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Sustainable Hybrid Distributed Energy System: A case study at Thingan, Makwanpur, Nepal

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Abstract
In rural areas where there is no national grid connection, renewable hybrid system may be a good solution for providing electrical energy. The sustainable development is possible only when there is good facility of electricity. This report proposed a sustainable hybrid system for the rural area, Thingan, Nepal. In order to have persistence, HOMER software is used for determining the optimized solutions. The best solution of optimized solution is obtained by using different dimensions and criteria for making the system sustainable. The different criteria used are technical, economic, environmental and social. Since different criteria are involved Multi-criteria Decision Analysis (MCDA) method is used for decision analysis. The obtained result indicates that the model with micro hydro, solar PV, wind turbine and battery system is more sustainable for Thingan. Sustainability is determined by reducing the cost, environmental hazards and increasing the social benefits, efficiency and reliability of the system.

Keywords
hybrid, HOMER, sustainable, energy

1. Introduction

In developing countries, it is difficult to maintain clean and sustainable energy and make it accessible to people [1]. Developing countries are still facing problems of electricity. The difficult topography, low population density and severe climatic conditions are the major problems of rural electrification [2]. So, the grid connection in every part of the country is not possible. In those regions, hybrid distribution generation system may be helpful for electrification. Distributed generation using renewable energy resources provides clean and abundant energy. When two or more energy resources are combined, they form a hybrid energy system. The main advantage of hybrid energy system is that the combination of different energy system may tribute the drawbacks of each individual energy resources and also increases the reliability of the power generation.

The main source of energy in Nepal is hydropower and it is contributing about 95% of the total installed capacity. Most of the hydro power plants are run-of-river type. Solar energy can be one of the best alternatives source of energy in rural areas as it is available almost every day. The average solar radiation in Nepal fluctuates from 3.6 to 6.2 kWh/m^2 per day and about 300 days a year are sunshine [3]. The wind potential in Nepal is viable in high and middle mountains of the country [4]. Alternative Energy Promotion Center (AEPC) has been developing hybrid energy system for rural electrification in Nepal.

The site selected for this research is a trihybrid system of solar PV, wind and micro hydro which is located at Thingan, Makwanpur district (Latitude: 27°26’35.60”N; Longitude: 85°14’42.20”E, WGS84, 1354 m ASL), Nepal.
Sustainability means an equitable distribution of limited resources and opportunities in context of economy, society, and environment [5]. For sustainability of any systems, appropriate assessment of the system should be done along with proper monetization [6]. In this study, sustainability refers to a set of indicators such as technical, economic, environmental and social appearances of the system. These criteria along with their sub-criteria has been studied to determine the sustainability of the system. Table 1 shows the normalized values of different

criteria and their respective global weight [6].

Table 1: Sustainability indicators with their respective normalized value and global weight [6]

Criteria	Sub-Criteria	Local Weight			Global Weight
		MHP	PV	Wind	
Technical	Energy Availability	0.333	0.156	0.25	0.085
	Efficiency	1	0.127	0.364	0.074
	Reliability	0.333	0	0.083	0.148
Economical	Capital Investment	0.731	0.238	0.753	0.141
	O & M Cost	0.922	0.482	0.623	0.112
Environmental	GHG Emission	0.936	0.893	0.975	0.09
	Land Used	0.813	0.819	0	0.087
Social / Ethical	Social Acceptability	1	0.5	0.5	0.073
	Job Creation	0.25	0.15	0.11	0.09
	End-use Benefits	0.125	0.625	0.625	0.094

For choosing optimal resources to evaluate sustainability of a system using various factors, Multi-criteria decision analysis (MCDA) method is used so that the ranking of different feasible hybrid system can be performed. MCDA also have various methods and among them Weighted sum method (WSM) has been used [7]. For sustainable energy system Weighted sum method (WSM) is most commonly used approach.

2. Methodology

Figure 1 illustrates the methods adapted for carrying out this research work.

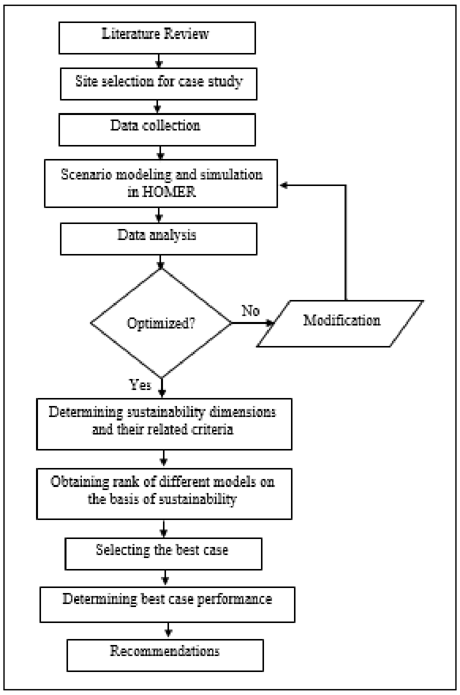

Figure 1: Flow chart of Research methodology

3. Data Source

3.1 Load Profile

A total of 173 houses were connected by the hybrid system with total population of 1700 in 2012 AD. Every house is accessible with 3 LED bulbs of 8 W each and a mobile charging point were provided [8]. Figure 2 shows the load profile of the village. It shows that peak consumption of electricity is found to be at 6 AM morning and at 7 PM evening and between 12 AM to 4 AM there is no consumption of electricity.

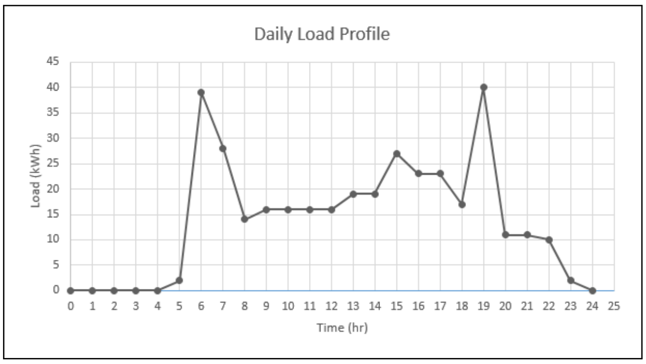

Figure 2: Daily Load Profile

3.2 Solar Potential Assessment

The use of HOMER software depends on the monthly average solar radiation data. The data was extracted from online data of NASA Surface Meteorology. Figure 3 shows the monthly average solar global horizontal irradiation of Thingan village. This shows that the annual average radiation is 4.82 kWh/m^2 per day.

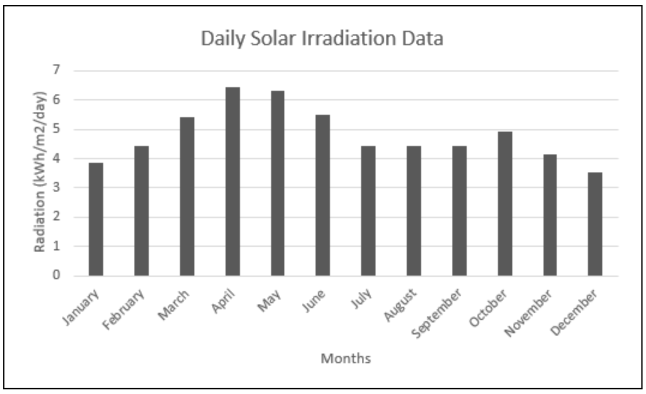

Figure 3: Monthly Solar Irradiation

3.3 Wind Potential Assessment

The input data for monthly average wind speed was retrieved from NASA Prediction of Worldwide Energy Resource (POWER) database. Figure 4 shows the monthly average wind speed. The annual average wind speed was estimated to be 3.2 m/s with the anemometer height of 10 m.

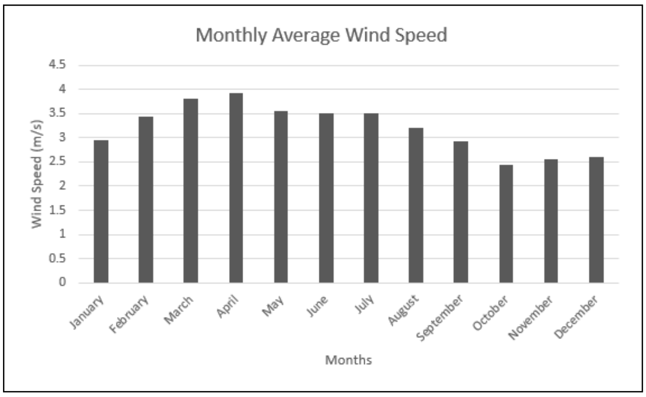

Figure 4: Monthly Average Wind Speed

3.4 Hydro Potential Assessment

The operation of hydro system of this place is based on run-off-river type with flow rate of 27 liters per second and net head of 120 m. HOMER takes an input of monthly average stream flow data and calculates actual flow accessible for the turbine. Figure 5 shows the monthly average flow rate. Here, the annual average flow was determined to be 32.8 l/s.

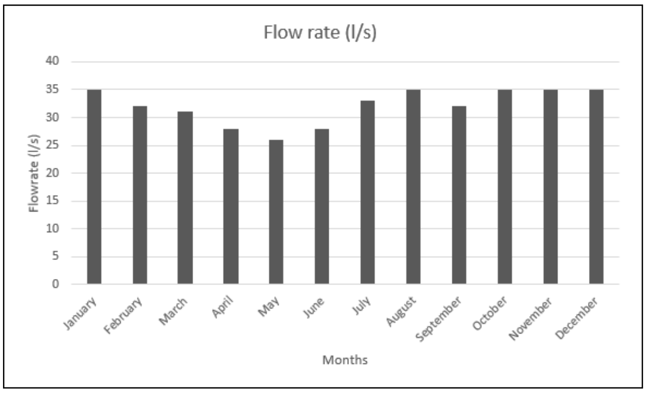

Figure 5: Average Flowrate (l/s)

4. HOMER Model

HOMER can provide many possible results from the simulation and it provides most feasible system regarding net present value. The hybrid system model consists of a micro hydro, wind turbines, solar PV modules, battery banks and converters. PV modules and batteries are connected in DC bus bar while hydro-power plant and wind turbines are connected in AC bus. The average power consumption was found to be 165 kWh per day with peak demand of 31.3 kW. The AC bus was set to 220V and DC bus bar was set to 24V. Figure 6 shows the hybrid model generated by HOMER software.

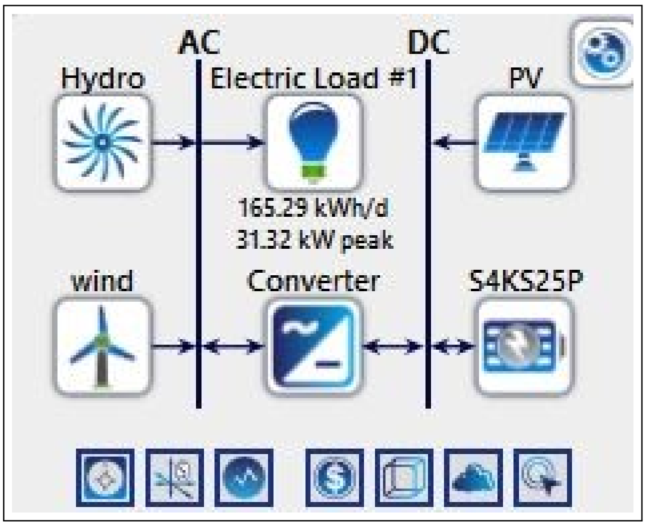

Figure 6: Hybrid model developed in HOMER

Table 2 shows the data input to HOMER. The cost of different components was collected from different distributers and also from research articles related to this topic.

Table 2: Inputs to HOMER Software

	PV	MHP	Wind	Battery	Converter
S	1	20	1	1.89 Ah	
C	1000	42000	1300	300	145
R	1000	42000	1300	300	145
O&M	5	750	50	10	0
L	20	20	20	5	5

S: Size
C: Capital Cost (in $)
R: Replacement Cost (in $)
O & M: Operation and Maintenance Cost (in $)
L: Liftime (in years)

Other additional inputs are the panel type for PV module which is flat plate type. The pipe head loss is considered 15% with minimum flow rate of 50%, maximum flow rate of 150% and efficiency of 80%. The Hub height of 10 m is used for wind turbine. The nominal voltage of 4 V with string size of 6 is used for battery.

5. Results

The simulation conducted in HOMER provided 3998 solutions where 2390 were feasible solutions and 1608 solutions were infeasible due to the capacity storage constraint. Among all those solutions, only 6 solutions were considered as categorized solutions. The categorized solutions have been illustrated in Table 3.

Table 3: Categorized solutions provided by HOMER

M	PV	W	Batt.	MHP	Conv.	NPC	COE
1			6	25.4275	5.0459	66053.8	0.08473
2	0.0206		6	25.4275	5.1846	66146.09	0.08484
3		1	6	25.4275	5.1037	68212.7	0.08749
4	0.3904	1	6	25.4275	5.1570	68706.28	0.08812
5	93.4098		114		34.7864	247234.5	0.31719
6	78.8046	1	132		34.4505	250477.6	0.32134

M: Model
PV: PV Module (in kW)
W: Wind Turbine (nos.)
Batt.: Battery (nos.)
MHP: Micro-Hydro Plant (kW)
Conv.: Converter (kW)
NPC: Net Present Cost (in $)
COE: Cost of Energy (in $)

5.1 Sustainability Analysis

For sustainability analysis, the feasible models were compared on the basis of sustainability indicators. In this study, only technical, economic, environmental and social indicators are analyzed. Weighted sum method of Multi-Criteria Decision Analysis (MCDA) has been applied for decision-making. For this, the average sumproduct of capacity and local normalized weight was determined. And then the global weight was determined.

Table 4: Sustainability index calculation

Model	1	2	3	4	5	6
Technical						
EA	0.32	0.31	0.3	0.29	0.15	0.15
Efficiency	1	1	0.98	0.96	0.13	0.13
Reliability	0.33	0.33	0.32	0.32	0	0
Global	0.09	0.09	0.09	0.09	0.08	0.08
Economic						
Capital	0.73	0.73	0.73	0.73	0.24	0.24
O & M	0.92	0.92	0.91	0.9	0.48	0.48
Global	0.13	0.13	0.13	0.13	0.12	0.12
Environmental						
GHG	0.94	0.94	0.94	0.94	0.89	0.89
Land Used	0.81	0.81	0.78	0.78	0.82	0.81
Global	0.09	0.09	0.09	0.09	0.09	0.09
Social/Ethical						
Acceptance	1	1	0.98	0.97	0.5	0.5
Job	0.25	0.25	0.25	0.24	0.15	0.15
Benefit	0.13	0.13	0.14	0.15	0.63	0.63
Global	0.08	0.08	0.08	0.08	0.09	0.09

Then the rank of different models on the basis of sustainability parameters was determined by calculating the total weight percentage of different criteria.

Table 5: Rank of different models

M	Tech.	Eco.	Env.	Soc.	Total	Rank
1	3.9774	5.4537	3.8946	3.4396	16.7653	4
2	3.9792	5.4536	3.8946	3.4399	16.7673	3
3	3.9779	5.4579	3.8963	3.4497	16.7818	2
4	3.9782	5.4569	3.8963	3.4538	16.7852	1
5	3.4918	5.3122	3.8922	3.7471	16.4433	6
6	3.4987	5.3187	3.8928	3.747	16.4572	5

This shows that model 4 which consists of 25.4 kW micro hydro, 0.4 kW PV system, a wind turbine, 6 numbers of batteries and 5.157 kW converter is more sustainable and model 5 is less sustainable.

Table 6: Per year production and consumption of electrical energy by model 4

Production	kWh/yr	%
Generic flat PV	608	0.269
Wind	221	0.098
Hydro	224979	99.6
Total	**225808**	**100**

Consumption	60313 kWh/yr
Excess Electricity	165419 kWh/yr
Unmet Electric Load	16.9 kWh/yr

The total electricity production by using model 4 is found to be 225,809 kWh/yr and the total electricity consumption by the village is 60,313 kWh/yr which shows that the excess electricity is 165,419 kWh/yr. The unmet electric load was 16.9 kWh/yr appeared due to the peak load condition. And the per unit cost of electricity is found to be $0.08812.

6. Result Validation

Table 7 shows the Levelized Cost of Energy(LCOE) for various sources of electricity.

Table 7: Levelized Cost of Energy (LCOE) [9]

Energy Plant Type	Cost ($/MWh)	Cost ($/kWh)
Offshore Wind	130.4	0.1304
PV SOLAR	60	0.06
Land-based Wind	55.9	0.0559
Hydro-electric	39.1	0.0391

It was developed by the US Energy Information Administration (EIA) in February, 2019. It shows that hydro-electricity is the cheapest source of energy. In this study also the model with micro-hydro was found to be the cheapest source but after doing the sustainability calculation the model with micro-hydro, solar and wind along with the battery system was found to be the cheapest as well as most sustainable model with per unit cost of electricity of $0.08812. This cost of electricity is little different due technological gap.

7. Conclusion and Recommendations

A good energy planning may help in sustainable development of any area. So to provide electrical energy in rural areas, hybrid system can be used. A study of tri-hybrid system located at Thingan village installed by Nepal Solar Volunteer Corps (NSVC) was carried out and different criteria and sub-criteria were studied to make the system sustainable. Based on the result achieved in this study, the hybrid system with solar PV, micro-hydro, wind turbine and battery bank was found to be more sustainable with cost of electricity (COE) $0.08812 per kWh (unit). This system is different from the installed system. In present scenario, consumers of Thingan are paying Rs 100 per month per house for the consumption of electricity as there is no electric meter provided to them. They are only using LED bulbs and mobile charging point as their load and only some of the houses has got television. The estimated consumption of electricity by each household is about 4 to 5 kWh (units) per month.

Electricity production per year from the optimized model is found higher than the electricity consumption per year so the end users can be increased in off-peak hours. Also, developing the local small and cottage industries such as dairy industry, poultry farming, different mills, etc. could help to increase the end user and uplift the economic status of the local residents. Also the employment opportunities could be increased.

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