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Economic Assessment of the Potential for Renewable Based Microgrids Generation Systems: An Application in a University Building

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ABSTRACT

This study evaluates the economic feasibility of implementing renewable energy-based microgrids at the University of Córdoba, Montería, Colombia. Simulations and optimizations were conducted using the HOMER Energy software, considering local renewable resources with significant potential. The analysis identified the combination of grid energy, photovoltaic systems, and a hydrokinetic turbine as the optimal solution, yielding a levelized cost of energy (LCOE) of 0.137 USD/kWh, an internal rate of return (IRR) of 11.9%, and a payback period of approximately 10 years. These results demonstrate the economic viability of microgrid implementation under these specific conditions. In contrast, the use of biomass gasification proved to be financially unviable due to its high initial investment costs, indicating the need for local technological development to reduce these barriers. Overall, the proposed system presents a sustainable and cost-effective alternative for energy generation in university facilities, contributing to energy diversification and long-term environmental benefits.

Keywords: Homer Energy, IRR, Microgrids, Renewable Sources
JEL Classifications: C6, O3, Q3, Q4

1. INTRODUCTION

Microgrids have emerged as an innovative response to contemporary energy challenges. These localized energy systems integrate multiple renewable energy sources into a cohesive and efficient electrical network. Microgrids can operate independently or in conjunction with the main grid, offering greater resilience and reliability in energy supply. The use of advanced technologies, such as smart grid solutions and energy storage systems, microgrids can optimize the generation, distribution, and consumption of electricity. This optimization is crucial for addressing the intermittency and variability associated with renewable energy generation, ensuring a stable and reliable energy supply (Almihat, 2023; Li et al., 2022). Furthermore, microgrids can facilitate demand response strategies, enabling a better alignment of energy supply with consumption patterns and thereby reducing peak demand pressures on the grid (Shafiee-Rad et al., 2021).

The integration of renewable energy sources into microgrids significantly reduces greenhouse gas emissions, thereby contributing to global efforts to mitigate climate change (Ganesan et al., 2017). On the other hand, the use of local renewable energy resources, microgrids can stimulate local economic development, reducing energy costs and generating employment opportunities in the installation, maintenance, and operation of renewable energy systems e (Ali et al., 2023; Boche et al., 2022). Moreover, local energy production can stimulate economic development by enabling the reinvestment of funds that would otherwise be spent on imported energy into the local economy, fostering new business opportunities and creating local jobs (Worku et al., 2021).

Microgrids offer a promising solution to address many of the challenges facing the traditional power grid, including increased resilience and reduced carbon emissions. However, the high initial cost of developing and installing microgrid infrastructure is a major barrier to their widespread adoption, particularly in regions with limited financial resources. To overcome this challenge, policy makers and stakeholders must explore innovative financing mechanisms and provide incentives to encourage investment in microgrids (Fridgen et al., 2018). Previous studies have highlighted that the economic viability of microgrids is strongly influenced by the structure of electricity tariffs and the regulatory environment, which can vary significantly across different regions (Vu et al., 2018). Traditional financing models may not adequately address the unique characteristics of microgrid projects, creating a gap in the capital available for development (Xu et al., 2023).

Although, there are research about the economic challenges of microgrids, the complexities of microgrid economics necessitate more comprehensive models. Additionally, the economic impacts of microgrids on local communities, including job creation and energy cost savings, require further exploration (Tsianikas et al., 2021). The studies have shown that the capital investment required for microgrid systems can be substantially higher than that of traditional energy solutions, necessitating a comprehensive analysis of potential returns on investment (Lee et al., 2021). Likewise, Adefarati and Obikoya (2019) demonstrated that integrating renewable energy technologies into microgrids can lead to significant reductions in costs associated with carbon emissions and operational expenses compared to fossil fuel-based systems. Such evaluations provide a clearer picture of the overall economic impact.

The current state of microgrid technology is characterized by a variety of design and operation strategies. For instance, recent studies have explored the optimal sizing and dispatch of microgrid components, such as photovoltaic (PV) systems, wind turbines, and battery storage, to maximize efficiency and minimize costs (Gómez-Hernández et al., 2019; Kama et al., 2022). Hybrid microgrids have been the subject of research aimed at developing advanced energy management systems that utilize predictive control strategies to optimize operation and guarantee a stable and reliable energy supply (Akinyele et al., 2018; Elkazaz et al., 2020). In the field of microgrid research, a variety of studies have emerged addressing diverse aspects of their implementation and operation. These include techno-economic analyses that assess the financial feasibility of microgrid projects (Quintero-Molina et al., 2020; Sánchez et al., 2018). Additionally, case studies conducted in regions such as Colombia have demonstrated that microgrids can provide a viable solution to energy access challenges faced by rural and marginalized communities, contributing to sustainable development (Colmenares-Quintero, 2023; García-Vera et al., 2020).

A significant gap in the literature is the dearth of detailed economic models specifically designed for microgrid applications in educational institutions. While previous studies have explored microgrid configurations and their technical aspects, there has been a limited focus on the economic implications of implementing these systems in university settings. This study fills this void by presenting a robust economic model that evaluates the costs, savings, and potential returns on investment associated with deploying microgrids at the University of Córdoba. This model not only considers capital expenditures but also operational costs and long-term financial benefits, providing a holistic view of the economic viability of microgrids in an academic context. Moreover, the study utilizes localized data, such as meteorological information and university-specific energy consumption profiles, to enhance the accuracy of its economic assessments. The central objective of this study is to assess the economic feasibility of implementing a renewable energy-based microgrid at the University of Córdoba, Colombia, considering various cost-benefit scenarios.

2. MATERIALS AND METHODS

This work analyzes a generation microgrid to meet the energy demand of the engineering building at the University of Cordoba (Colombia). To this end, the Homer Energy Pro® is used to assess different grid configurations to meet building demand, selecting the configuration with the lowest generation cost. In this case, the Homer Energy Pro® software was used to simulate the grid-connected system considering solar systems, one hydrokinetic turbine, and one biomass gasification system integrated to an internal combustion engine. A storage system with lithium-ion batteries is considered in this case. A microgrid with a hydrokinetic turbine, a biomass gasification and a solar energy system is simulated to supply the building demand combined with the local power grid. The generation distribution and economic feasibility were assessed in this case.

2.1. Case Study Description

The University of Cordoba is a public higher education institution with more than 60 years of service. This study focuses on the engineering building (Figure 1).

The building has 4 floors, including offices and classrooms. Regularly, the building operates between 6:00 am to 9:00 pm from Monday and Friday.

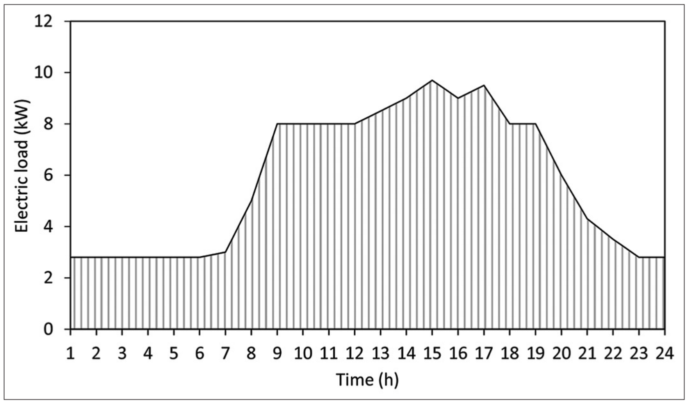
2.2. Power Demand Profile of the Building

The electric 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 average electric load profile measured between Monday and Friday.

Based on the power demand measured in the building, the daily consumption of electricity averages 118 kWh between Monday to Friday, dropping to 67.21 kWh during the weekend. A maximum random variation of 10%/h and 15% day-day was defined for the

Figure 1: Engineering building

Figure 2: Electric load profile of the building



variability of data over time. This is required to simulate small transient loads.

2.3. Renewable Energy Sources Available for Microgrid Systems

The department of Córdoba is in the northwest of Colombia, with a weather ideal for solar energy systems (Mendoza Fandiño et al., 2021). Moreover, the department mostly depends on agriculture activities, generating large amounts of biomass wastes (Sagastume et al., 2021). Furthermore, the river Sinú (i.e., the largest in the department) is close to the engineering building.

2.3.1. Solar radiation

Figure 3 shows the monthly average radiation measured daily in Monteria (IDEAM, 2020).

The results show that solar radiation average daily averages between 4.50 and 5.03 $\frac{\text{kWh}}{\text{m}^2 \cdot \text{day}}$ through the year. The highest values coincide with the dry seasons, while the lowest values coincide with the rainy seasons. Moreover, the clearness index varies between 0.54 in January and 0.46 in September.

2.3.2. River velocity

Based on the measurements of (CVS, 2018) the variation of the river velocity is depicted in Figure 4.

The figure shows that the velocity in the river varies from 1 to 2 m/s through the year. Particularly, between April and October the velocities vary from 1.8 to 2.0 m/s because of the rainy seasons. Moreover, between November and March the velocity varies from 1 to 1.4 m/s because of the dry season.

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

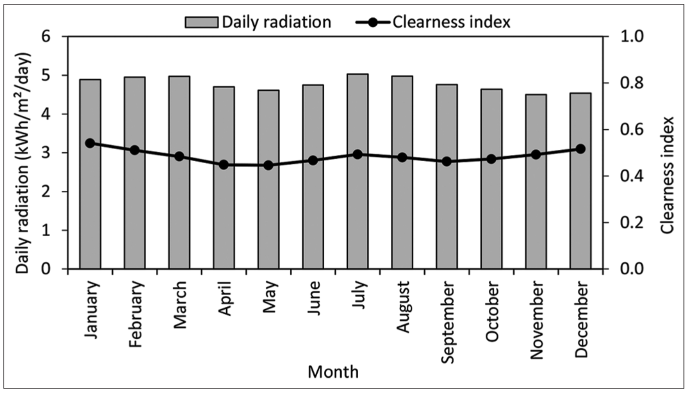
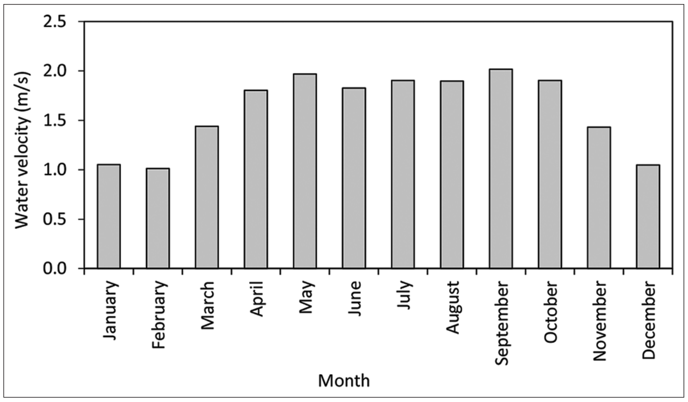


Figure 4: Monthly average of the water velocity at the Sinú river (CVS, 2018)



2.3.3. Agricultural biomass wastes

The department of Córdoba has an annual production of 30,855 t of maize cob (Fenalce, 2019). Figure 5 shows the daily demand of maize cob biomass for the gasification system, and the availability through the year.

Maize harvest is developed between August and March where the availability of maize cob biomass varies from 124 to 870 t/day. Moreover, the available gasifier requires 0.12 t/day to operate. Given the seasonality of maize, between April and July is necessary to storage biomass during the harvest season.

2.4. Topology of the Microgrid Simulated

Figure 6 shows the diagram of the microgrid proposed.

The microgrid proposed consists of an AC and a DC bus interconnected through a converter. The electric load of the building was 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.

2.4.1. Solar panels

Table 1 shows the characteristics of the solar panels selected.

The photovoltaic system required has a maximum capacity of 3.6 kW. Thus, it needs 12 Jinko Eagle PERC60 300W panels.

Figure 5: Maize cob biomass demand and availability through the year (Fenalce, 2019)

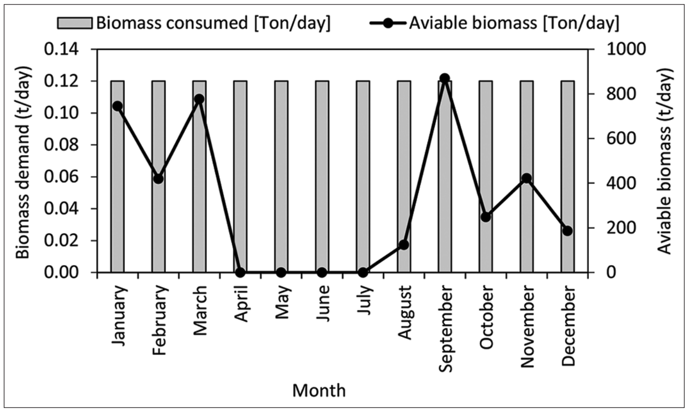


Figure 6: Proposed microgrid

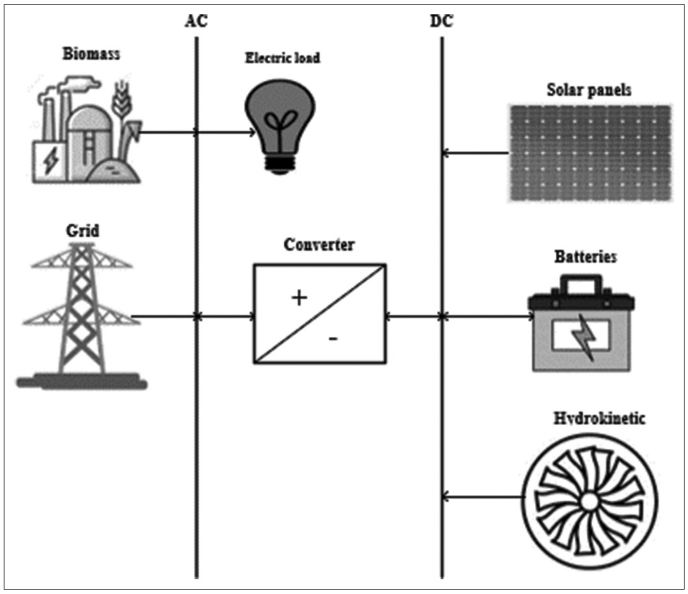


Table 1: Solar panel characteristics

Model	Jinko Eagle PERC60 300W
Type	Flat plate
Manufacturer	Jinko Solar
Rate Capacity (kW)	0.30
Temperature Coefficient	−0.39
Operating Temperature (°C)	45
Efficiency	18.33

2.4.2. Gasification system

A gasification system to produce syngas from maize cob was manufactured as shown in Figure 7.

Syngas is produced with a calorific value of 5 MJ/kg in the gasifier. For a demand of 0.12 t of maize cob per day, the system will produce from 12 to 17 kW of syngas during the day. The gasification system was combined with a 6.5 kW Gunset internal combustion engine. Figure 8 shows the efficiency curve of the engine.

The engine operates with an efficiency of 30% in the range considered for the system (i.e., between 3.8 kW and 6.3 kW).

2.4.3. Hydrokinetic turbine

Based on the characteristics of the water flow in the river, a generic turbine with a capacity of 1 kW is selected. The characteristic power curve of the turbine is shown in Figure 9.

2.5. Economic Assessment and Optimization

The economic assessment considers the fixed and variable costs of the system. The software in this case assesses the net present cost (NPC) and the unit cost of energy (COE). The NPC is the present cost of the difference between the costs and revenues during the life of the system. The NPC considers the capital, operating and maintenance costs. The NPC is calculated as (Baldinelli et al., 2020a):

$$\mathrm{NPC} = \frac{\mathrm{CA}_{\mathrm{total}}}{\mathrm{CRF}} \tag{1}$$

where, CAtotal is the total annual cost and CRF is the capital recovery factor.

The capital recovery factor was calculated as:

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

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

$$i = \frac{i_0 - f}{1+f} \tag{3}$$

where, i0 is nominal interest rate and f is annual inflation rate.

The unit COE, which is a function of the annual cost and of the energy consumed in the system (i.e., the energy from renewable sources and from the grid), is calculated like (Baldinelli et al., 2020b):

$$\mathrm{COE} = \frac{\mathrm{CA}_{\mathrm{total}}}{P_{\mathrm{ER}} + P_{\mathrm{grid}}} \tag{4}$$

where, PER is the energy from renewable sources (i.e., solar fotovoltaic, hydrokinetic turbine, and biomass gasification), and Pgrid is the energy from the grid.

The economic analysis was performed with the costs and lifetime shown in Table 2, considering a nominal interest rate of 10%.

The microgrid simulated operates according to the algorithm shown in Figure 10.

The algorithm prioritise the energy generated from the renewable sources, injecting the surplus electricity into the grid. In this case, SOC stands for the battery state of charge, with the minimum defined at 40%, while P_{load} is the energy demand of the building.

The optimization problem looks to minimize the objective functions:

Figure 7: Gasification power generation system

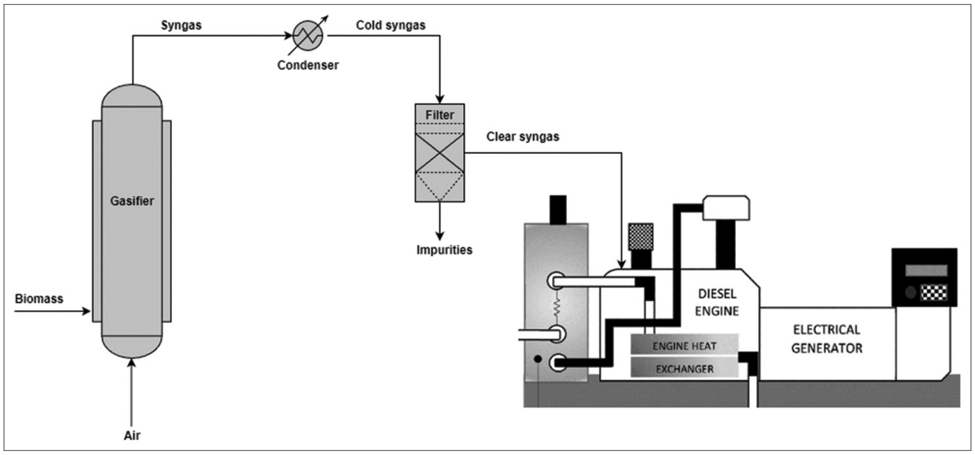


Figure 8: Characteristic curve of the simulated engine

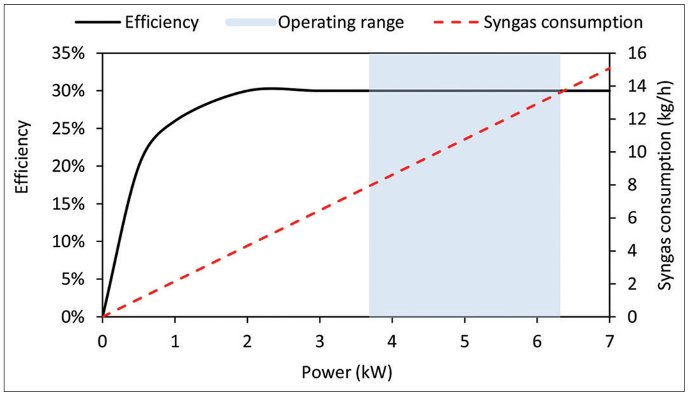
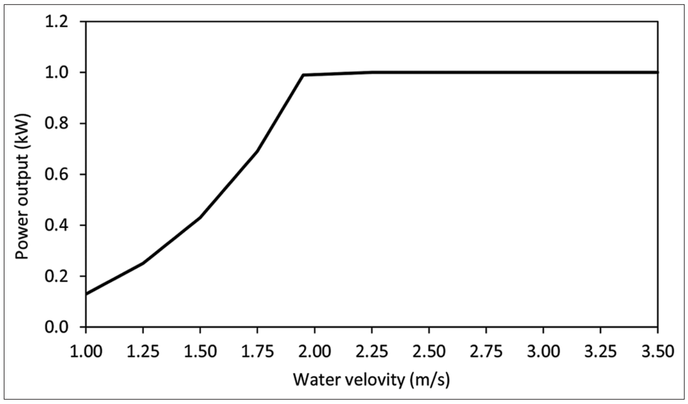


Figure 9: Power curve of the turbine under study Based on the water velocity in the river, the turbine will operate between 0.13 and 0.99 kW



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

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

This functions are constrained by the equations:

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

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

where, P_{store} is the energy stored in the batteries and $P_{injection}$ is the electricity surplus injected to the grid.

Table 2: Costs considered in the microgrid

Equipment	Cost (USD)	Lifetime
Capital cost		
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 (% of capital cost)	4%	-
Biomass cost (USD/t)	0.135	-
Grid power (USD/kWh)	0.149	-

3. RESULTS AND DISCUSSION

A total of 5,814 configurations were simulated on the software. Of these configurations, 3,872 were technically feasible. In this case, configurations were categorized according to their architecture. Table 3 shows the best alternatives obtained and the base case in which the grid supports 100% of the building's demand.

The table shows that the lowest COE corresponds to the Battery – G – H configuration, which can support 36.6% of the electricity demand in the building, at a COE of 0.137 USD/kWh. The NPC for this configuration amounts 68,976 USD. Other configurations have a higher share of renewables, yet at a higher COE.

Figure 11 shows the monthly energy generation for the optimal configuration.

The results show that from 30% to 40% of the electricity is supported with renewables. Thew results show that solar energy remains rather constant through the year, while the hydrokinetic turbine varies from 0.1 to 0.67 kW during the year.

Figure 12 shows the NPC calculated for 25 years of the microgrid operation. The initial capital cost in year 1 requires 10,000 USD. In years 15 and 20 the replacement costs of some system components with a lifespan under 25 years were considered. The revenue that can be obtained from wasted components in recycling companies was also considered.

Table 3: Best system alternatives categorized by microgrid architecture

Configuration	Solar (S) (kWh/year)	Hydrokinetics (H) (kWh/year)	Biomass (B) (kWh/year)	Grid (G) (kWh/year)	COE (USD/kWh)	Renewable share (%)
Bat. – G – H – S	9,863	5,519	0	24,600	0.137	36.6
Bat. – G – S	9,550	0	0	30,165	0.146	22.2
Bat. – G – H	0	5,519	0	33,611	0.148	13.3
Bat – B – G – H – S	9,391	5,519	9,291	15,783	0.260	59.2
Bat. – B – G – S	9,742	0	9,622	20,3923	0.267	47.4
Base case (100% G)	0	0	0	38,779	0.149	0

*Bats: Batteries

Figure 10: Microgrid operating algorithm.

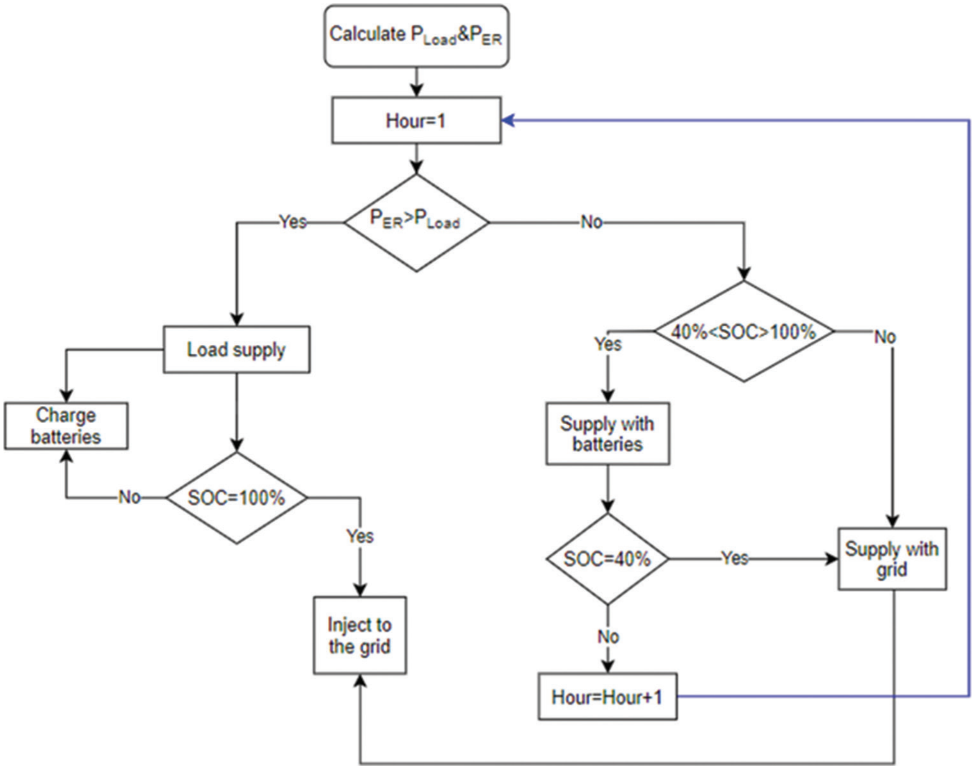


Figure 11: System power generation by month and source

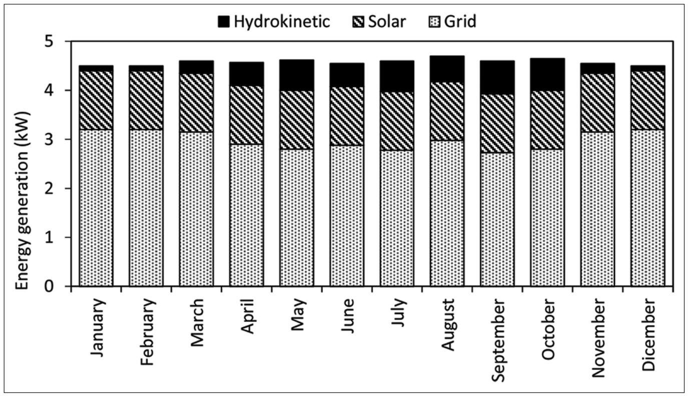
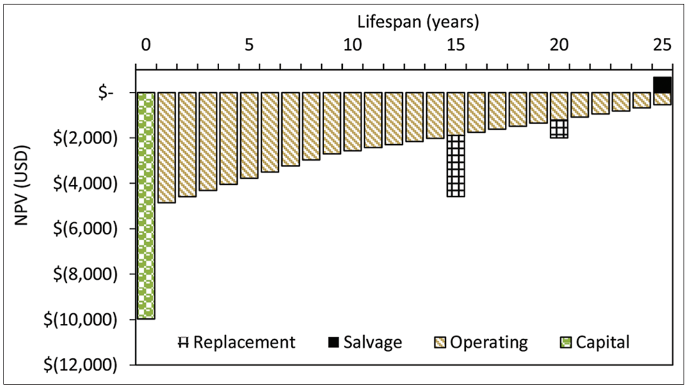


Figure 12: Economic assessment of the optimum configuration



Contrasting the optimal alternative to the base case 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 microgrid optimal configuration is economically feasible and might be attractive considering that the reference interest rate (10%) is lower than the IRR. However, these values are very close and variations in the costs can lead to a loss of viability.

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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