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ECONOMIC OPTIMIZATION OF GENERATION MICROGRIDS WITH RENEWABLE SOURCES: A CASE STUDY AT THE UNIVERSITY OF CORDOBA, COLOMBIA

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Abstract. *In this paper a study of generation microgrids at the University of Cordoba, Monteria, Colombia is carried out, performing a simulation and optimization using Homer Energy software, with the most potential energy sources which are present in the place and performing an economic evaluation of zero internal rate of return, where it was concluded, that by combining all the available sources, it was not possible to obtain economic viability, that is to say, the investment could not be recovered throughout its useful life, also, the energy produced by biomass gasification, presents high initial investment costs, so it was concluded that it is necessary to develop local technology to reduce these costs. Finally, it was found that the most optimal alternative was the combination of grid energy, solar energy and hydrokinetic turbine, presenting generation costs of 0.137 USD/kWh, an internal rate of return (IRR) of 11.9% and an investment recovery time close to 10 years which indicates that the implementation of microgrids in the case study is viable.*

Keywords: *Homer Energy, IRR, microgrids, renewable sources*

1. INTRODUCTION

The generation of energy through renewable sources has been the subject of several theoretical and experimental studies, which seek to evaluate and improve the alternatives for the generation of clean energy, since this is a pressing need that even forms part of the objectives of sustainable development (Aberilla et al., 2020). The current electrical system in Colombia has considerable energy losses, especially at low voltage levels (Romero-Lopez & Vargas-Rojas, 2010). These losses can be decreased by making use of smart grids which to be materialized requires the construction of energy microgrids (Banguero et al., 2019).

In Colombia, with the structuring of Law 1715 of 2014 (renewable energy law), the integration of new technologies to the country's energy matrix has begun, being solar and wind energy the most promising ones, with a view to strengthening the electric system by improving aspects related to environmental impact, reliability and affordability to the service (López et al., 2020). However, renewable energies present problems of consistency of supply since they are strongly dependent on weather conditions and present great intermittency, so it has become necessary to combine renewable technologies with non-renewable ones and energy storage systems to solve this problem (Haghighat Mamaghani et al., 2016).

A microgrid is a controlled set of loads, generating elements and energy accumulators that for the national grid behaves as a single element, it also allows the connection and disconnection of this to operate in island mode (Hassan et al., 2020). Around the world there have been several research studies of microgrids integrating renewable energy sources, Baldinelli et al., economically evaluates several energy storage systems for networks with 100% renewable energy (Baldinelli et al., 2020). On the other hand, Bertheau studied microgrid models with solar energy, wind energy and battery storage for small islands in the Philippines, using an approach that combines geospatial analysis, cluster analysis and energy system modeling (Bertheau, 2020). For their part Gholami & Dehnavi propose a particle swarm algorithm to optimize the cost of power generation in microgrids for solar power, wind power, and power and heat systems without load uncertainty and with uncertainty (Gholami & Dehnavi, 2019).

This article performs an analysis of alternatives based on the generation costs of a microgrid with renewable energy at the University of Cordoba in Colombia, using the Homer Energy Pro® software where the grid-connected system was modelled with solar energy, hydrokinetic turbine and biomass gasification integrated to internal combustion engine, as

renewable energy sources and lithium-ion batteries, as storage technology. The work is divided into 4 sections: section 1 presents a general context of the subject as an introduction, section 2 presents the methodology used in the research, section 3 shows and discusses the results and finally section 4 shows the conclusions of the research and details key aspects for future research.

2. MATERIALS AND METHODS

2.1 Case study description

The University of Cordoba is a public higher education institution located in Monteria with more than 50 years of service training professionals, currently has undergraduate and graduate programs. Its areas of knowledge are divided into 7 faculties where the engineering faculty is located with its buildings and laboratories for complementary training. In this case, the study focuses on the engineering building as shown in Figure 1, which consists of 4 floors, divided by administrative and financial offices and classrooms. It has 16 classrooms spaced throughout the building and its hours of operation are from 6:00 am to 9:00 pm Monday through Friday.

With the above mentioned, a simulation of a microgrid with 3 types of generation such as hydrokinetic, biomass and solar energy, in conjunction with the local power grid, focused on generating the necessary electrical power for the engineering building of the University of Cordoba, was carried out. In addition, the optimal distribution in generation and investment and the feasibility from the economic point of view were evaluated.



Figure 1. Building defined as case study

2.2 Microgrid consumption profile

The load profile of the building was estimated based on a load balance according to the equipment and facilities available and their hours of operation. Since the building operates mainly on weekdays and on weekends there are some basic services, a load profile was defined for each case;

Figure 2 shows the load profile for weekdays. For weekends, a load profile was defined based on the minimum consumption obtained. According to the defined profiles the building has a consumption of 117.76 kWh/day on weekdays and 67.21 kWh/day on weekends, with a load factor 0.33. A maximum random variation of 10% per hour and 15% day-day was also defined to introduce variability of the data over time, thus modeling the behavior of small transient loads.

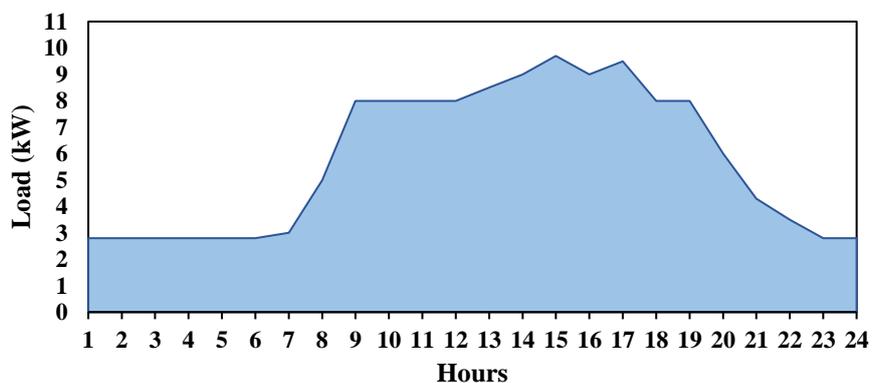


Figure 2. Building load profile

2.3 Potential of renewable sources

The department of Córdoba is located in northwestern Colombia and due to its geographic position, it is in a privileged location for the use of renewable sources, mainly solar energy, which is available throughout the year, with a high proportion and little instability. On the other hand, being a department, whose main activity is agriculture, it generates large amounts of waste that can be used to generate energy from biomass, as in the case of corn cob. Finally, a large part of the department is crossed by the Sinú River, which passes through the University of Córdoba and represents an interesting energy potential.

The city of Monteria presents high levels of solar radiation throughout the year.

Figure 3 shows the monthly behavior according to data obtained by (IDEAM, 2020), where average values between (4.50-5.03) kWh/m²/day are observed. The first three months of the year present radiation values close to 5 kWh/m²/day, because they coincide with the dry season, while the last three months do not exceed 4.70 kWh/m²/day because they are rainy seasons. However, the highest values are recorded in the middle of the year, in the months of July and August. The clearness index is also observed during each month, with the highest peak in January with an average value of 0.54 and the lowest in September with a value of 0.46.

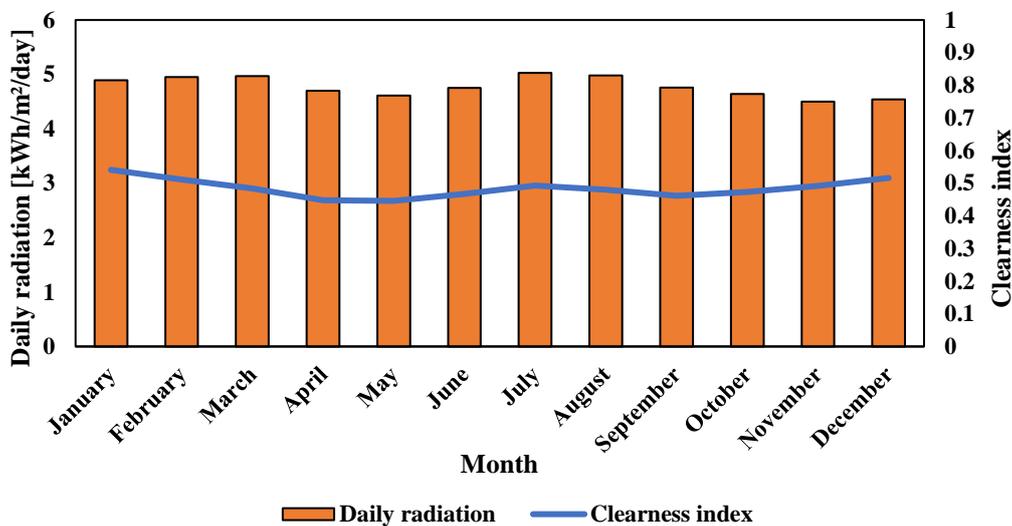


Figure 3. Radiation and Clearness index of the city of Monteria (IDEAM, 2020).

Figure 4 shows the monthly behavior of the Sinú river velocity according to statistics provided by (CVS, 2018), showing that in months such as May and September, velocities of 1.97 and 2.01 m/s are reached respectively, which are the highest due to the existing flow presented by the rains in those months. On the other hand, months such as January, February and December, which are months of intense drought, it can be noted that the average velocities are of 1 m/s. They are the most critical in terms of velocity and depth due to the low flow at the time. However, the remaining months present good values where energy use would be interesting to implement energy conversion mechanisms.

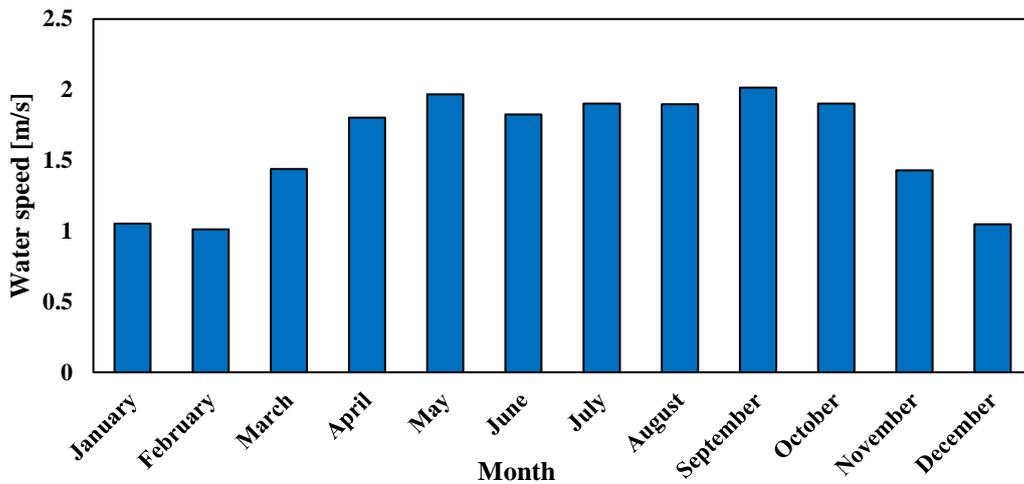


Figure 4. Sinú river velocity per month (CVS, 2018).

According to (Fenalce, 2019), in the department of Córdoba, there is an annual production of 30855 tons of corn cob, which serves as biomass for energy use. Months where the amount of available biomass presents the highest values are September with 869.40 tons/day, March with 776.25 tons/day and January with 419.18 tons/day, as shown in Figure 5. However, months between April and July, corn production is almost nil because it is in the planting and growth stage. On the other hand, the amount of biomass consumed by the gasifier is in the order of 0.12Ton/day. In some months, the amount of biomass available does not satisfy its consumption, it is necessary to stack and store the remaining biomass where it is abundant, thus showing that the department has the availability to supply the consumption of biomass used in gasification processes.

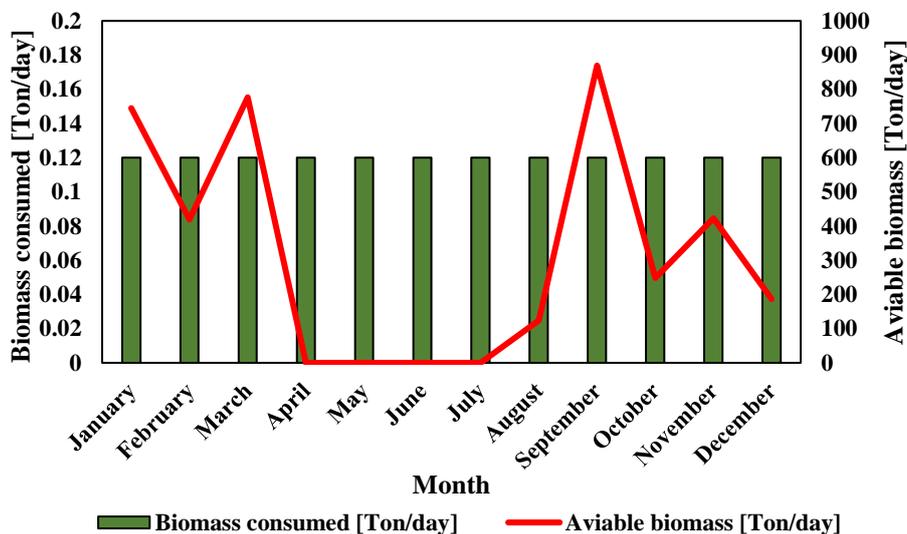


Figure 5. Corn cob generation per month in Córdoba and biomass consumption from the gasification system (Fenalce, 2019)

2.4 Topology of the simulated microgrid

The microgrid studied consists of an AC and a DC bus interconnected by means a converter, the building loads were simulated by means of a single element connected to the AC bus. Grid connection and solar energy, hydrokinetic turbine and biomass gasification coupled to internal combustion engine were considered as renewable energy sources and lithium batteries were used as storage elements. Figure 6 shows the diagram of the simulated microgrid.

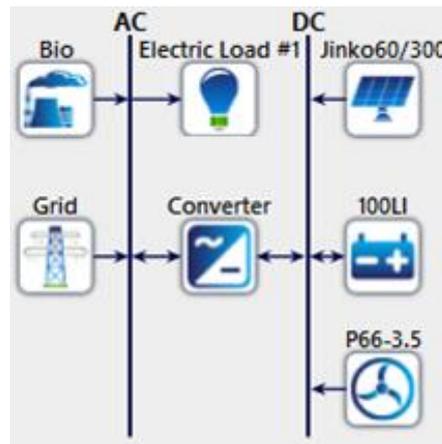


Figure 6. Simulated microgrid diagram

The photovoltaic system included has a maximum capacity of 3.60 kW composed of 12 panels with 300 W capacity. Table 1 shows the characteristics of the selected solar panel.

Table 1. Characteristics of the selected solar panel

Name	Jinko Eagle PERC60 300W
Abbreviation	Jinko60/300
Panel Type	Hat plate
Rate Capacity (kW)	0.30
Temperature Coefficient	-0.39
Operating Temperature (°C)	45
Efficiency	18.33
Manufacturer	Jinko Solar

For biomass generation, a diesel internal combustion engine was simulated with gas integrated with corn cob gasification. A 6.5 kW Gunset engine was selected (see Figure 1) and a calorific value of 5 MJ/kg was defined for the gas.

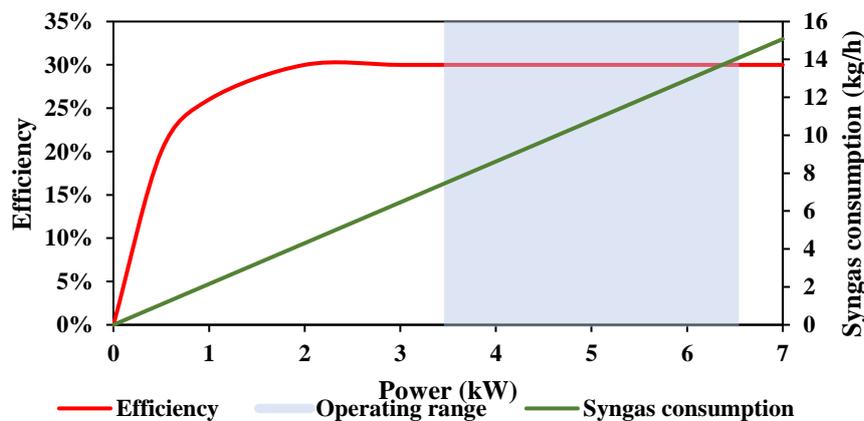


Figure 7. Characteristic curve of the simulated engine

As for the simulation of the hydrokinetic turbine, a generic turbine with a capacity of 1 kW and a characteristic curve resulting from its own design was defined. Figure 8 shows the power curve of the turbine studied.

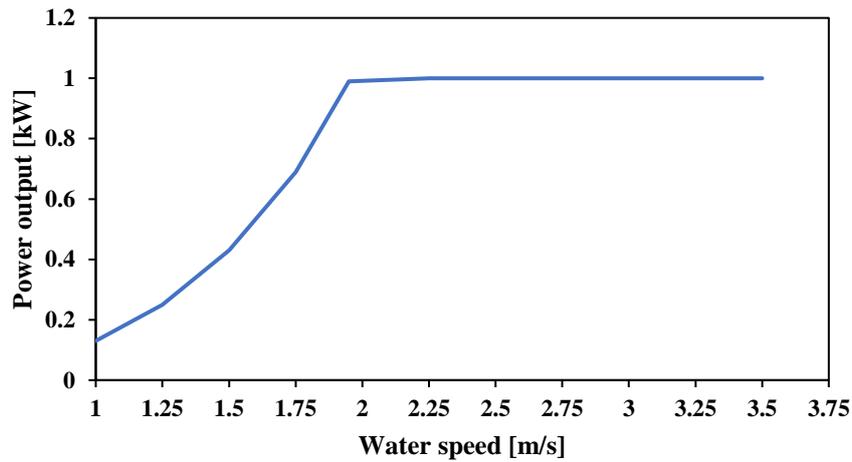


Figure 8. Power curve of the turbine under study

2.5 Economic analysis and optimization

The economic evaluation of the system was carried out considering the fixed and variable costs of the system, which were evaluated in the software by means of two parameters, the net present cost (NPC) and the unit cost of energy (COE). These parameters are described below.

The NPC is the present value of all costs incurred during the life of the system, subtracted from the revenues obtained. This parameter considers, initial capital costs, operation and maintenance costs, equipment replacement costs, among others. The NPC is calculated by means of the following equation (1) (Baldinelli et al., 2020).

$$NPC = \frac{CA_{total}}{CRF} \quad (1)$$

Where, CA_{total} is the total annual cost and CRF is the capital recovery factor.

The capital recovery factor was calculated using the following equation (2).

$$CRF = \frac{i \cdot (i + 1)^N}{(i + 1)^N - 1} \quad (2)$$

i represents the real interest rate and is calculated using the equation (3).

$$i = \frac{i_0 - f}{1 + f} \quad (3)$$

Where, i_0 is nominal interest rate y f is annual inflation rate.

The unit cost of energy (COE) is calculated based on the annual cost and energy consumed in the system, including energy generated by renewable sources and energy consumed from the grid. The COE is calculated using the equation (4), (Baldinelli et al., 2020).

$$COE = \frac{CA_{total}}{P_{ER} + P_{grid}} \quad (4)$$

Where, P_{ER} is the energy produced by renewable sources and includes solar energy, hydrokinetic turbine and biomass. and P_{grid} is energy supplied by the grid.

The economic analysis was performed with the costs and life time shown in the ttttt, and a nominal interest rate of 10% was considered.

Table 2. Costs considered in the microgrid

Equipment	Cost [USD]	Lifetime
Solar panel	1.506,19	25 years
Inverter	1.344,81	15 years
Batteries	1.075,85	3 years

Hydrokinetic turbine	1.613,77	20 years
Biomass gasifier	1.143,09	20 years
Internal combustion engine	753,09	15 years
Operation and maintenance	4% of the investment	NA
Biomass cost	0.135/ton	NA
Grid power	0,149 /kWh	NA

The simulated microgrid operates according to the algorithm shown in Figure 9, gives priority to energy generated from renewable sources and injects excess energy into the grid.

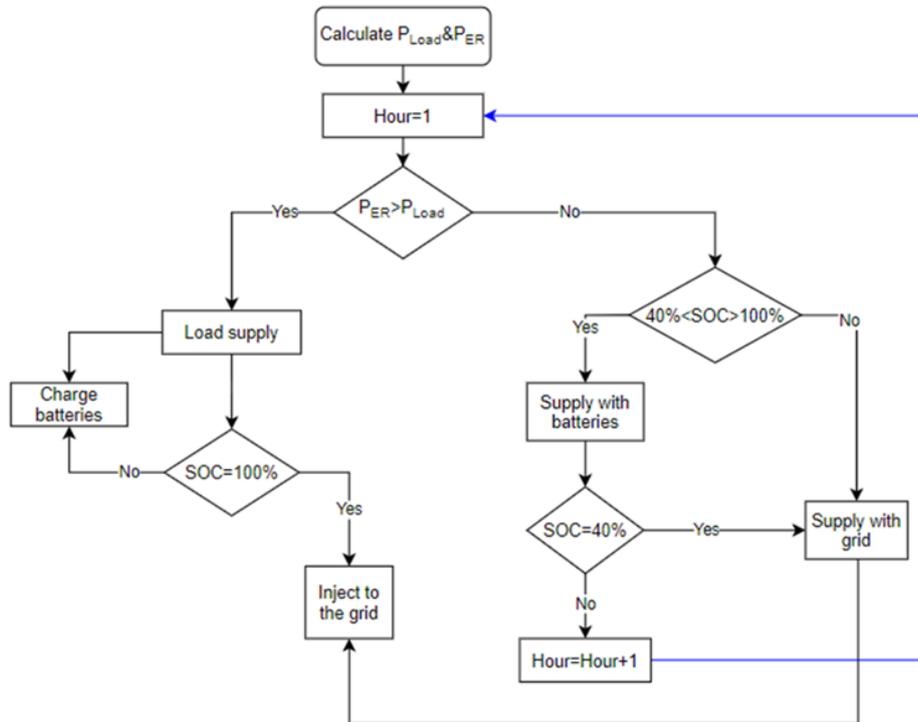


Figure 9. Algorithm of operation of the microgrid

In the above diagram SOC represents the battery charge level, for which a minimum value of 40% was defined. P_{load} is the energy demand of the building.

The optimization problem to be solved is posed from the equation (5) to the equation (8).

$$\min\{COE\} \quad (5)$$

$$\min\{P_{grid}\} \quad (6)$$

Subject to:

$$P_{Stored} + P_{grid} + P_{ER} = P_{load} + P_{injection} \quad (7)$$

$$P_{ER}, P_{grid}, P_{Stored}, P_{load}, P_{injection} \geq 0 \quad (8)$$

Where, P_{store} is the energy stored in the batteries and $P_{injection}$ is the surplus energy injected into the grid.

3. RESULTS AND DISCUSSION

This work analyzes a generation microgrid to meet the energy demand of a building at the University of Cordoba in Colombia using the Homer PRO simulation software, which allowed analyzing the different system configurations that meet the system load requirements and selecting the one with the lowest generation cost. The model developed in the software evaluated 5814 configurations of which only 3872 were viable, these were categorized according to their

architecture and Table 3 shows the five best alternatives together with the base case, where the grid supplies 100% of the system's energy.

Table 3. Best system alternatives categorized by microgrid architecture

Architecture	Solar (kWh/yr)	Hydrokinetics (kWh/yr)	Biomass (kWh/yr)	Grid (kWh/yr)	COE (USD/kWh)	Renewable fraction (%)
Solar-Batteries-grid-hydrokinetics	9863	5518.80	0	24600	0.137	36.60
Solar-Batteries-grid	9550	0	0	30165	0.146	22.20
Batteries-grid-hydrokinetics	0	5518.80	0	33611	0.148	13.30
Solar-Biomass-Batteries-grid-hydrokinetics	9391	5518.80	9291	15782.8	0.260	59.20
Solar-Biomass-Batteries-grid	9742	0	9622	20392.53	0.267	47.40
Base case (100 % Grid)	0	0	0	38779	0.149	0

Table 3 shows that the optimal system configuration is the solar-batteries-grid-hydrokinetics architecture, which has a generation cost of 0.137 USD/kWh, an NPC of 68976 USD and a renewable energy share of 36.60%. Figure 10 shows the distribution of monthly energy generation in this architecture. It is also evident that the system consumes more than 50% of the energy from the grid, since the renewable generation systems are not able to supply all the demand, however, they present a high penetration of the grid.

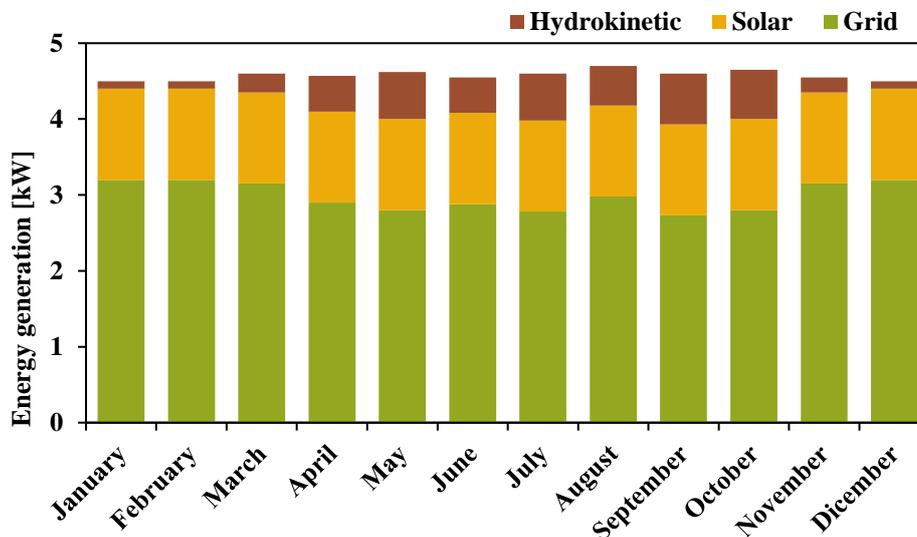


Figure 10. System power generation by month and source

Figure 10 shows that the generation of solar energy in the different months remains approximately constant, which is since throughout the year, the department of Cordoba receives high solar radiation, additionally it is observed that the generation of energy with hydrokinetic turbine, presents variations month to month, due to fluctuations in the speed of the river, being September the month with the highest energy produced.

Figure 11 shows the cash flow over the 25-year life of the system, the green bars represent the initial investment required, while the orange bars represent the replacement cost of the system components, which have a useful life of less than 25 years. The brown bars represent the operating cost of the microgrid and finally the blue bar indicates the money that can be obtained by scrapping some components at the end of their useful life.

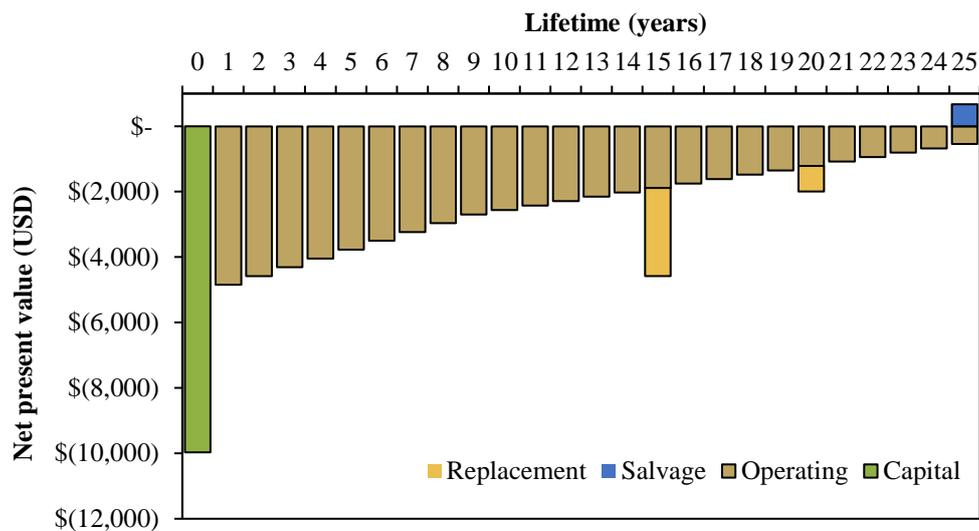


Figure 11. Generation system cash flow

Comparing the optimal alternative with the base case (100% energy from the grid) we obtain an internal rate of return (IRR) of 11.90%, with an investment recovery time of 9 years and 8 months. This indicates that the proposed microgrid is viable from the economic point of view, given that the reference interest rate (10%) is lower than the IRR, however, it should be considered that the two values are very close, so the project is susceptible to loss of viability in the event of variations in the proposed costs.

4. CONCLUSIONS

The integration of renewable energy sources through microgrids proved to be viable for the case study of the University of Cordoba, estimating an internal rate of return of 11.90% for the optimal generation alternative, using the following technologies: photovoltaic systems, hydrokinetic turbine, energy storage through lithium batteries and interconnection with the grid. The optimal generation system presented an energy cost 8% lower than the commercial rate in Colombia and an investment recovery time close to 10 years, showing that generation with solar energy and hydrokinetic turbine is an interesting alternative in the department of Córdoba. On the other hand, biomass is an energy source with great potential, but its use by means of gasification technology does not seem to be viable on a small scale, so this alternative should be evaluated at higher generation capacities and the development of local technology can also be studied to reduce the high initial investment costs.

5. ACKNOWLEDGEMENTS

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