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SIZING OF A HYBRID SOLAR/WIND MICROGENERATION WITH STORAGE FOR A COMMUNITY OF XAI-XAI IN MOZAMBIQUE

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Abstract. *The use of renewable energy from a hybrid system to generate electricity in remote areas has been a viable alternative to meet the electricity demands of isolated communities without resorting to the conventional electricity distribution grid. This project analyzes the technical and economic feasibility of implementing a hybrid solar/wind system with battery storage for a community in the Xai-Xai district of Mozambique. For this purpose, climatological data on wind, solar radiation, as well as load demand were provided as input parameters in the HOMER software. The proposed system obtained 64.9% and 35.1% of the energy generated by photovoltaic and wind sources, respectively, and is characterized as a promising alternative to meet the demand in that community. The sensitivity analysis and the optimization results show that the optimal solutions are significantly affected by the uncertainty of key variables.*

Keywords: *Hybrid System, Microgeneration with storage, Solar/Wind energy.*

1. INTRODUCTION

Applications of renewable energy systems for electricity generation in isolated communities have become a priority for countries seeking sustainable development (DAWOOD et al., 2017). Nevertheless, it´s known that the main restriction that hinders the massive use of renewable energy systems is its intermittence (ZHANG et al., 2017), therefore, they need energy storage to deal with the large fluctuation of production (DAWOOD et al., 2019). Besides, renewable resources face major limitations when used in their structure independently and flexibly. But when Solar energy is combined with wind energy, the system solves these constraints by generating a hybrid grid of renewable energy. These combinations allow for higher yields in energy production, thus making better use of its advantages to overcome its limitations (VENDOTI et al., 2018, 2019).

In Mozambique, although much of the remote and isolated areas depend mainly on small independent diesel generation systems, which are now a possible economic alternative to provide electricity to these areas, many other rural and isolated communities in the country, such as Xai-Xai, lack any source of electricity to supply their demand (FORTES; MUTENDA; RAIMUNDO, 2020). Therefore, the hybrid solar-wind system is a sensible and favourable alternative for remote electrification of villages and communities in Mozambique.

The present work aims to size microgeneration, based on a hybrid solar-wind system for an isolated community near the city of Xai-Xai, the capital of the province of Gaza in Mozambique, in which through the use of the HOMER software a technical, economic and sensitivity analysis of this hybrid energy system will be made. Sensitivity analysis is performed considering variations in key parameters such as project lifetime and nominal discount rate (NDR). Also, the environmental and social benefits achieved by the installation of a hybrid energy system are analyzed. The reason for using HOMER is that it has some unique features such as a wider range of renewable resource inputs, a realistic and constantly updated component library, possible combinations under various constraints, and more system architecture options (BAHRAMARA; MOGHADDAM; HAGHIFAM, 2016).

As a contribution, this work stands out for the following innovative features inherent to the study area: Unlike previous work that considered solar energy as a renewable energy source with a diesel generator as a support facility, this work considers the combination of solar photovoltaic sources and wind turbines to ensure reliable energy supply, considering the local conditions in remote rural areas of Mozambique, thus promoting the massive penetration of hybrid and 100% renewable technology in the country. Nevertheless, despite presenting high investments, renewable sources such as solar and wind energy are today a reality to supply energy for this public, and through a careful analysis of energy resources, it is possible to reduce costs (PINHO et al., 2008).

2. MATERIALS AND METHODS

2.1 Study area

The target community for the implementation of this study is located near the District of Xai-Xai, the capital of Gaza Province, in Mozambique with Latitude 25º 04' 45" S and Longitude 33º 64' 07" E. It is 210 km north of Maputo City and is geographically limited to the south by Chilaulene and the Indian Ocean, to the east by Chonguene, to the west by Chicumbane, and the north by the Limpopo and Ponela Rivers, occupying an area of approximately 1908 km². Mozambique has high and consistent radiation throughout the nationwide, making the sun the most abundant renewable resource with a global potential of 23 TW (MIGUEL; FERNANDES, 2014). In terms of wind resource, 16 sites with a total of 4.5 GW of wind potential in the Centre and South of the country were confirmed over more than a year of measurements, with emphasis on several areas in the south of the country close to huge consumption centers (FUNAE, 2019). Nevertheless, these potentials, namely wind speed and solar radiation intensity (Figure 1), are the main input variables for the sizing of the proposed system.

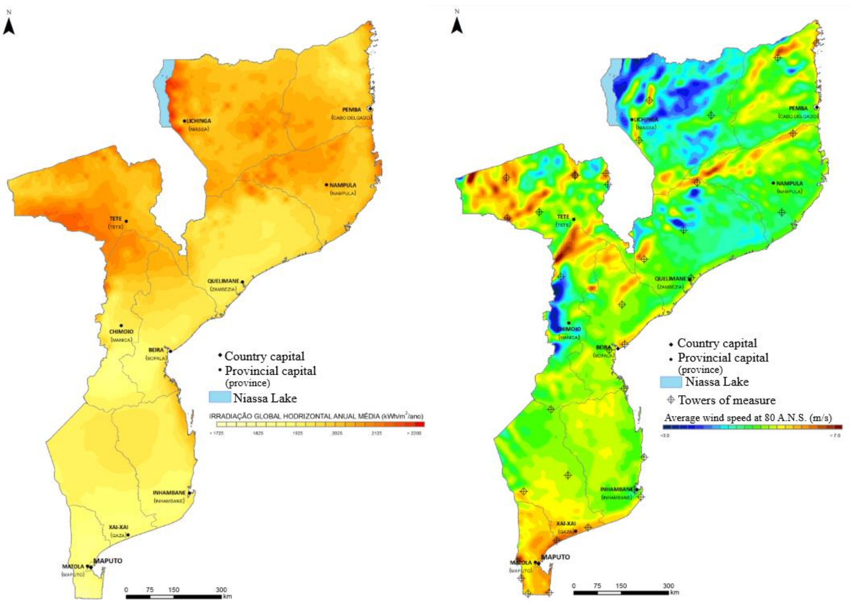

Figure 1 - Atlas of solar and wind potential of Mozambique by (FUNAE, 2019)

In Mozambique, access to energy for conversion into electricity has been limited for most of the rural population (UAMUSSE et al., 2015). The use of microgrids for these rural areas would be the solution for electricity to reach these communities that are not contemplated with this essential service. Figure 2 illustrates a representation of a scheme showing the constituent parts of a microgrid to be sized.

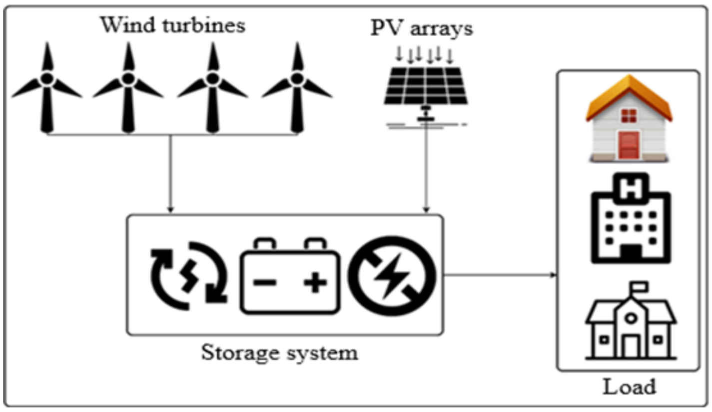

Figure 2 - Schematic representation of the constituent parts of the microgrid

The proposed system aims to supply electricity for a community of 30 families, the residential electricity demand for this community is reasonably low, having as main use lighting, refrigeration of consumer goods, TVs and mobile phones charging a primary school, and a health post for the conservation of medicines. For such purpose, a load of 170 kWh has been estimated to meet the demand of this small community near Xai-Xai in Gaza province, Mozambique.

2.2 Features of the designed system

The HOMER software performs the sizing and operational strategy for this hybrid renewable energy system, based on three main tasks which are simulations, optimization, and sensitivity. The proposed system makes a combination of photovoltaic cells, wind turbines, both connected to an energy storage system and inverter (Figure 3). It has a PV system with DC generation and wind turbines with AC electric generators. The batteries are as electrical energy storage, while the inverters convert the electrical energy between the direct current (DC) load and the alternating current (AC) load.

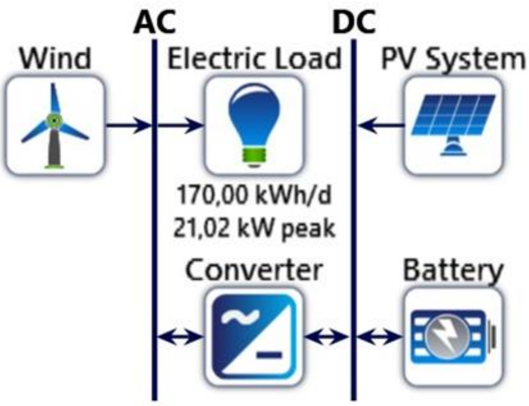

Figure 3 - Hybrid system architecture configured by HOMER software

2.3 Techno-economic analysis

For techno-economic analysis of the hybrid power system, indicators such as the Net Present Cost (NPC) and Cost of Energy (COE) are considered. To calculate the COE, HOMER divides the annualized cost of producing electricity by the total useful electric energy production, which is calculated as follows (HIENDRO et al., 2013):

$$COE = \frac{C_{ann,tot}}{E_{served}} \tag{1}$$

where $C_{ann,tot}$ is the total annualized cost of the system $(\$/yr)$ and E_{served} is the total electrical load served (kWh/yr).

The annualized cost is the sum of annualized capital cost $(C_{ann,cap})$, annualized replacement cost $(C_{ann,rep})$, and annualized Operation and Maintenance cost $(C_{ann,O\&M})$ of the system components and can be calculated by the Equation (2) (DAS et al., 2017):

$$C_{ann,tot} = C_{ann,cap} + C_{ann,rep} + C_{ann,O\&M} \tag{2}$$

The total Net Present Cost (NPC) of a system is the present value of all the initial capital costs, replacement costs, and O&M costs minus the present values of all the revenues which include salvage values of system components over the entire lifetime of the project. The NPC is calculated using Equation (3) (DAS et al., 2017):

$$NPC = \frac{C_{ann,tot}}{CFR_{(i,n)}} \tag{3}$$

where $CRF_{(i,n)}$ is the capital recovery factor and is determined by Equation (4) (LI et al., 2013):

$$CRF_{(i,n)} = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{4}$$

whereby i is the real annual interest rate and n is the number of years.

The annual real interest rate i can be calculated by the following Equation (5):

$$i = \frac{i' - f}{1+f} \tag{5}$$

where i' is the nominal interest rate and f is the annual inflation rate. In this study, an 2% annual inflation rate is considered.

In this analysis, the financial appraisal is determined by the payback period, which is calculated using the following Equation (HOSSAIN MONDAL, 2010):

$$Payback\ period = \frac{I}{R - E} \tag{6}$$

where I is the investment, R is the return, and E is the expenses.

3. RESULTS AND DISCUSSION

3.1 Load profile

Figure 4 illustrates the projections of daily, seasonal, and annual load profiles. On the one hand, the daily profile of the load characteristics is concentrated between 06 pm to 09 pm daily, in the order of 5 kW to 11 kW of power demanded in the system. The Seasonal load profile, on the other hand, is relatively constant, i.e. with no variations, whose average power requirement is 12 kW over the year. The annual load profile shows that higher power will be demanded after 08 pm.

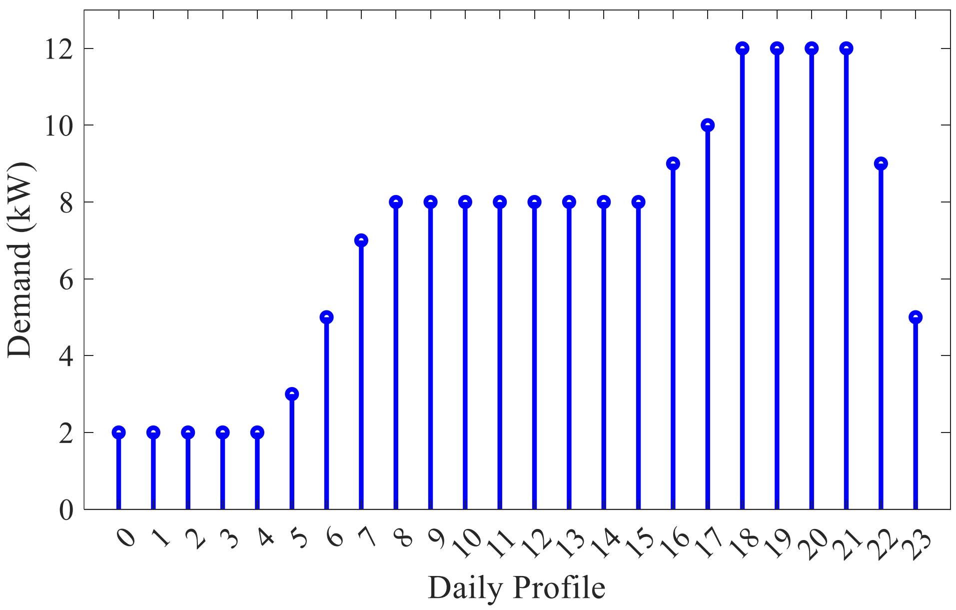

Figure 4 - Load profile demand to be met by the hybrid system

3.2 Solar and wind resources

The annual average solar radiation from the site was estimated at 5.16 kWh/m²/day and the maximum solar radiation was found at 6.7 kWh/m²/day (Figure 5). The data show that the site has good solar potential and can produce energy efficiently using photovoltaic (PV) panels. Furthermore, the monthly average wind speed for the study area, at 10 meters high, is estimated at 6.51 m/s, reaching speeds above 7 m/s in the months between September and November, for 12 months. The PV module and wind turbine used in the design are the SunPower, and SPR-440NE-WHT-D brands, respectively. The choice for such a turbine brand was based on the low initial wind speed required for start-up, resulting in increased production and lower risks of power failures.

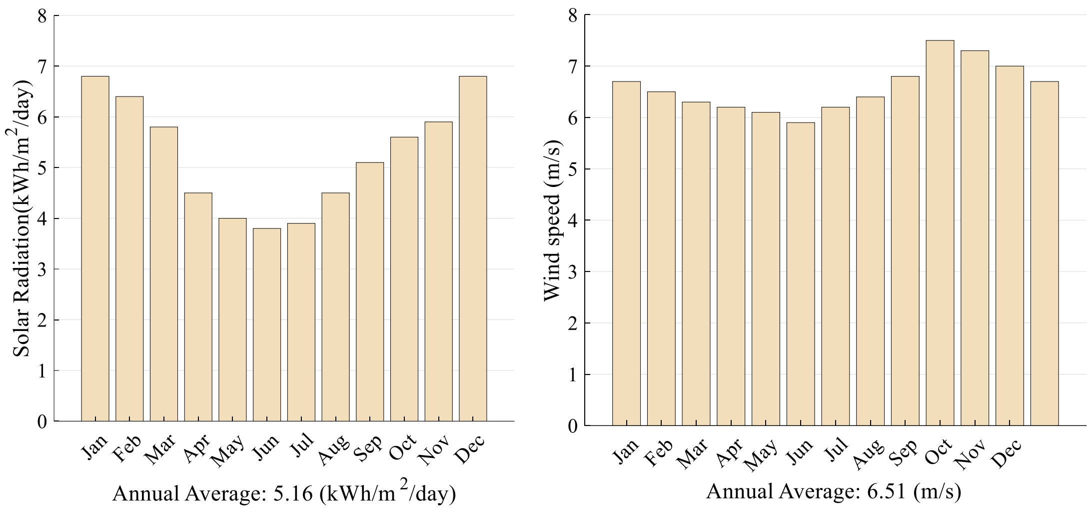

Figure 5 - Global Horizontal Irradiance and Wind Speed of Xai-Xai City by Homer software

3.3 Sensitivity analysis results

The input parameters for the HOMER software has generated several possible combinations for the desired system. Table 1 shows the combinations that will best suit the system.

As is well known, solar and wind power sources, apart from being intermittent ones, have relatively high costs. Therefore, in this paper, different values of the annual discount rate, associated with the lifetime of the system, were considered to assess its sensitivity and thus predict the behaviour of the system due to market volatility. For the sensitivity analysis, the discount rate and the system lifetime were varied from 6%, 8%, 10%, and 20, 25, and 30 years, respectively. As can be seen in Table 1, the simulations performed show that an optimal combination for the system the following variables were selected: 10% discount rate, and 25 years lifetime, as highlighted in the table.

Table 1 - Sensitivity analysis of different systems

Sensitivity		Architecture						Cost			
Discount rate (%)	Project lifetime (yrs)	Options	PV (kW)	Wind	Battery (q)	Converter (kW)	Initial capital ($)	Operating cost ($/yr)	NPC ($)	COE ($)
10,0	20		39,8	6	404	22,8	$335.602	$10.930	$444.180	$0,721
8,00	20		50,5	5	392	28,5	$342.265	$10.520	$464.102	$0,646
6,00	20		68,2	5	322	26,0	$364.867	$8.596	$482.506	$0,569
10,0	25		63,4	7	283	31,1	$378.862	$11.036	$498.263	$0,743
8,00	25		73,4	6	281	27,4	$381.506	$10.975	$523.390	$0,653
6,00	25		71,3	6	284	25,9	$379.319	$11.212	$555.936	$0,569
10,0	30		63,4	7	283	27,5	$377.752	$12.902	$525.180	$0,741
8,00	30		63,1	7	284	32,0	$378.672	$13.573	$567.883	$0,657
6,00	30		71,3	6	284	22,2	$378.083	$13.648	$616.343	$0,569

For the selected combination, the system will consist of 7 wind turbines and 283 acid batteries (12V), and photovoltaic plate strings. Despite having relatively higher initial capital, compared to the three combinations above, the chosen combination won because it has a shorter return on investment (9.18 years), and a very attractive profit margin (16.3%) when compared to the other configurations presented in Table 1, as shown in Table 2.

Table 2 – Payback rate

Metric	Value
Return on investiment (%)	16,9
Internal rate return (%)	16,3
Simple payback (yr)	9,18
Discounted payback (yr)	9,54

3.4 Economic Analysis of the proposed system

For the economic analysis, besides the initial investment costs, the proposed system consists of operation and maintenance costs, and equipment replacement costs, throughout its useful life. Nevertheless, Figure 6 graphically summarizes the component costs by category. As can be seen, PV has the highest initial capital (41.86%), followed by wind turbines (33.26%), batteries (22.41%), and inverters with 2.47%.

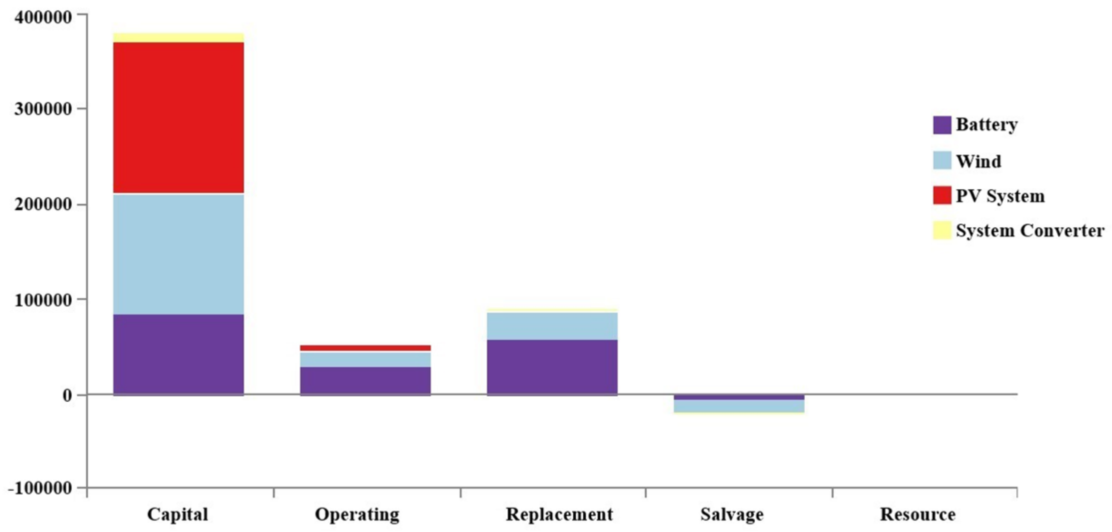

Figure 6 - Cost summary of PV/Wind/Battery hybrid system by category

The investment payback is proposed to be obtained by selling electricity to the community. This hybrid system costs $ 498.263 for its 25-year of a lifetime and considering that the cost of energy (COE) is $0.7482/kWh. The chosen system presented in Table 1 shows an annual excess of generated electricity of 57.5% seen in Table 3. Such electricity excess can be redirected to small local businesses and local agricultural production, which could result in a reduction in the COE to $0.4302/kWh, in favour of the community.

Table 3 – Excess of produced energy

Quantity	kWh/yr	%
Excess eletricity	92.561	57,5
Unmet Electric Load	30,2	0,0487
Capacity Shortage	60,0	0,0983

Considering 25 years of project life, Figure 7 presents the maintenance plan of the system. Thus, it is proposed that the replacement of components such as batteries, inverters, and turbines, occur twice for the batteries, once for the inverters, and once for the wind turbines, in the 10th, 15th, and 20th year, respectively. After 25 years, the system may have remained with 75% of the useful life of the newly changed wind turbines, 50% of the batteries, and 33.3% of the inverter, which corresponds to 4.26% of the capital invested in the system.

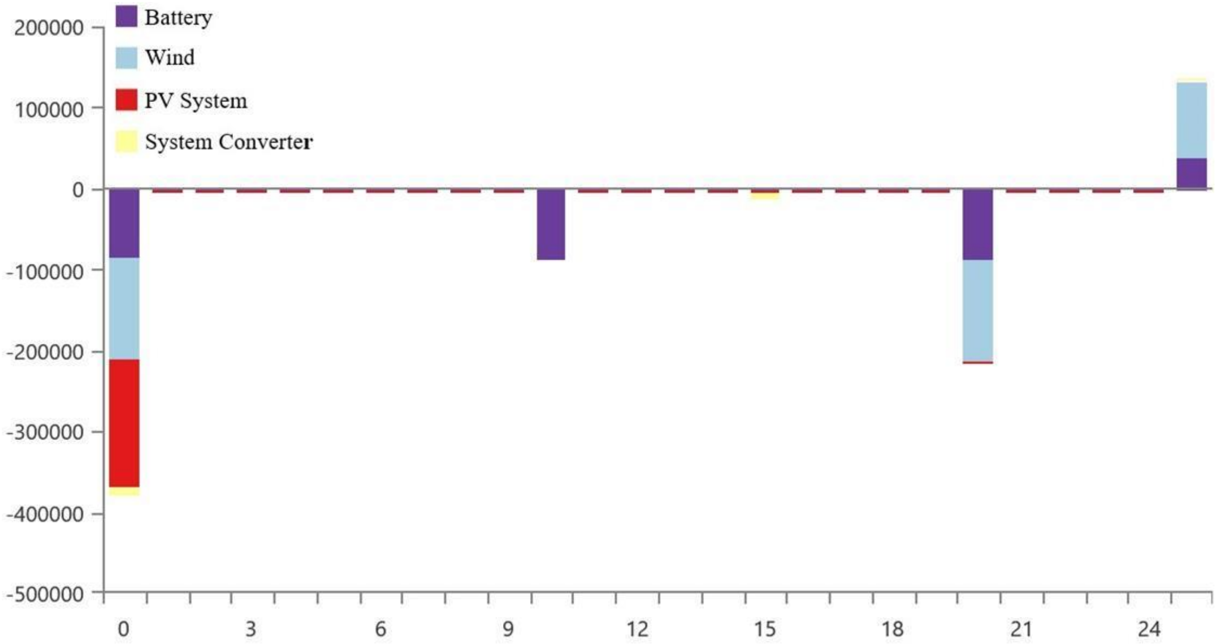

Figure 7 - System Cash Flow

Figure 8 shows the monthly average electric energy production for the two sources used to satisfy the demand. With a larger portion produced by the PV system, indicated by the orange colour column, while the light blue colour column represents the wind energy generation. The production of the chosen combination produces 104.453 kWh/year of electricity, equivalent to 64,9% for PV and 54.477 kWh/year equivalent to 35,1% for wind source relatively.

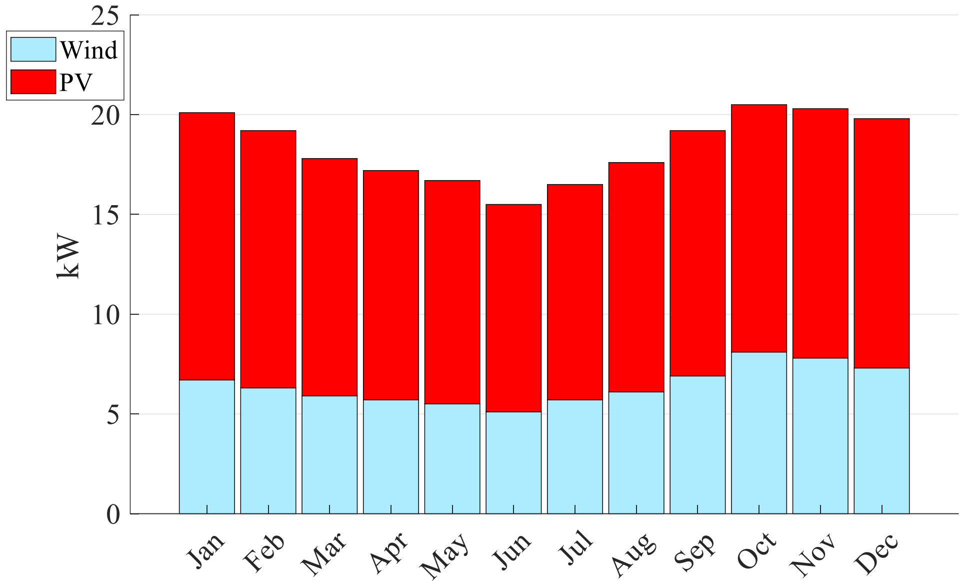

Figure 8 - Power produced monthly by the system

Figure 9 presents the daily energy offer profile of the system for the month of October. Where, the PV system generates energy in the period of (06 AM-06 PM), with maximum peak generation occurring between 10 AM and 01 PM. In this period the wind generation helps in the attendance of the demand, and the excess of the generated energy charges the batteries. As observed in Figure 4, from 04 PM the load increases. During this period the wind turbines, together with the storage system, simultaneously satisfied the load until midnight. So, from this period to 06 AM, the demand is satisfied by the wind power generation taking into account the low use of electricity, as it is sleeping time.

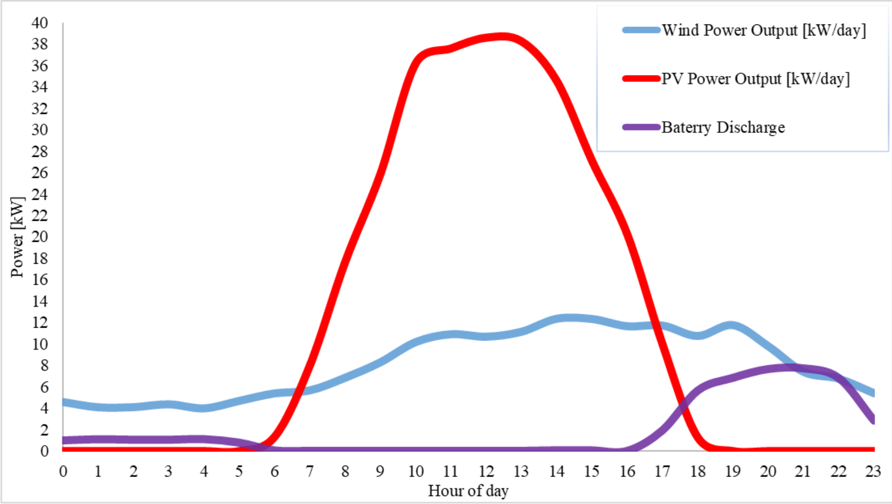

Figure 9 - Daily power flow to the system

3.5 Social Impact

Electricity access plays a major role in improving the quality of life of the population, particularly for isolated communities. Electricity is also responsible, by the way, for allowing access to information/knowledge through television, radio and the internet. Therefore, with the access to electricity, the education of the population can be improved with the possibility of evening literacy courses, for the benefit of the older populations living in isolated communities, thus discouraging rural exodus. It can also provide greater agricultural productivity with the introduction of irrigation, drainage of flooded areas, conservation of products such as vegetables, fruit, milk and fish. Therefore, firstly, the project implementation would provide the community with reliable renewable energy that will make them independent from varying fossil fuels price and supplies. Secondly, this project can serve as a demonstration project for other companies and industries that can take it as an example and replicate it in other communities across the country. And finally, the introduction of new renewable energy generation can pave the way for the generation of a new market sector that will create new job opportunities for the local population, thus improving their socioeconomic status.

4. CONCLUSION

From the simulation made, the results show that the district of Xai-Xai, Mozambique has enough potential for wind and solar energy to supply electricity to the community with 30 families. The wind turbine generates 35,1 percent of the energy compared to 64,9 percent for photovoltaic panels. The wind turbine and battery bank are needed to meet the loads at night in a hybrid PV/wind system, although both contribute the highest cost to the system. The system profile shows that the operation of the system is complimentary, as expected, however, due to the urgent needs of the system to meet the demand in that community, it is considered the charging of the batteries by the portion supplied by the PV system during the day so that the stored energy is used in a shared way with the wind system tonight. The sensitivity analysis and optimization results show that the optimal solutions are significantly affected by the uncertainty of key variables, such as solar radiation and wind speed. So, this work provides evidence that ensures reliability to energy supply, considering the local conditions in remote rural areas of Mozambique, thus promoting the massive penetration of hybrid and 100% renewable technology in the country. Nevertheless, despite presenting high investments, renewable sources are today a reality to supply energy for rural communities, and through a careful analysis of energy resources and the promotion of good public policies, it is possible to reduce costs.

5. ACKNOWLEDGEMENTS

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