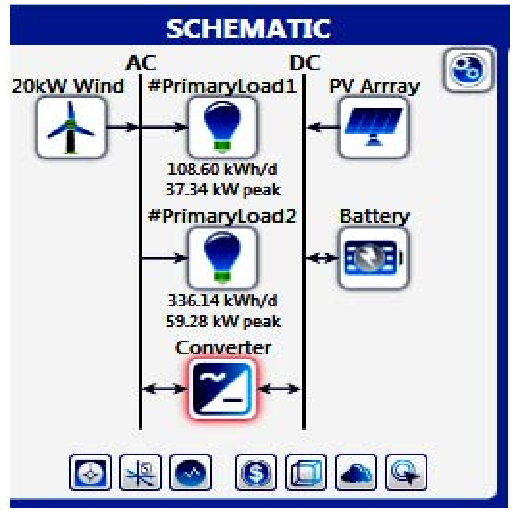


Fig. 12: M2

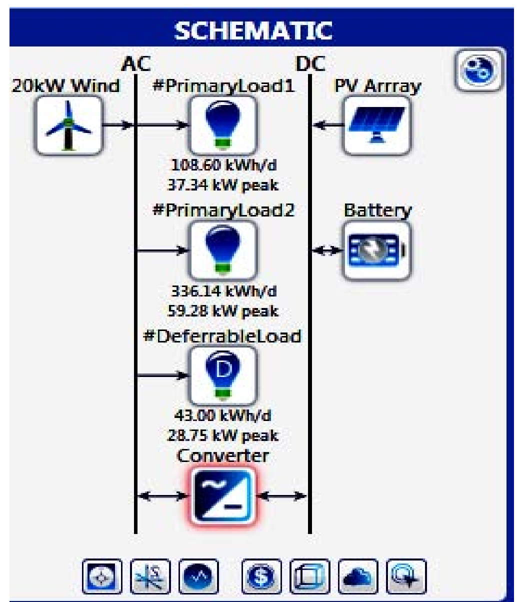


Fig. 13: M3

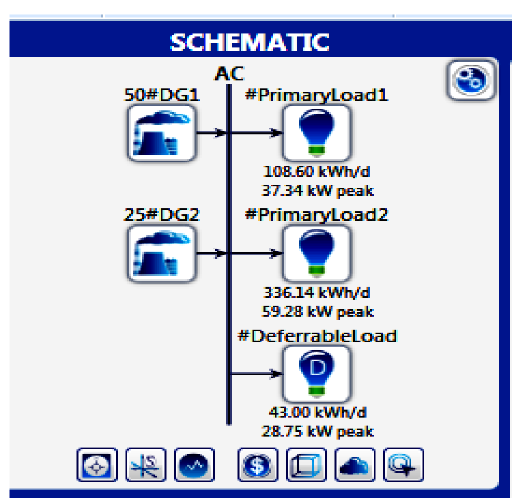


Fig. 14: M4

e) Economics, Constraints and Sensitivity Values

The Economics and the Constraints are the key parameters for the optimization, as well as the Energy Planning. From [7, 8], the nominal discount rate and the expected inflation rate set with the sensitivity values for the analysis. The other parameters also inputted in the Economics menu box of HOMER Pro as shown in Fig. 15. It is needed to change the System fixed capital cost, and System fixed O&M cost for the other models.

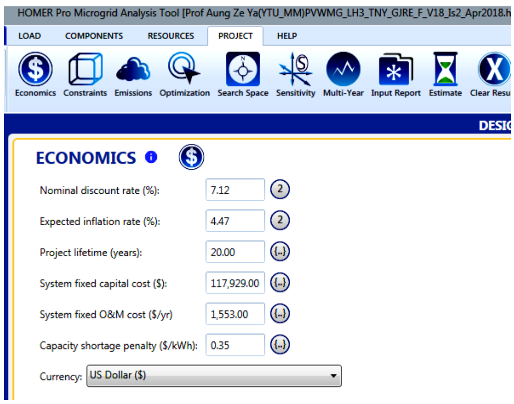


Fig.15: Economics Parameters of M3

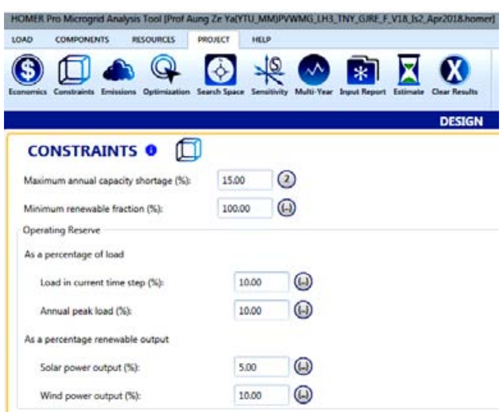


Fig.16: Constraints of M1 to M3

Fig. 16 explores the parameters of the Constraints of M1 to M3. Also, it required to the relevant change of the Constraints setting of the M4.

f) Inputs of Main Components

The parameters of the main components of the standalone PV Mini-grid modeled in HOMER Pro.

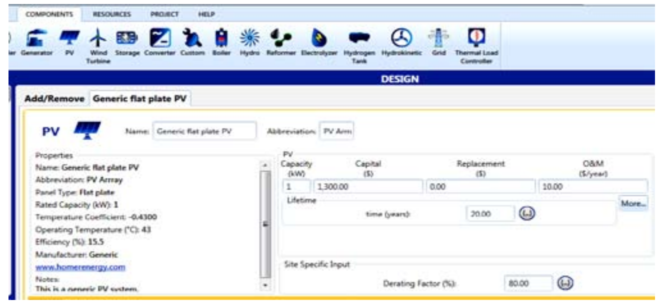


Fig.17: Inputs of PV System in HOMER Pro (M1 to M3)

The costs of PV for 1 kW are: Capital cost 1300 $; Replacement cost 0 $; Operation and maintenance cost 10 S/year, and lifetime 20 years. The advanced input is the ground reflectance 20%, and the array (panel) slope is 20.92°. Temperature inputs also set with PV Array temperature coefficient (%/°C) -0.43, and PV Array operating cell temperatures 43; and efficiency of the standard test condition is 15.5% as reflected in Fig. 17. The battery inputs for 1 kWh are: Capital cost 360 $; Replacement cost 300 $; Operation and maintenance cost 20 S/year; lifetime ten years. The converter inputs are: for 1 kW are: Capital cost 500 $; Replacement cost 450 $; Operation and maintenance cost 10 S/year and lifetime fifteen years. The costs of 20 kW Wind Generator is: Capital cost 14500 $; Replacement cost 0 $; Operation and maintenance cost 400 S/year, and the lifetime 20 years. It can easily imagine that the input components of Renewables are high-quality products due to their high costs.

For Diesel Mini-Grid (Model4, M4), 50 kW Diesel Generator costs are: Capital cost 10000 $; Replacement cost 8000 $; Operation and maintenance cost 1.5 $ per hour; and the lifetime 15000 hours as shown in Fig.18. The Diesel fuel price inputted 0.62 and 0.72 $/L. 25 kW Diesel Generator costs are: Capital cost 4500$; Replacement cost 4000 $; Operation and maintenance cost 0.75 $ per hour; and the lifetime 15000 hours.

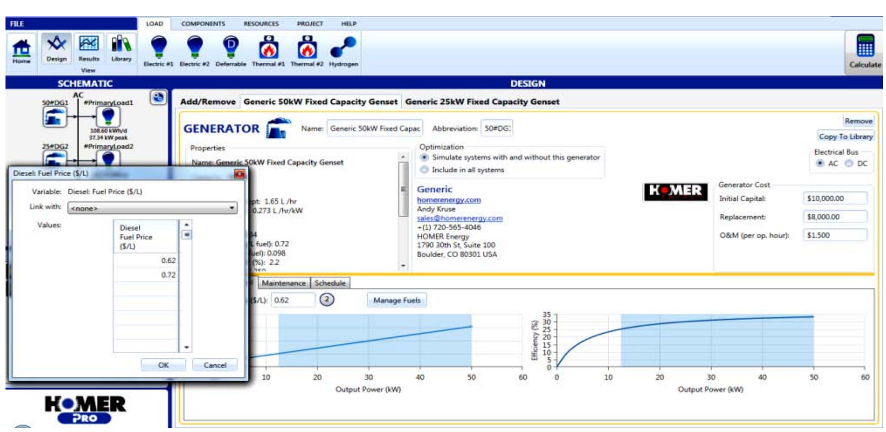
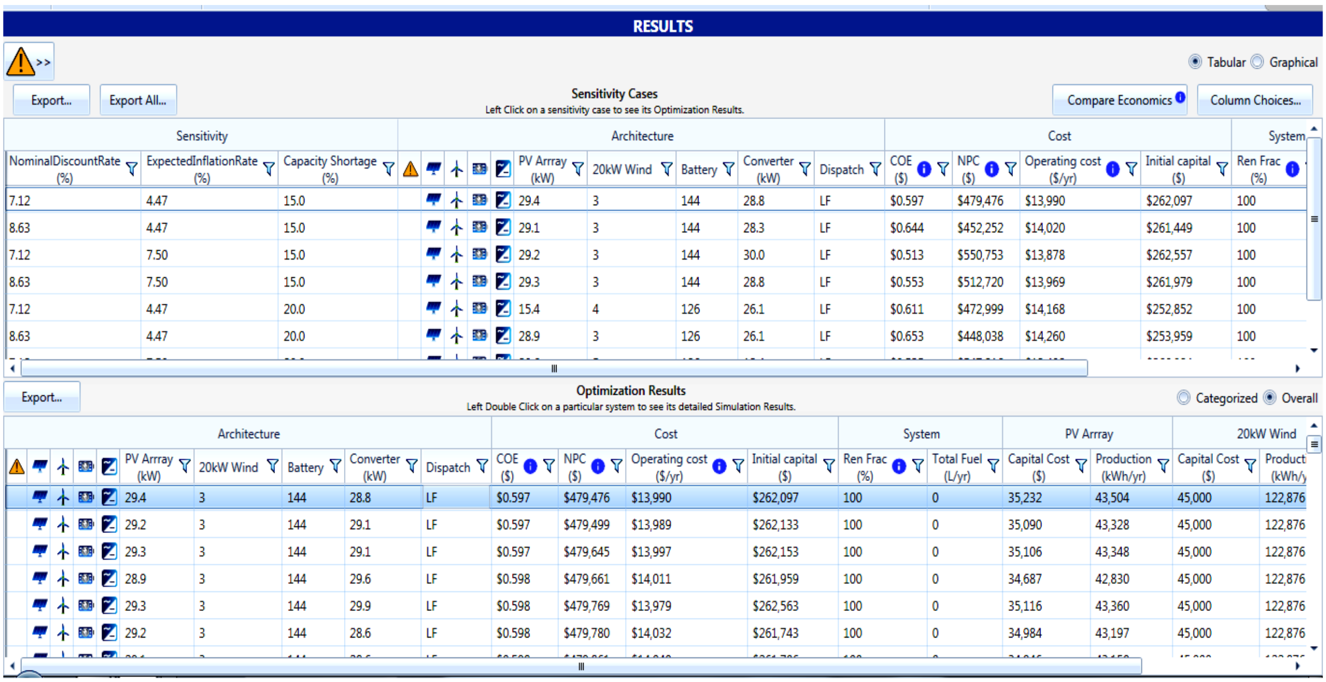


Fig.18: Inputs of Diesel Generator1 (50 kW of Diesel Mini-Grid, M4)

III. Results and Discussions

The thousands of Techno-Economic designs simulated for the four Models in HOMER Pro. Then, the optimum designs calculated with the Tabular results of two: the upper portion is the Sensitivity Cases and the lower portion is the Optimization Results as reflected in Figs. 19 to 22. The displayed results are listed for the models from the top to bottom of the optimistic to the least cost-effective options [24]. M1 to M3 connected with the different demands. Hence, the different capacities of the Architecture, the costs, system and other respective results predicted. The outcomes of M4 (the same demands as M3 with the different type of generation) reflected its consequent negative impacts.



RESULTS

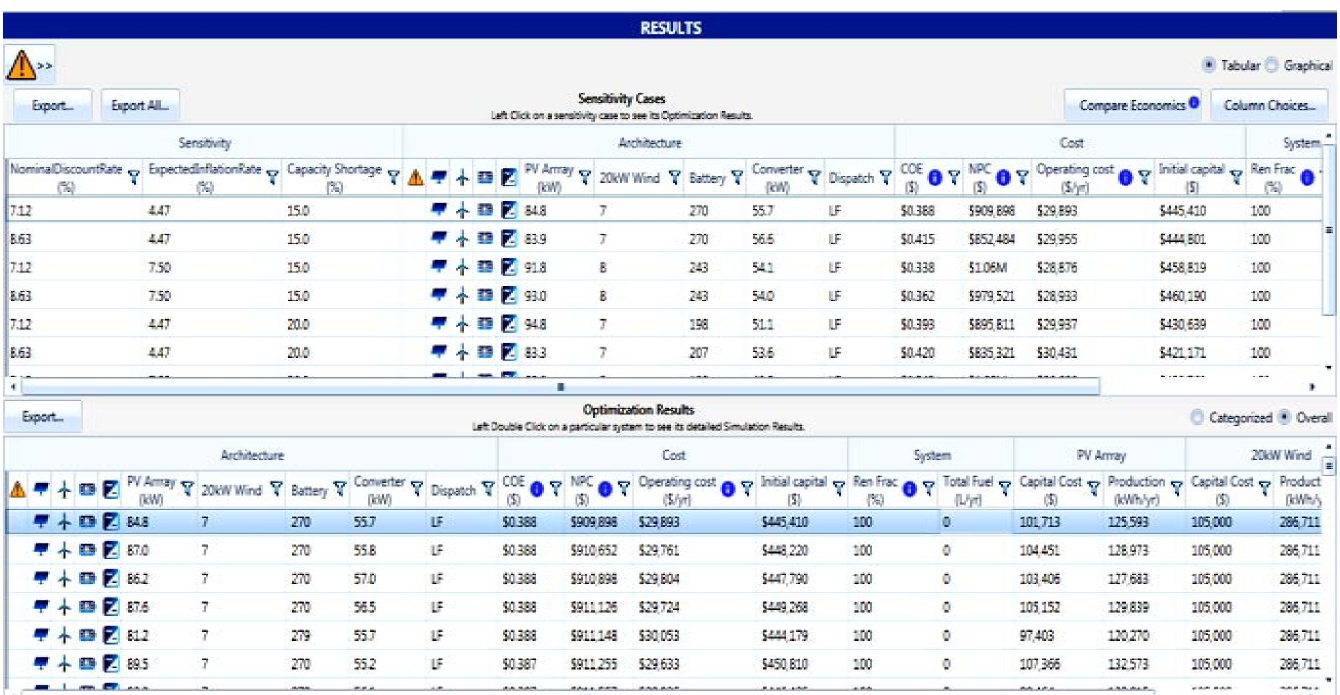
Sensitivity Cases
Left Click on a sensitivity case to see its Optimization Results.

NominalDiscountRate (%)	ExpectedInflationRate (%)	Capacity Shortage (%)	PV Array (kW)	20kW Wind	Battery	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
7.12	4.47	15.0	29.4	3	144	28.8	LF	$0.597	$479,476	$13,990	$262,097	100
8.63	4.47	15.0	29.1	3	144	28.3	LF	$0.644	$452,252	$14,020	$261,449	100
7.12	7.50	15.0	29.2	3	144	30.0	LF	$0.513	$550,753	$13,878	$262,557	100
8.63	7.50	15.0	29.3	3	144	28.8	LF	$0.553	$512,720	$13,969	$261,979	100
7.12	4.47	20.0	15.4	4	126	26.1	LF	$0.611	$472,999	$14,168	$252,852	100
8.63	4.47	20.0	28.9	3	126	26.1	LF	$0.653	$448,038	$14,260	$253,959	100

Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

PV Array (kW)	20kW Wind	Battery	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	PV Capital Cost ($)	PV Production (kWh/yr)	20kW Wind Capital Cost ($)	20kW Wind Product (kWh/y
29.4	3	144	28.8	LF	$0.597	$479,476	$13,990	$262,097	100	0	35,232	43,504	45,000	122,876
29.2	3	144	29.1	LF	$0.597	$479,499	$13,989	$262,133	100	0	35,090	43,328	45,000	122,876
29.3	3	144	29.1	LF	$0.597	$479,645	$13,997	$262,153	100	0	35,106	43,348	45,000	122,876
28.9	3	144	29.6	LF	$0.598	$479,661	$14,011	$261,959	100	0	34,687	42,830	45,000	122,876
29.3	3	144	29.9	LF	$0.598	$479,769	$13,979	$262,563	100	0	35,116	43,360	45,000	122,876
29.2	3	144	28.6	LF	$0.598	$479,780	$14,032	$261,743	100	0	34,984	43,197	45,000	122,876

Fig.19: Simulative Tabular Results of M1 in HOMER Pro



RESULTS

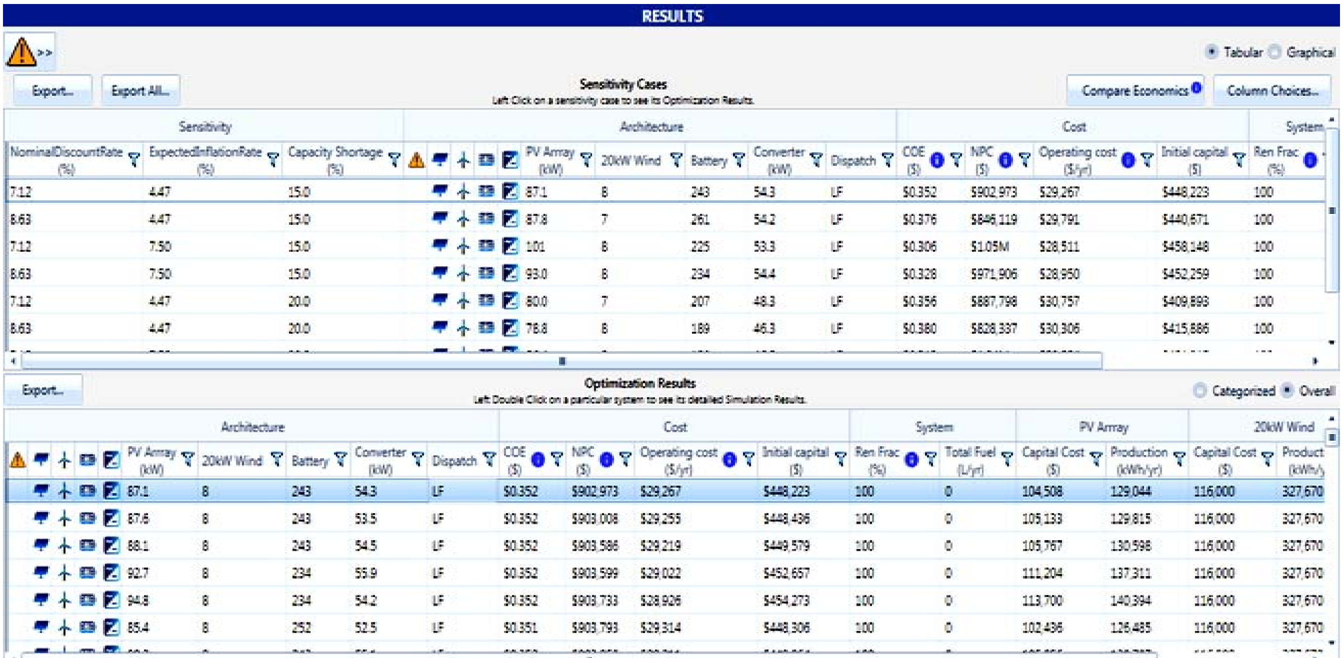
Sensitivity Cases
Left Click on a sensitivity case to see its Optimization Results.

NominalDiscountRate (%)	ExpectedInflationRate (%)	Capacity Shortage (%)	PV Array (kW)	20kW Wind	Battery	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
7.12	4.47	15.0	84.8	7	270	55.7	LF	$0.388	$909,898	$29,893	$445,410	100
8.63	4.47	15.0	83.9	7	270	56.6	LF	$0.415	$852,484	$29,955	$444,801	100
7.12	7.50	15.0	91.8	8	243	54.1	LF	$0.338	$1.06M	$28,876	$458,819	100
8.63	7.50	15.0	93.0	8	243	54.0	LF	$0.362	$979,521	$28,933	$460,190	100
7.12	4.47	20.0	94.8	7	198	51.1	LF	$0.393	$895,811	$29,937	$430,639	100
8.63	4.47	20.0	83.3	7	207	53.6	LF	$0.420	$835,321	$30,431	$421,171	100

Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

PV Array (kW)	20kW Wind	Battery	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	PV Capital Cost ($)	PV Production (kWh/yr)	20kW Wind Capital Cost ($)	20kW Wind Product (kWh/y
84.8	7	270	55.7	LF	$0.388	$909,898	$29,893	$445,410	100	0	101,713	125,593	105,000	286,711
87.0	7	270	55.8	LF	$0.388	$910,652	$29,761	$448,220	100	0	104,451	128,973	105,000	286,711
86.2	7	270	57.0	LF	$0.388	$910,898	$29,804	$447,790	100	0	103,406	127,683	105,000	286,711
87.6	7	270	56.5	LF	$0.388	$911,126	$29,724	$449,268	100	0	105,152	129,839	105,000	286,711
81.2	7	279	55.7	LF	$0.388	$911,148	$30,053	$444,179	100	0	97,403	120,270	105,000	286,711
89.5	7	270	55.2	LF	$0.387	$911,255	$29,633	$450,810	100	0	107,366	132,573	105,000	286,711

Fig. 20: Simulative Tabular Results of M2 in HOMER Pro



RESULTS

Sensitivity Cases

Left Click on a sensitivity case to see its Optimization Results.

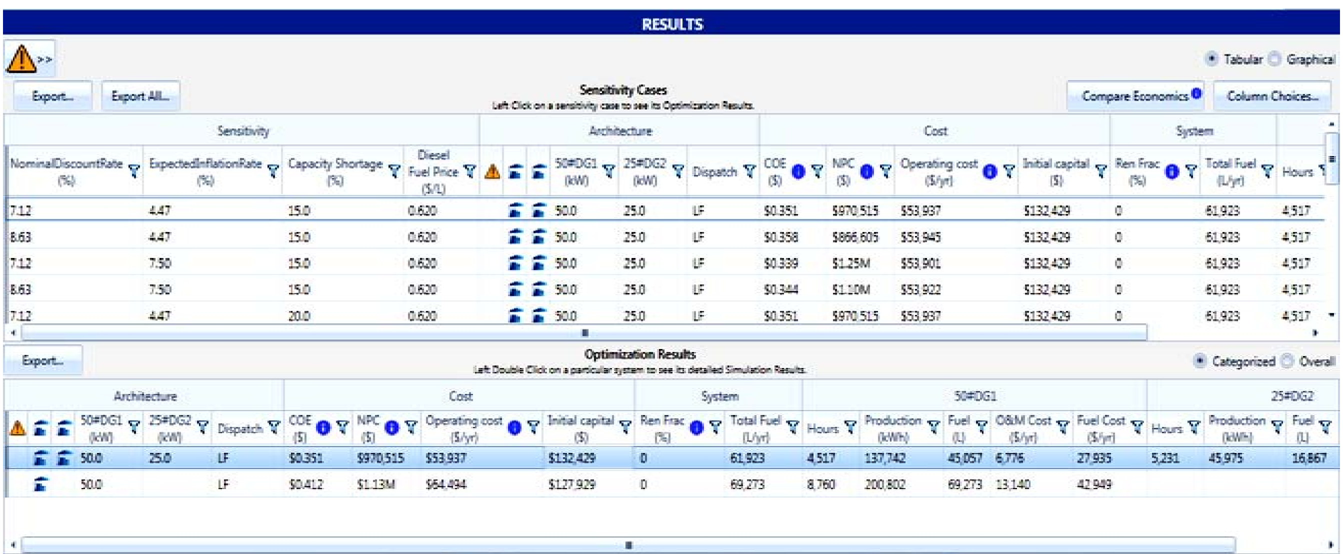
NominalDiscountRate (%)	ExpectedInflationRate (%)	Capacity Shortage (%)	PV Array (kW)	20kW Wind	Battery	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
7.12	4.47	15.0	87.1	8	243	54.3	LF	$0.352	$902,973	$29,267	$448,223	100
8.63	4.47	15.0	87.8	7	261	54.2	LF	$0.376	$846,119	$29,791	$440,671	100
7.12	7.50	15.0	101	8	225	53.3	LF	$0.306	$1.05M	$28,511	$458,148	100
8.63	7.50	15.0	93.0	8	234	54.4	LF	$0.328	$971,906	$28,950	$452,259	100
7.12	4.47	20.0	80.0	7	207	48.3	LF	$0.356	$887,798	$30,757	$409,893	100
8.63	4.47	20.0	78.8	8	189	46.3	LF	$0.380	$828,337	$30,306	$415,886	100

Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

PV Array (kW)	20kW Wind	Battery	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	PV Array Capital Cost ($)	PV Array Production (kWh/yr)	20kW Wind Capital Cost ($)	20kW Wind Product (kWh/y)
87.1	8	243	54.3	LF	$0.352	$902,973	$29,267	$448,223	100	0	104,508	129,044	116,000	327,670
87.6	8	243	53.5	LF	$0.352	$903,008	$29,255	$448,436	100	0	105,133	129,815	116,000	327,670
88.1	8	243	54.5	LF	$0.352	$903,586	$29,219	$449,579	100	0	105,767	130,598	116,000	327,670
92.7	8	234	55.9	LF	$0.352	$903,599	$29,022	$452,657	100	0	111,204	137,311	116,000	327,670
94.8	8	234	54.2	LF	$0.352	$903,733	$28,926	$454,273	100	0	113,700	140,394	116,000	327,670
85.4	8	252	52.5	LF	$0.351	$903,793	$29,314	$448,306	100	0	102,436	126,485	116,000	327,670

Fig. 21: Simulative Tabular Results of M3 in HOMER Pro



RESULTS

Sensitivity Cases

Left Click on a sensitivity case to see its Optimization Results.

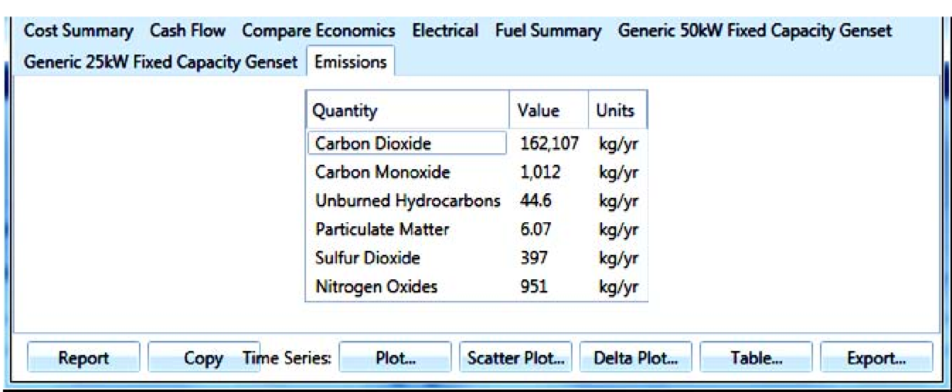
NominalDiscountRate (%)	ExpectedInflationRate (%)	Capacity Shortage (%)	Diesel Fuel Price ($/L)	50#DG1 (kW)	25#DG2 (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Hours
7.12	4.47	15.0	0.620	50.0	25.0	LF	$0.351	$970,515	$53,937	$132,429	0	61,923	4,517
8.63	4.47	15.0	0.620	50.0	25.0	LF	$0.358	$866,605	$53,945	$132,429	0	61,923	4,517
7.12	7.50	15.0	0.620	50.0	25.0	LF	$0.339	$1.25M	$53,901	$132,429	0	61,923	4,517
8.63	7.50	15.0	0.620	50.0	25.0	LF	$0.344	$1.10M	$53,922	$132,429	0	61,923	4,517
7.12	4.47	20.0	0.620	50.0	25.0	LF	$0.351	$970,515	$53,937	$132,429	0	61,923	4,517

Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

50#DG1 (kW)	25#DG2 (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	50#DG1 Hours	50#DG1 Production (kWh)	50#DG1 Fuel (L)	50#DG1 O&M Cost ($/yr)	50#DG1 Fuel Cost ($/yr)	25#DG2 Hours	25#DG2 Production (kWh)	25#DG2 Fuel (L)
50.0	25.0	LF	$0.351	$970,515	$53,937	$132,429	0	61,923	4,517	137,742	45,057	6,776	27,935	5,231	45,975	16,867
50.0		LF	$0.412	$1.13M	$64,494	$127,929	0	69,273	8,760	200,802	69,273	13,140	42,949			

Fig. 22: Simulative Tabular Results of M4 (Diesel Mini-Grid) in HOMER Pro



Cost Summary | Cash Flow | Compare Economics | Electrical | Fuel Summary | Generic 50kW Fixed Capacity Genset | Generic 25kW Fixed Capacity Genset | Emissions

Quantity	Value	Units
Carbon Dioxide	162,107	kg/yr
Carbon Monoxide	1,012	kg/yr
Unburned Hydrocarbons	44.6	kg/yr
Particulate Matter	6.07	kg/yr
Sulfur Dioxide	397	kg/yr
Nitrogen Oxides	951	kg/yr

Report | Copy | Time Series: | Plot... | Scatter Plot... | Delta Plot... | Table... | Export...

Fig. 23: Simulative GHG Emissions Results of M4 (Diesel Mini-Grid) in HOMER Pro

Table 4: Comparison of the Main Results of Four Models

Model	Design	Capacity	Annual Production/ Throughput (kWh/yr)	Cost of Energy ($)	Net Present Cost ($)	Operating Cost ($/ yr)	Initial Capital ($)	Diesel Fuel		
								(L/yr)	($/L)	($/yr)
M1	PV	29.4 kW	43504	0.597	479476	13990	262097	-	-	-
	Wind	60 kW	122876							
	Battery	144 kWh	19037							
	Converter	28.8 kW	-							
M2	PV	84.8 kW	125593	0.388	909898	29893	448220	-	-	-
	Wind	140 kW	286711							
	Battery	270 kWh	38361							
	Converter	55.7 kW	-							
M3	PV	87.1 kW	129044	0.352	902973	29267	448223	-	-	-
	Wind	160 kW	327670							
	Battery	243 kWh	34360							
	Converter	54.3 kW	-							
M4	DG1	50	137742	0.351	970515	53937	132429	45057	0.62	27935
									0.72	32441
	DG2	25	45975					16867	0.62	10457
									0.72	12144

The main results of four models mentioned in Table 4. M3 can supply all demands with the lowest cost of energy (COE) among three Models of PV-Wind-Battery Hybrid. Also, it observed that COE of M3 and M4 are not much differed. Fig. 23 mentioned the evident Emissions, the six pollutants from M4. There are no Diesel fuel consumptions, Diesel fuel costs, and no impacts (zero GHG Emission) by M3. Thus, M3 is selected as the proposed system of this research. Figs. 24 to 33 revealed the graphical results of M3.

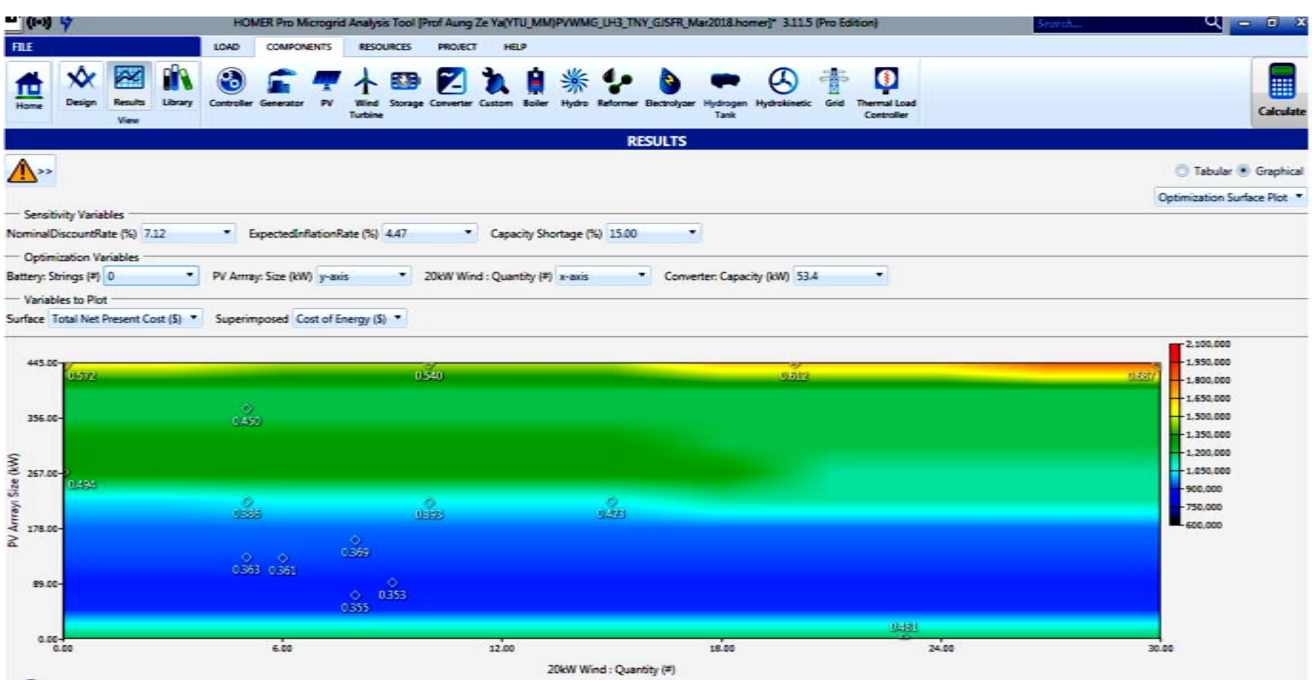


Fig. 24: Simulative Results: Optimization Surface Plot of PV Array vs. Wind with Variables: Total NPC and COE

In Fig.25, the less portion of yellow color around the middle of year (during rainy season) reflects the decrement of PV power output. In Fig. 26, the large portions of the red and yellow colors represent the large Wind power outputs near the middle and end of the year. Its blue color shows the less Wind power outputs.

It is clear that Wind power can compensate the period of less PV generation. PV can also support the large generation when Wind power decreases in the hot season. By implementing the PV or Wind only Mini-Grid at the focused village Lel Hpet, these advantages from PV-Wind Hybrid cannot be achieved.

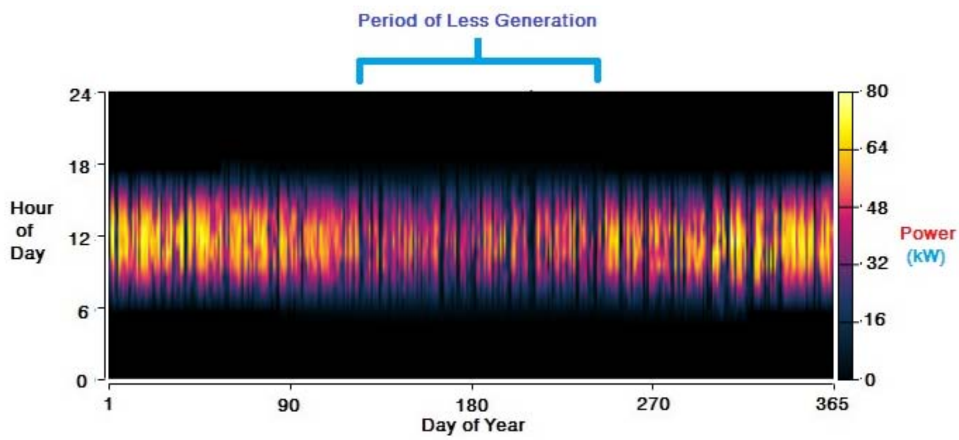


Fig. 25: Simulative Results: PV Power Output of Proposed Zero-Emission, PV-Wind-Battery Hybrid

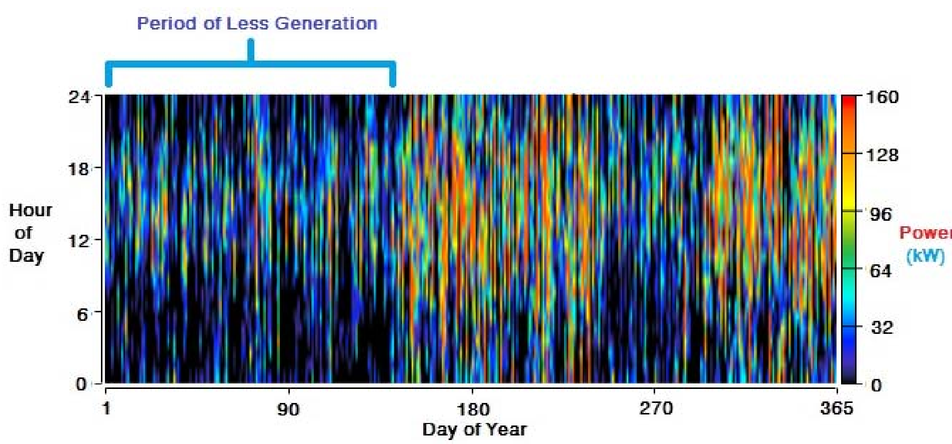


Fig. 26: Simulative Results: Wind Turbine Power Output of Proposed Zero-Emission, PV-Wind-Battery Hybrid

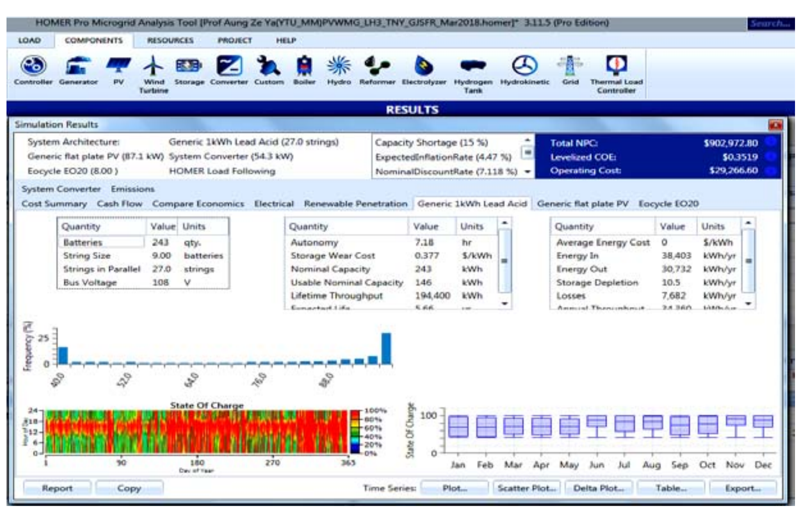


Fig. 27: Simulative Results: Storage Battery System of Proposed Zero-Emission, PV-Wind-Battery Hybrid

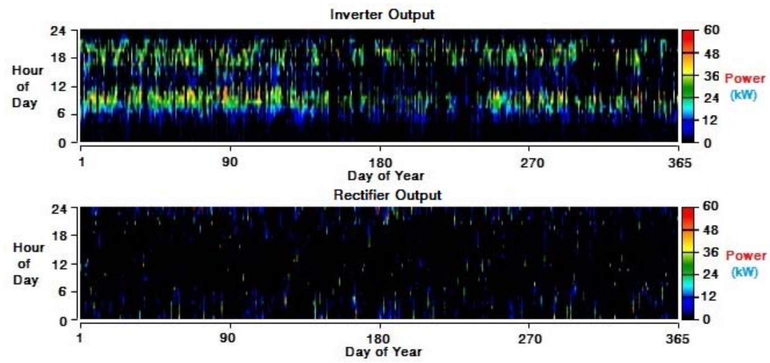


Fig. 28: HOMER Pro Simulative Results: Converter of Proposed Zero-Emission, PV-Wind-Battery Hybrid

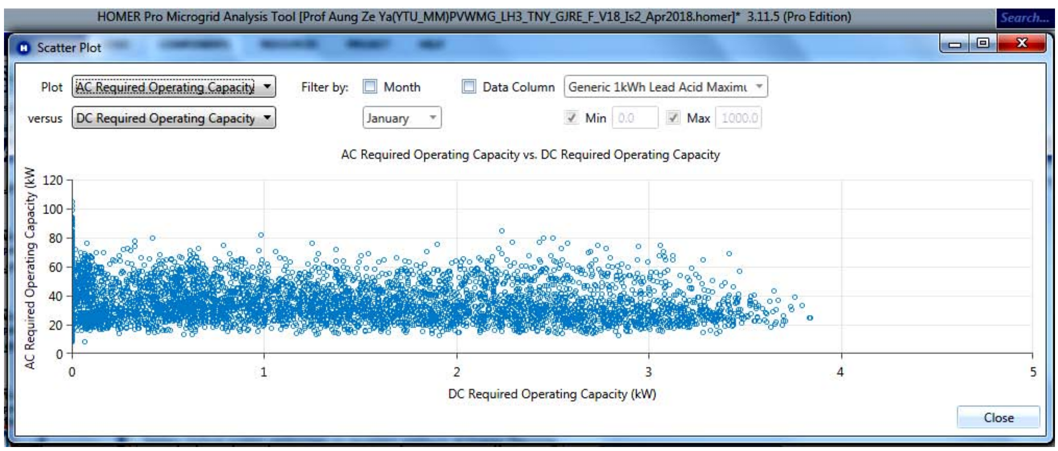


Fig. 29: Simulative Results: Scatter Plot of AC Required Operating Capacity vs. DC Required Operating Capacity

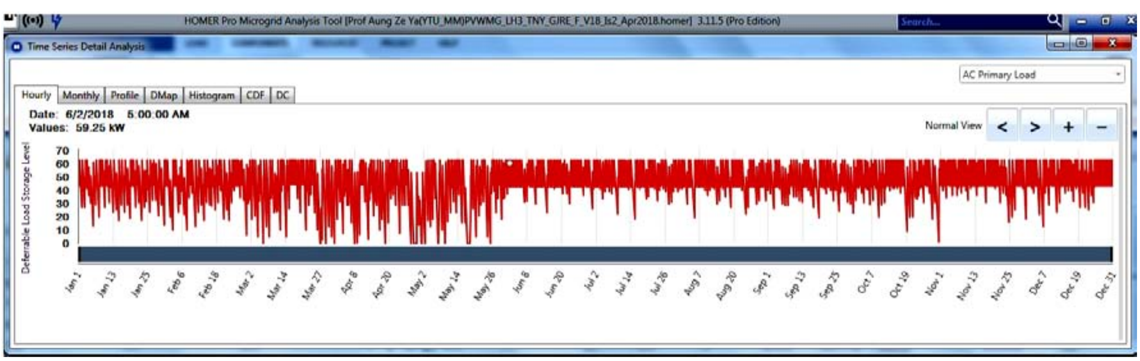


Fig. 30: HOMER Pro Simulative Results: Time Series Detail Analysis of the Deferrable Load Storage Level

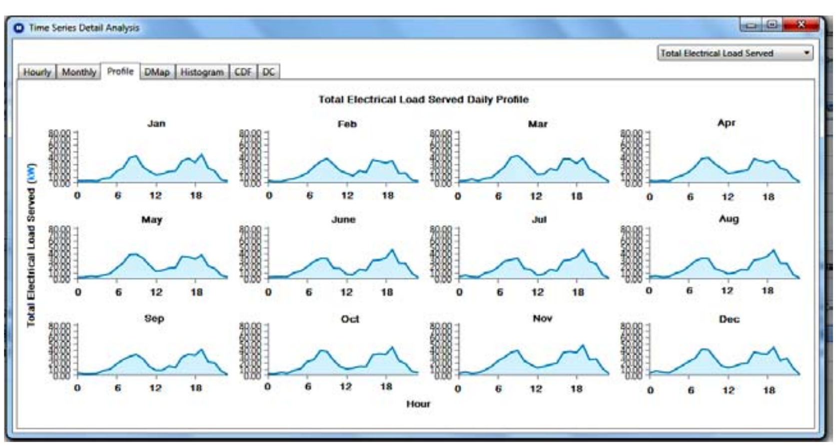


Fig. 31: HOMER Pro Simulative Results: Time Series Detail Analysis of the Total Electrical Load Served Daily Profile

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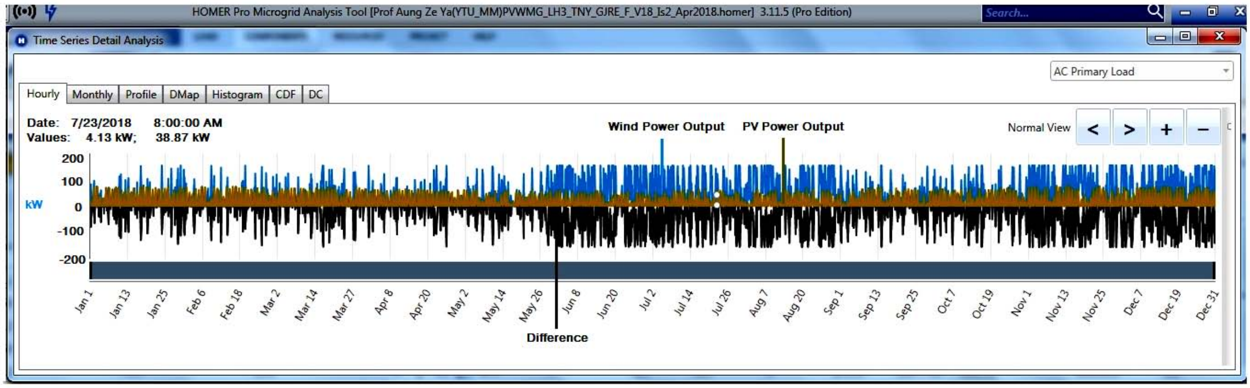

Fig. 32: Simulative Results: Time Series Detail Analysis of the Difference: Wind Power vs. PV Power Output

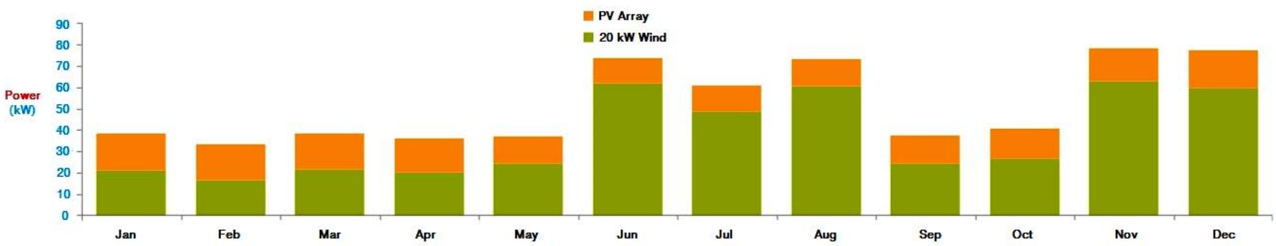

Fig. 33: Simulative Results: Monthly Average Generation of Proposed Zero-Emission, PV-Wind-Battery Hybrid

IV. Conclusions

The Off-Grid option is included in Myanmar's 2030 NEP (National Electrification Planning towards Universal Access). The Off-Grid Rural Electrification rate is about 36% by the end of 2017 [12]. It is in dire need to promote for the development of the whole country. This work contributes in that Mission as well as the priority of the conservation of Coastal Eco-System. Also, it is in line with the Goal 7 of the world's 2030 Agenda: 17 SDGs (Sustainable Development Goals) [25, 26].

Three HOMER Pro Models of PV-Wind-Battery Hybrid Mini-Grids with different demands compared and the lowest COE resulted from the Model with the largest capacities of main components. This recommends the capacity of Off-Grid Mini-Grid should be large from the economical point of view. The defined problems can be solved by the implementation of the proposed one. It can fulfill the villagers' dreams of the sufficient Electricity to the village Lel Hpet with 24-hour supply and improve their Socio-Economic Development.

The capacities of the proposed Model (M3) are: PV 87.1 kW (annual generation 129044 kWh/yr), Wind 160 kW (annual generation 327669 kWh/yr), Battery 243 kWh, and the converter 54.3 kW. In annual generation-mix, Wind shares 71.7% and PV shares 28.3%. Thus, it proved Wind power is more beneficial than PV power in Tanintharyi Coast, Southern Myanmar. 27 battery strings (9 batteries per string) are connected in parallel and the Bus voltage is 108 V. The battery capacities are: Energy Input 38403 kWh/yr, Energy Output 30732 kWh/yr, Annual Throughput 34360 kWh/yr, Lifetime Throughput 194400 kWh/yr, and Expected Life 5.66 years. The financial parameters of M3 are: Net Present Cost 902973 $, COE 0.352 $, Operating Cost 29267 $, and Initial Cost 448223 $. The obvious savings by M3 are: the Diesel fuel consumption 61924 L/yr, the Diesel fuel cost; 38392 S/yr (for fuel price 0.62 $/L) and 44585 $/yr (for fuel price 0.72 $/L). In addition, the evident reductions of GHG Emissions are: Carbon Dioxide 162107 kg/yr, Carbon Monoxide 1012 kg/yr, Unburned Hydrocarbons 44.6 kg/yr, Particular Matter 6.07 kg/yr, Sulfur Dioxide 397 kg/yr, and Nitrogen Oxides 951 kg/yr.

There is no doubt that this research work is instrumental for the strategic planning of standalone PV-Wind-Battery Hybrid Mini-Grid by applying Global Standard tool, HOMER Pro. This article obviously highlighted Sustainability benefits can be gained from Zero-Emission, 100 % Renewable Energy System at Off-Grid village that has abundant PV and Wind potentials.

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