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Techno Economic Evaluation of Off-grid Hybrid Solar-Wind Power System for Village Malo Bheel, Tharparkar Sindh Pakistan

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Abstract Global energy demand has increased drastically due to increased world population, industrialization and high consumption in domestic sector. In Pakistan, the village Malo Bheel, District Tharparkar is among those 38% of the rural areas who do not have access to grid electricity while the remaining is experiencing power outages. Pakistan has huge untapped renewable energy potential in the form of wind and solar resources. Wind and PV hybrid system offer promising and cost effective solution for the off-grid rural communities in Pakistan. The techno-economic study of PV-wind hybrid system has been carried out to suggest the most economical electricity generation system for 57 households with varying load in Malo Bheel village. The primary objective of this study is to estimate the appropriate dimension of off grid hybrid photovoltaic-wind with minimal battery storage. The Cost of Energy (COE) and Net Present Cost (NPC) for hybrid system obtained using HOMER software is $0.13 per kWh and $66,445 respectively which is considerably less than the standalone solar and wind systems. Therefore, it is concluded that the hybrid power system for Malo Bheel, District Tharparkar is more feasible than other systems.

Keywords: *hybrid system, HOMER, rural, off-grid, PV, wind*

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1. Introduction

Energy supply to demand is a challenge of today's modern world. The energy demand has increased significantly due to increased world population, industrialization and improvement of the living standards of the people. To meet the rising global energy demand, the exploitation of fossil fuels is increased that has caused drastic climatic consequences. Figure 1 shows the futuristic scenario about the available resources that might not be able to meet energy demand after next 70 years [1]. Therefore, the clean and alternative energy resources potential such as, wind, solar, hydro *etc*. should be harnessed and utilized in order to achieve universal access to energy.

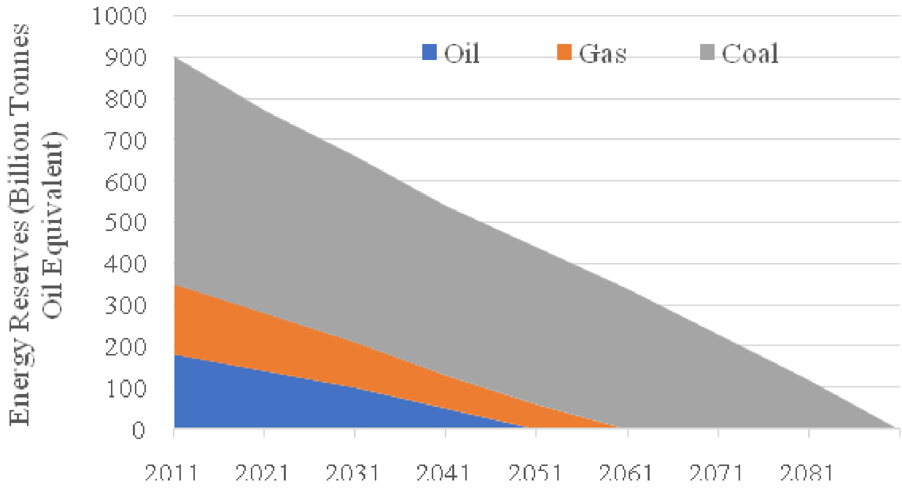

Figure 1. Depletion rate of fossil fuels in billions TOE with passing 10 years [1]

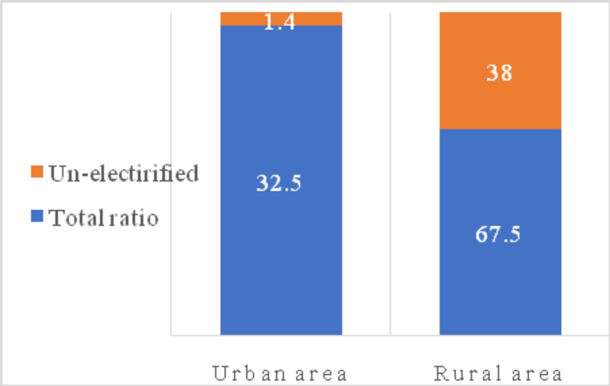

Figure 2. Electrification status of Pakistan

According to an estimate, about 97 million people of world are living in the rural areas. Out of which, only 46% has access to electricity although these regions are enriched with renewable energy resources and man power [2]. About total 27% area of Pakistan and 38% of its rural area has still no access to electricity [1]. The deficiency of electricity generation and demand is about 5000 MW, despite of this that Pakistan has abundant potential of renewable energy sources.

Fortunately, Pakistan is lying in such a geographical region which has great potential for renewable energy resources, *i.e.* solar, wind, biogas production, bio-energy from biomass and feedstock, mini and micro hydel. Pakistan receives solar insolation 5.5 kWh/m^2 per day and wind speed of 5–7 *m/s* exists in the coastal areas of Sindh and Baluchistan provinces with more than 20,000 MW of economically feasible wind power potential [2].

Selected location for this study; Malo Bheel is a small village near Islamkot, town of Tharparkar district Sindh Pakistan. The latitude and longitude of the area are 24.68N and 70.24E. The Malo Bheel village has average daily wind and solar potential of about 4.87 *m/s* and 5.2 kWh/m^2 *per day*, respectively.

The objectives of this research are to analyze the techno-economic feasibility of wind, solar and hybrid solar–wind system using Hybrid Optimization of Multiple Energy Resources (HOMER) software and to propose the renewable off-grid power system for small village Malo Bheel in Tharparkar, Sindh Pakistan.

Figure 3. Village Malo Bheel ©Google Maps

2. Renewable Energy Potential in Pakistan

2.1. Solar Energy Potential in Pakistan

The use of solar energy is increasing all around the world, due to the rapidly declining solar panel manufacturing costs. The location of Pakistan in a relatively hot region makes it ideal for solar power generation [4,5]. The average solar energy available is nearly 5.5 kWh/m^2/day having annual mean sunshine duration between 8–10 hours per day and 300 days (1500–3000h) per year [2]. A report issued by National Renewable Energy Laboratory (NREL) in cooperation with USAID provides a Figure 4 of 2.9 Million MW of solar potential in Pakistan [6].

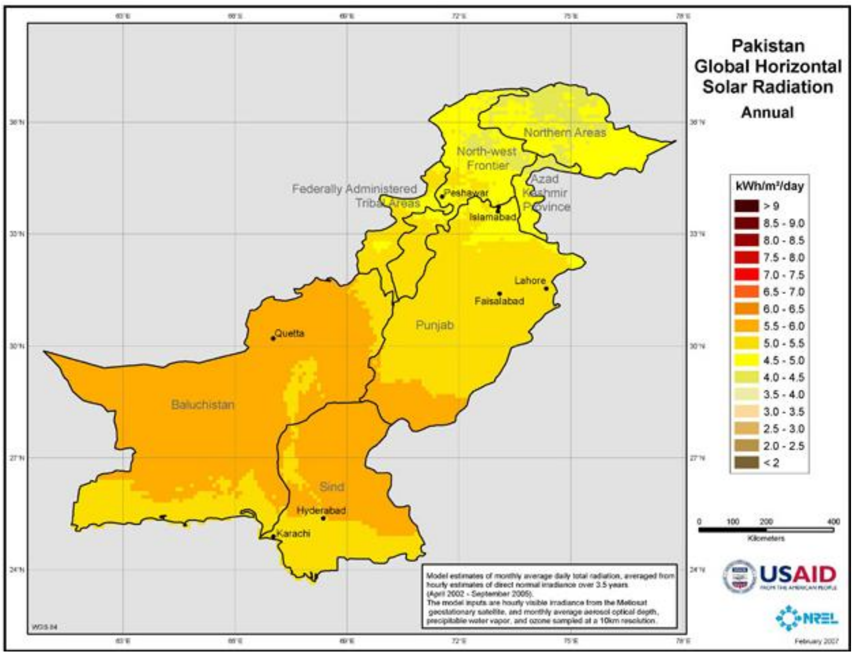

Figure 4. Solar resources available in Pakistan by NREL

A design and cost study, of PV systems for use in houses, was presented by Ghafoor and Munir to provide a better understanding of PV system to the local people so that they may be able to choose solar systems according to their own requirements [7]. The study on solar thermal technologies is already underway in University of Agriculture Faisalabad and similar such technologies have also been developed viz solar tunnel dryer, solar roaster, solar distillation, hybrid dryer, solar desalination system etc.

2.2. Wind Energy Potential in Pakistan

Wind energy in Pakistan also has the potential to harness wind energy and use it as another clean energy supply source. A survey was conducted in 2002 by Pakistan Meteorological Department (PMD) in collaboration with Ministry of Science and Technology (MoST) to study the winds along Pakistan's coastal belt which showed that the wind energy could be harnessed along those coastal areas of Sindh and Baluchistan. The above-mentioned areas have wind speeds ranging from 4 to 9 m/s at a height of 10 m increasing up to 12.5 m/s at a height of 50 m [9].

The effect of elevation 2009–10 is shown in Figure 5 on average annual wind speed at Gharo–Keti Bandar wind corridor [10]. Pakistan is still accelerating towards this new technology. Only a few working units are in operation by various organizations. A 50 MW wind power plant installed by Fauji Fertilizer Company (FFC) and a 56.4 MW power project installed by Zorlu Enerji Pakistan Limited are examples of working wind power plants in the country.

3. Hybrid renewable energy systems

Hybrid renewable energy systems are becoming more pervasive than before for power generation in remote areas. Many experts confirm that it is not possible for a single renewable energy source to replace all conventional energy sources (fossil fuels), whereas with a combination of different clean energy sources this becomes more viable. Such a system is called hybrid energy system [11]. Hybrid renewable energy systems usually have storage units in order to operate in duration of low power production [8].

Hybrid systems are usually a combination of renewable electricity generation units, such as wind, PV, hydro, biomass integrated with conventional ones, such as gas turbines, diesel generators and fuel cells which improves system performance and stability in energy supply. Solar radiation and wind energy both are not available continuously and thus, by using both wind and solar technologies the periodical gap between demand and supply of each technology can be filled and the disadvantage of each one can be minimized.

This research uses the HOMER software developed by NREL for designing micro-power systems. In the HOMER analysis, the hybrid renewable energy technology system is designed, followed by a techno-economic analysis. It compares a wide range of components with different constraints and sensitivities to optimize the system design. HOMER performs simulations to satisfy the given demand using alternative technology options and resource availability. Based on the simulation results, the best suited configuration is selected i.e. having low NPC and least COE.

HOMER is a computer model that used for designing and analyzing hybrid power systems for both off-grid and grid-connected power systems for remote, stand-alone, and distributed generation (DG) applications. It contains a powerful optimizing function that is useful in determining the cost of various energy project scenarios.

HOMER models both conventional and renewable energy technologies. HOMER allows the user to input an hourly power consumption profile and match renewable energy generation to the required load. This allows a user to analyze micro-grid potential, peak renewables penetration, ratio of renewable sources to total energy, and grid stability, particularly for medium to large scale projects.

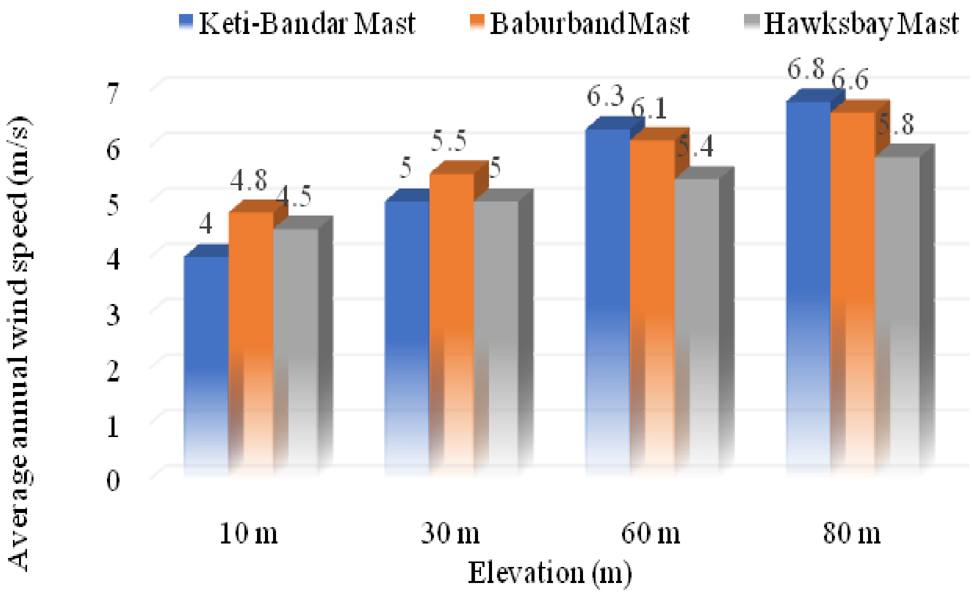

Figure 5. Average annual wind speed at Gharo-Keti Bandar wind corridor

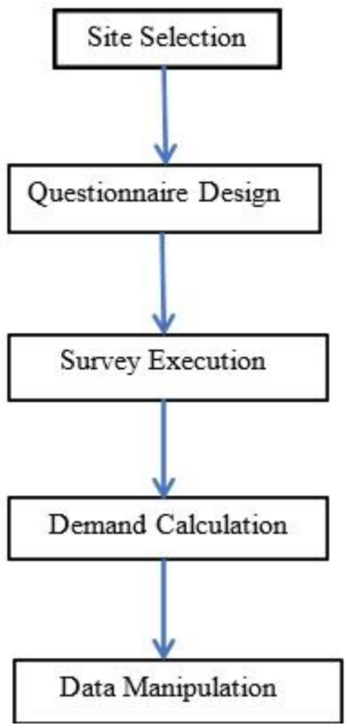

Figure 6. Methodology

4. Methodology

1. Site Selection

The rural remote areas of Pakistan have daily blackout of about 12 to 14 hours. However, there are also some rural areas where there is even no grid connection such as Malo Bheel Village at Islamkot, Tharparkar, southern part of Sindh. The total population of the Malo Bheel village is 362 and the residents has total 136 mud huts and 01 school. The village is about 20 km away from the Islamkot city. In addition, the monthly average income of a family is also very less of about 8 to 10 thousand. Therefore, in order to provide the basic necessities of electricity to isolated low density pollution, the off-grid power system can be a best choice.

2. Questionnaire Design

The information was collected from a sample of 30 households in the area. The questionnaire design focused on the social and financial profile of the respondents. The social profile consisted of the questions related to the education levels, current fuel usage and relevant issues and awareness regarding renewable energy. While financial profile included their current expenditures on fuels and monthly family income.

3. Survey execution

The survey questionnaire was filled by the trained surveyor and the questions were asked in the local Sindhi language. Total 30 household representatives were surveyed.

4. Demand calculation

The demand estimation is a crucial element of the entire system design and further improvement is possible here by incorporating social information of the users as well as their preferences.

5. Data Manipulation

HOMER software was used for the data manipulation to get optimized results.

5. Results

This study considered a combination of different technologies, namely wind turbines, solar photovoltaic (SPV), converter and batteries. In the hybrid system, wind turbine is AC-coupled and the SPV, demand from the village and batteries are connected to its DC side.

A. ***Resource Assessment***

The solar resource used for Malo Bheel village at a location of latitude 24.6838N and longitude 70.2498E was taken from National Aeronautics and Space Administration (NASA) Surface Meteorology and Solar Energy website [12]. The annual average solar radiation was scaled to be 5.197 kWh/m^2/day.

The monthly average wind resource data from an average of ten years was taken from the NASA resource website based on the longitude and latitude of the village. Minimum wind speed required for power generation is 3.0 m/s. While the annual average wind speed for the location is 4.87 m/s with the anemometer height at 10 meters.

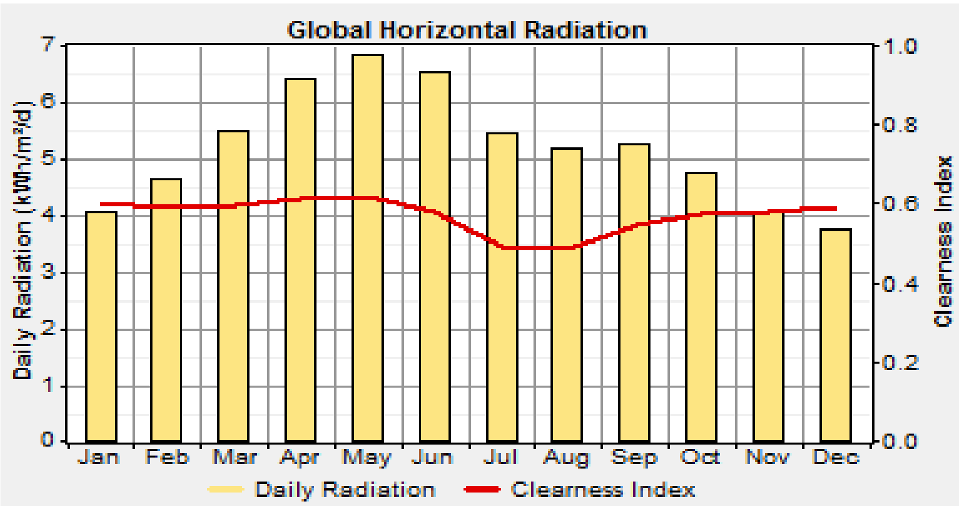

Figure 7. Global horizontal solar radiations

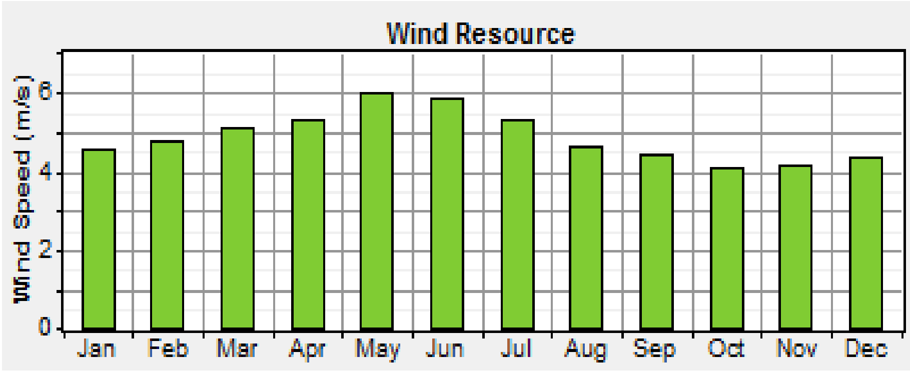

Figure 8. Wind energy resource of Malo Bheel

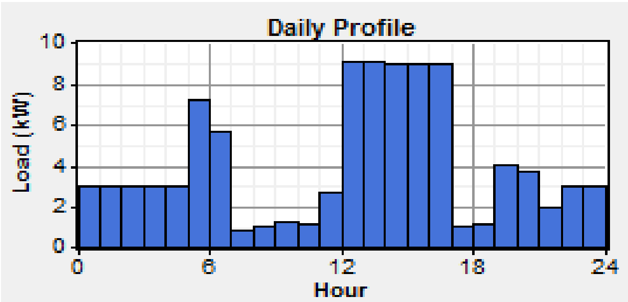

Figure 9. Daily primary load profile

B. *Demand Calculation*

In this study, the current electric load has been carefully estimated considering existing load profile data. The estimated load demand is 97.125 kWh/day and 9.86 kW peak.

C. *Cost & Components Configurations*

The components used in the system are solar photovoltaic panels, wind turbines, batteries and convertor. The details of these components are given below.

The Solar Photovoltaic Panels (SPV) panels are connected in parallel. The power generated by SPV is more than wind turbines at this location due to better solar insolation. Table 1 shows the cost and simulation parameters of SPV.

Table 1. Photovoltaic panel financial parameters

Size	**1kW (DC)**
Capital Cost ($)	400
Replacement Cost ($)	00
O & M Cost/ year ($)	00
Lifetime (year)	25
Derating Factor (%)	80
Slope Angle	25 °

Table 2. Wind Turbine input parameters

Model Name	WES 5 Tulipo
Size (kW)	2.5
Capital Cost ($)	2500
Replacement Cost ($)	2000
O & M Cost/ year ($)	10
Lifetime (year)	15
Hub Height (m)	25

Table 3. Battery input parameters

Model Name	**Vision 6FM200D**
Nominal Capacity (Ah)	200
Capital Cost ($)	130
Replacement Cost ($)	130
O & M Cost/ year ($)	10
Lifetime (year)	6.4
Voltage (V)	12
Lifetime throughout (kWh)	917

Table 4. Inverter input parameters

Size (kW)	**1**
Capital Cost ($)	180
Replacement Cost ($)	180
O & M Cost/ year ($)	00
Lifetime (year)	25
Inverter efficiency (%)	90

A horizontal-axes wind turbine is considered in the simulation. The wind turbine produces AC power. The amount of electricity generated by the wind turbine mainly depends on the availability of wind and variations in the wind speed. Some parameters of wind turbine model WES 5 Tulipo have been mentioned in Table 2.

Batteries are used as a backup in the system and to maintain a constant voltage during peak loads or a shortfall in generation capacity (Table 3).

The capital cost, replacement cost and Operation & Maintenance costs for one unit of the convertor are given in Table 4.

As HOMER helps to minimize the total net present cost (NPC) both in finding the optimal system configuration and in operating the system, economics plays a crucial role in the simulation of cost effective and highly efficient system. The indicator chosen to compare the different configurations' economics is the life-cycle cost (LCC), and the total NPC is taken as the economic figure of merit. All economic calculations are in constant dollar terms. The project's lifetime is considered to be 25 years with an annual discount rate of 6%. Basis for taking 25 years life of solar panel is that UK Feed-in Tariffs for PV are calculated for an economic lifetime of 25 years, indicating that the Department of Energy and Climate Change believes that panels will produce for at least that long [13].

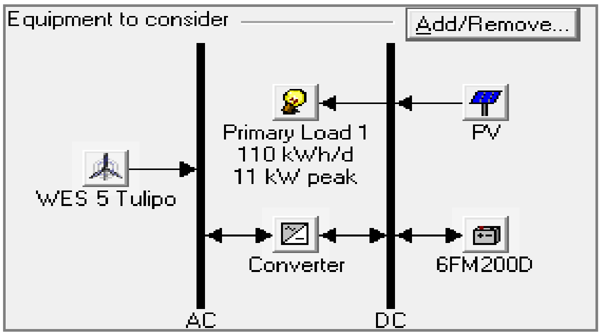

Figure 10. Designed system in HOMER

The program set-up includes all the simulations and possible arrangements that were tested for solar PVs and wind turbines, for several sensitivity value ranges of generation capacity, financing costs, wind speed and solar irradiation.

The hybrid system is designed by the combination of solar photovoltaic panels and the wind turbine along with the battery storage with minimum number of convertors. Wind & solar produces power separately but then combined for power supply to load or battery. The optimization results shown below in Table 5 describes that a hybrid system is more cost-effective. It offered low COE per kWh, low capital cost and low NPC.

The Figure 11 shows the monthly production of electricity from wind as well as solar. The different proportion of both resources can be seen in different months.

The reason for the lowest power solar power production in the month of July and August is that it is mostly cloudy in these months that ultimately affect the efficiency of solar photovoltaic panels. While wind power production is lowest in the month of October and November due to low wind speed.

The net present cost (NPC) of the system, cost of energy (COE) per kWh, capital cost, replacement and operation & maintenance (O & M) costs were also calculated. COE is the cost of energy per unit produced, & it is produced by software itself. NPC is sum of all costs of the project including materials, equipment or etc. means all types of cost are added for 25 year. The NPC and COE of hybrid system is $66,445 and $ 0.13 respectively. Cost details of the various components' costs of a hybrid system gained from optimization results in 25 years lifetime of the project has shown in Figure 12.

Table 5. HOMER simulation categorized/combined results

PV (kW)	WES5	6FM200D	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Batt. Lf. (yr)
40	4	76	6	$ 36,960	2,307	$ 66,445	0.130	1.00	6.4
80		96		$ 44,480	3,314	$ 86,838	0.169	1.00	4.4
	20	88	18	$ 64,680	3,831	$ 113,658	0.222	1.00	8.3

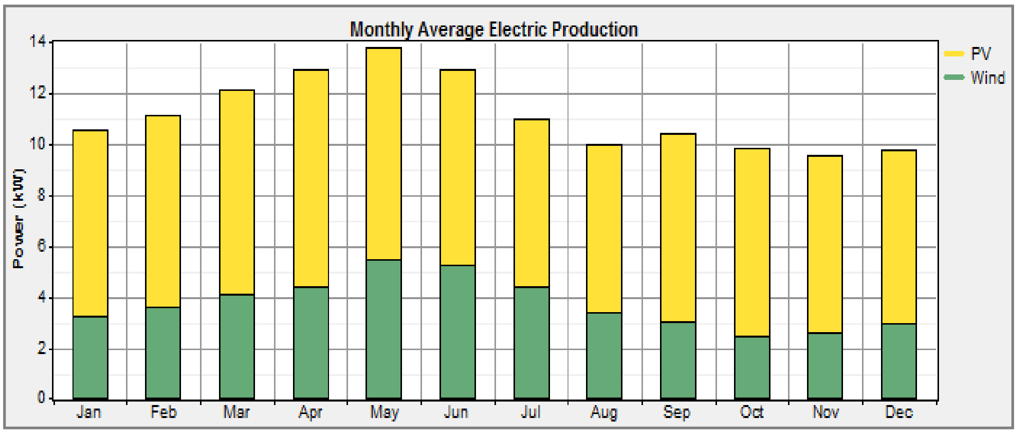

Figure 11. Proportion of electricity production by solar and wind

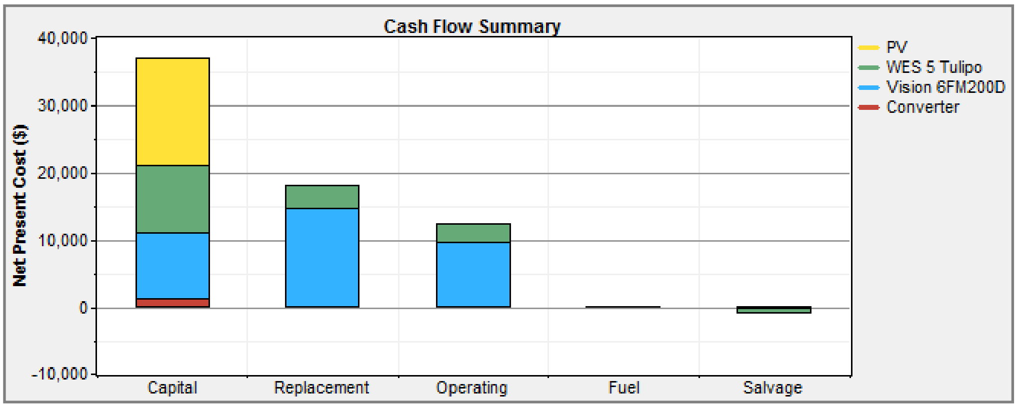

Figure 12. Cash flow summary by cost type

6. Conclusions

This study presents preliminary feasibility for implementing wind and solar hybrid power system for rural electrification of Malo Bheel locality in the southern part of Pakistan. Malo Bheel village can be provided access to electricity through abundant renewable resource present in the area. The results of the assessment made on the availability of energy resources in the study area shows promising data for the implementation of the proposed system, as the annual average potential is approximately 4.87 m/s for the wind velocity resource and 5.197 kWh/m^2/day for the solar insolation resource, respectively. The economic comparison of standalone wind and solar system with hybrid system has been done using HOMER. It has been concluded that the hybrid combination appears to be more technically and economically feasible, because the costs of electricity production using this system are the lowest (0.130$/kWh) compared to the other two options (0.169$/kWh for solar only and 0.222$/kWh for wind only) and also has minimal storage requirement.

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