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Assessment to Identify the Techno-economic and Sustainable Hybrid Energy Model for Remote Area of Nepal

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Abstract
Isolated Hybrid Energy Systems have been attracting to supply electricity to rural areas in most of the aspects such as economic, reliability, sustainability and environmental protections, especially for communities living far in the areas where grid extension is difficult. In this study a techno-economic ten hybrid model from different energy resources available at local area, is identified which can fulfill the dynamic demand of a community containing 136 households and a primary school at remote area i.e. Jumla Dangibada Village of Nepal. Scaled annual average load of 162 kWh/day with load factor of 0.171, average demand of 6.77 kW and peak demand of 39.4 kW was involved during optimization of the power system. The simulation and optimization was done based on the electricity load, climatic data sources, economics of the components and other parameters in which the net present cost has to be minimized to select an economic feasible power system. The cost of energy is found to be 0.199US$/kWh for techno-economic optimization result whereas energy cost for sustainable energy model is 0.364US$/kWh.

Keywords
Hybrid Energy Model – Cost of Energy – Sustainable Energy – HOMER

1. Introduction

To the date more than 550,000 people living in remote areas had been electrified with more than 307 micro hydro plants and 3,099 solar home systems in all over the country, and 12% of Nepalese people are electrifies through renewable energy sources [1]. Due to the difficulty of grid extension in each village of Nepal, the isolated energy system is the single solution to provide the electricity in the remote area. For remote area: Dangibada village, Jumla, Nepal lies in hilly region at $29^o16'33.41''$N and $81^o11'0.12''$E with an altitude of 2306 meters above sea level is selected as a case study area to analyze the system's performance and sustainability.

Sustainability and a sustainable system can be defined as the system, which enhances social, economic, financial, ecological, geographical and political well-being permanently. The global requirement for sustainable energy and sustainability will become increasingly important over the next fifty years as the environmental effects of fossil fuel use become apparent. As the emerging technologies of renewable energy source and its component become more cost-effective and attractive, a greater level of both small-scale and large scale deployment of these technologies will become evident.Technical, Economical, Environmental, Social/Ethical indicators are considered to measure sustainability of the energy system as shown in table 1. For this research, the global weight of sustainable indicator and their normalized values for different technology for developing country is used from thesis report [4] as shown in table 2 and table 3.Table 3 presents the normalized sustainable index values of technology wise energy indicator for sustainability. The indicator values near to one represents it is highly favorable for sustainability and near to zero is unfavorable for sustainability.

Even with of the high potential renewable energy resources in Nepal, 40% of the population still lives without access to electricity [5]. There is a challenge to provide the energy to the population because of mainly two reasons. First, the national electrical utility is unable to supply the current electrical demand of the

Table 1: Sustainability Indicators and Measurements [2], [3]

Criteria	Sub Criteria	Measurements
Technical	Energy Production Capacity	Ratio of the total produced energy to the total number of population (kWh per HH per year)
	Efficiency	Production and conversion efficiency in percentage (combined)
	Reliability	Ease of availability of cleaner technology (Yes/ No)
Economical	Capital Cost	Initial Investment Cost (USD)
	Operation and Maintenance Cost	O & M cost (USD)
	CO_2 Emission	Total Carbon production
Environmental	Land Requirement	Land used over the entire life of the system
Social/Ethical	Social Acceptability	Preference of public for the deployment of the technology
	Job Creation	Total number of employment created over the entire life of the system
	Social Benefits	Direct and indirect benefits received by the local people

Table 2: Computation of Global Weightage [4]

Criteria	Sub Criteria	Global Weight
Technical (G= 0.308)	Energy Production Capacity	0.085
	Efficiency	0.074
	Reliability	0.148
Economical (G= 0.254)	Initial Investment	0.141
	Operation and Maintenance Cost	0.112
Environmental (G= 0.180)	CO_2 Emission	0.091
	Land Requirement	0.087
Social/Ethical (G= 0.262)	Social Acceptability	0.073
	Job Creation	0.094
	Social Benefits	0.094

nation. Second, even if there is a possibility of sufficient power generation, construction and connection of grid system to each village is challenging due to the geographical, social, technical and financial factors [6] . In addition, some of the factors such as high system cost, poor reliability and power quality, low power factor, and problems in maintenance and monitoring occur in the connected system [7]. This research aims to identify techno-economic and sustainable isolated hybrid energy system suitable for remote area i.e. Dangibada Village, Jumla, Nepal.

2. Methodology

The model development and analysis for optimized models was performed by using HOMER software. HOMER is energy optimization software which optimize the available energy resources based on the bottom-up approaches. This software is used to optimize the energy system based on available resources in an area to fulfill the energy demand by providing different inputs like resources data, technical and economic information. After simulation the results were analyzed. Then the possible energy mix models are compared and analyzed based on their sustainability factors as well. The parameters that should be required in calculation and analysis are taken from literature review.

2.1 Multi-Criteria Decision Analysis for Sustainable Energy System

A multi-criteria decision making (MCDM) method is used to identify a set of appropriate sustainable energy technology and resource options for providing access to cleaner energy [8]. The multidimensional aspects of sustainability are technical, economic, social, environmental, and institutional. Each of these dimensions is captured through relevant indicators, including the following, to arrive at a composite index of sustainability for each option [3].

The Weighted Sum Method is the most commonly used

Table 3: Normalized values of Energy indicators in developing country, per type of technology [4]

Criteria	Sub Criteria	Micro Hydro	Solar PV	Wind	DG
Technical	Energy Production Capacity	0.333	0.156	0.25	1.000
	Efficiency	1.000	0.127	0.364	0.455
	Reliability	0.333	0.000	0.083	1.000
Economical	Initial Investment	0.731	0.238	0.753	1.000
	Operation and Maintenance Cost	0.922	0.482	0.623	0.584
Environmental	CO_2 Emission	0.936	0.893	0.975	0.000
	Land Requirement	0.813	0.819	0.000	0.320
Social/ Ethical	Social Acceptability	1.000	0.500	0.500	0.460
	Job Creation	0.250	0.150	0.110	0.075
	Social Benefits	0.125	0.625	0.625	0.000

approach, especially in single dimensional problems. If there are M alternatives and N criteria then the best alternative is the one that satisfies the following expression:

$$A^*_{WSM} = Max\Sigma_i^j a_{ij} w_j \text{ for i = 1, 2, 3, ... N}$$

Where A^*_{WSM} is the WSM score of the best alternative, N is the number of decision criteria, aij is the actual value of the i th alternative in terms of the j th criterion, and wj is the weight of importance of the j th criterion. The total value of each alternative is equal to the sum of products.

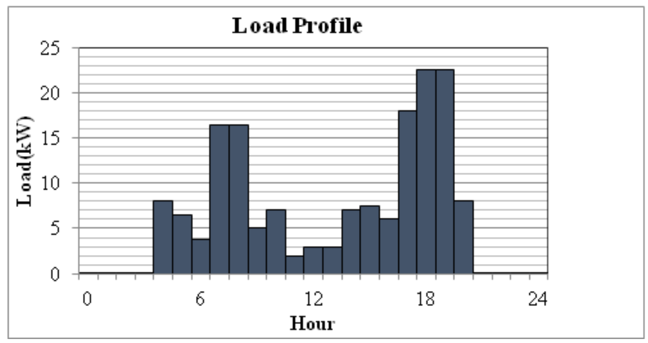

Figure 1: Load profile of different months [9]

2.2 Assumptions and Input Parameters

2.2.1 Electric Load

For the load profile of the case area, the electricity demand analysis based on the demand assessment survey was performed on each household at 2014 AD by the experts under the support of the AEPC [9]. Taking 2014 AD as base year, the demand pattern of the area is identified. The daily load profile of that area is given in figure 1. After assuming the day to day variability of 15% and time-step to time-step variability of 20%, the scaled annual average load is found to be 162 kWh/d with load factor of 0.171. The average demand and peak demand are measured to be 6.77 kW and 39.4 kW.

2.2.2 Solar PV

The solar radiation of the case area is taken from the online data of NASA Surface Meteorology and Solar Energy website [10] as shown in figure 2 that data is validate with report [11]. Using the data, the annual average for daily solar radiation of the region is found to be 5.230 kWh/m^2/d with average clearness index of 0.594.

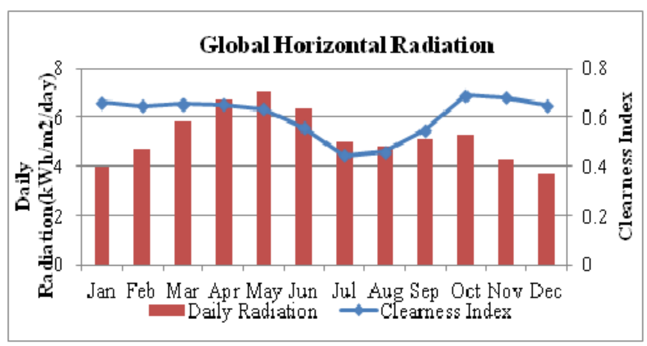

Figure 2: Global Horizontal Radiation [10]

2.2.3 Wind

Power density of wind less than or equal to 100 W/m^2 are not useful to generate the electricity. Only the wind having greater than 200 W/m^{2}of power density is used in isolated conditions to generate electricity, where as it was found to be 30 W/m^2 for the Case study area (Jumla district)[11]. For the wind speed profile of specific case study area, secondary data is used from the report and given in figure 3 [9]. Using the data scaled annual average speed of the case area is 4.62 m/s and the power density is found to be 30 W/m^2.

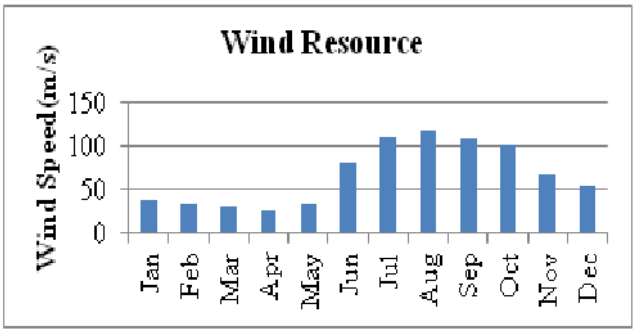

Figure 3: Seasonal Pattern of Wind Resource [9]

2.2.4 Micro Hydro power

The water flow discharge data required to generate electricity from micro hydro was taken from the report [9] as shown in figure 4. For the area, an annual flow rate of 67.3 L/s is considered in Q_{50} design, and a net head of 65 meters, with electrical power output of 38.6 kW. There is no residual flow with 50% minimum flow ratio and 150% maximum flow ratio. Similarly, the efficiency of micro hydro and pipe head loss are assumed to be 90% and 5%.

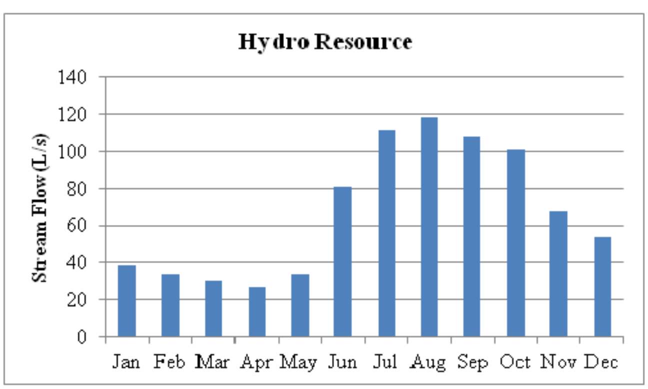

Figure 4: Seasonal pattern of Water Resource [9]

2.2.5 Diesel and Others

Availability of diesel depends on the transportation. So, DG set becomes a popular solution to generate the electricity in isolated conditions. So, to analyze the performance of different possible energy model, DG set is also considered. In this study, number of options for DG sets were given so that optimum model will be obtained. Similarly, a hybrid charge controller is used in between the AC and DC bus bars to exchange the power. The hybrid energy model has an option of multiple string having 6 batteries (Surrette 4KS25P) of nominal voltage 4V and nominal capacity 1,900 Ah (7.6 kWh). Annual real interest rate and project period are assumed to be 6% and 25 years. Table 4 presents the input parameters for this analysis. The component cost were taken from the web page of Alibaba Global Trader: Nepalese Suppliers. There may some cost variations (Maximum of 10%) based on the transportation cost and discount rate on bulk order.

3. Results and Discussion

The proposed hybrid model to utilize the energy resources and fulfill the dynamic demand of case study is shown in figure 5. Here, the model was considered so that maximum use of available resource can be utilized and the required load demand will be fulfilled. As shown in figure 5, it consists of an AC bus of voltage level 220 V and is fed from micro hydro power plant of 38.6 kW and a DG Set. Similarly, the DC bus of voltage level 24V DC was fed from solar PV system, wind turbine and battery bank. A converter is used between the DC and AC bus bar to exchange the power. The loads were connected to the AC bus. For this case study, the annual peak demand and energy demand were calculated to be 39 kW and 162 kWh/d as shown in figure 5. There may be number of hybrid energy models to meet the demand of case area. In this research,top ten optimized hybrid energy models are considered on the basis of local energy resources available as discussed in methodology section and diesel generator is considered for performance study at low load factor.

Table 4: Input values of cost Estimation [12], [13]

Component	Rating	Capital Cost (US$)	Replacement Cost(US$)	O & M cost	Min. Life	Additional Information
Solar PV	1kW	1000	1000	Not considered	25 years	Derating factor: 80% Slope: 30 degree Azimuth: 0 degree Ground reflectance: 20%
Wind System	1 kW	1300	1300	50 US$/year	15 years	Hub height: 10m Weibull k: 2 Autocorrelation factor: 0.85
Hydro	38.6 kW	80000	80000	1500 US$/year	25 years	Efficiency: 90% Pipe head loss: 5%
DG	1 kW	375	375	0.05 US$/ hour	15000 hours	Minimum load ratio: 30%
Battery	1900Ah	300	300	10 US$/ year	5 years	4V, 1900Ah,
Converter	1kW	145	145	Not cosidered	5 years	Inverter efficiency: 90% Rectifier Efficiency: 85 %

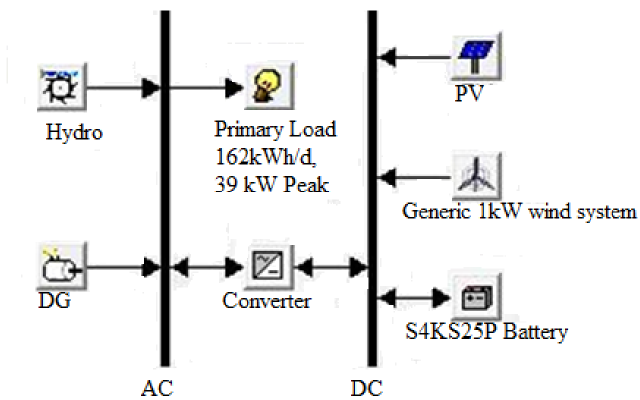

Figure 5: Configuration of energy resources input for optimum hybrid model development

3.1 Techno-economic optimized hybrid energy model

Table 5 lists the 10 possible hybrid models that can be implemented and meet the dynamic demand of the case area by utilizing the available resources. For this case study, it was found that, the load demand cannot be fulfilled by the wind with battery and wind-hydro hybrid with battery models. The possible models that can fulfill the dynamic demand are listed in table 5 based on least energy cost. The rating of different components, Initial Investment Cost (IIC), Operating and Maintenance cost, Total Net Present Value (TNPV) and Cost of Energy (COE) for each models are given in table 5. As shown in table 5, the model 1(M1) containing solar with battery is found to be optimized with COE of 0.199 $/kWh. On the other hand, DG set without battery is the worst model in COE. All of the input data for each model are given in table 4. The model 1 of energy system should meet the load demand of the community that includes 136 households with a primary school at remote area of Nepal. Here, the model is considered so that maximum use of available resource can be utilized and the required load demand will be fulfilled. The main components of the model to fulfill the demand consist of Solar PV, battery bank and the controller which consists of a 69 kW of solar PV, system controller and 114 batteries. All of the systems are operated in DC mode, and there is no requirement of AC conversion, since the load of the community is of tire 3 categories and only used for basic needs like electricity, mobile charge and a few number of televisions.

Acharya et al. study [14] shows that the levelized cost of electricity for solar wind hybrid system in vorleni Makawanpur, Nepal between NRs. 11.94 to 24.21/kWh by changing the capacity of technology. Poudel et al. research [15] find the levelized cost of electricity for solar based charging station at Tribhuvan International Airport, Nepal is NRs. 19.97/kWh. In this study the

Table 5: Optimized models with their economical parameters

Model	Hybrid Model	Solar kW	Wind kW	Hydro kW	DG kW	Batt No.	Con kW	IIC US$	O/M cost US$/year	TNPV US$	COE US$ /kWh
M1	Solar with Battery	69	0	0	0	114	-	103,200	3,699	150,485	0.199
M2	Hydro-DG with Battery	0	0	38.6	25	30	8	99,535	7,101	190,312	0.252
M3	Solar-Wind-Hydro-DG with Battery	4	1	38.6	25	30	8	104,835	6,705	190,546	0.252
M4	Hydro-Solar with Battery	52	0	38.6	0	78	36	160,620	4,862	222,769	0.295
M5	Solar-Wind-Hydro with DG	15	3	38.6	35	0	8	113,185	11,099	255,066	0.334
M6	DG-Solar with Battery	13	0	0	25	60	16	42,695	18,163	274,883	0.364
M7	DG with Battery	0	0	0	30	30	8	21,410	27,244	369,677	0.489
M8	Solar-Wind with Battery	65	15	0	0	114	-	294,200	16,379	503,582	0.667
M9	DG-Solar	15	0	0	40	0	8	31,160	61,219	813,744	1.077
M10	DG	0	0	0	38	0	-	14,250	68,657	891,912	1.18

model containing solar PV and batteries is found to be least cost with COE of 0.199US$ per kWh which is similar to the research[15]. Solar wind hybrid system has quite high energy cost due to the poor wind resource data results in small capacity of wind plant.

3.2 Sustainable hybrid energy Model

For different possible models that may fulfill the demand of the case area, the factors and indicators are given in table 6. Weighted sum method is used for the development of sustainable indicator. Capacity of hybrid energy technology are developed by using HOMER software and sustainable index values are taken from literature review as discussed in section 1. From the table 6, the different indicators such as technical, economic, environmental and social of all of the models are listed and prioritized on the basis of their scope and weightage, and presented. Higher the total percentage of influence, the rank be first. Based on the rank on different indicators, the models are prioritized and given in the last column. From, this analysis, the model 6(M6) is found to be more sustainable considering all of the sustainable indicators. Similarly, model 1 is found to be less sustainable.

Table 6: Rank of Energy Model based on sustainable indicators

Model	Tech	Eco	Env	Social	Total	Rank
M1	2.04	3.08	2.27	2.17	9.56	10
M2	2.53	3.21	2.27	1.98	9.98	7
M3	2.52	3.21	2.27	2.00	9.99	6
M4	2.26	3.13	2.27	2.10	9.75	8
M5	2.54	3.21	2.27	2.03	10.05	5
M6	2.71	3.26	2.26	2.06	10.29	1
M7	2.75	3.30	2.22	1.93	10.19	3
M8	2.10	3.13	2.28	2.17	9.67	9
M9	2.72	3.27	2.25	2.04	10.28	2
M10	2.75	3.30	2.22	1.93	10.19	4

Referring to table 6, the architecture of system containing DG-Solar with Battery is more sustainable. Model 9(M9) is the next system with second highest total percentage and models (9, 7, 10, 5, 3, 2, 4, 8 & 1) are ranked in order of decreasing the total percentage next to model 6, respectively. For model 6 it costs $0.364/kWh. Taking into account this parameter as comparison benchmark, model 1 is the winner from all 10 architectures, but it is less sustainable.

4. Conclusion

The prime system for techno-economic optimization ranked first has a renewable fraction of 100% containing 69 kW of solar PV system and 114 batteries at 24 V DC system., whereas the most sustainable model has 13 kW of solar PV, 25kW of DG set, 16 kW of Converter system and 60 batteries. The proposed energy system consists of 60 batteries (Model No: S4KS25P), in the architecture of 10 parallel string each containing six batteries. However, ten additional comparison approaches for different possible models were also used beyond the NPC to select a techno-economic system design. The COE is 0.199US$/kWh in techno-economic optimization result where as COE in sustainable energy optimization model is 0.364US$/kWh.

From this study, it is concluded that a techno-economic model is not necessarily sustainable too.

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