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Optimal Analysis of Microgrid with HOMER According to the Existing Renewable Resources in the Sector of El Aromo and Villonaco, Ecuador †

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Abstract: In today's world, the integration of renewable energies is essential to meet the surging global energy demand and reduce pollution. Ecuador, with its favorable geographical location, boasts abundant renewable resources. Currently, the country has large-scale renewable energy projects such as "El Aromo" in Manabí, led by Solarpack, and Villonaco in Loja, with its wind power plant. In this study, Homer Pro software is used to simulate two microgrids with solar and wind energy in the mentioned sectors, allowing us to conduct comprehensive economic and energy analyses to determine the most viable configurations.

Keywords: distributed; Ecuador; generation; optimization; photovoltaic; renewables; wind

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1. Introduction

This work presents a study of two grid-connected microgrids in different areas of Ecuador, incorporating solar and wind energy sources. The study areas are El Aromo in the province of Manabí, where the country's largest photovoltaic power station is projected, and Villonaco, located in Loja, where large-scale wind projects are being developed. As documented in [1–4], there is currently a growing interest in integrating renewable energy sources to form energy microgrids. Simulations allow us to predict behaviors and facilitate decision-making regarding microgrid characteristics.

Currently, several computer tools can be employed for the design, planning, and analysis of microgrids, including ETAP, OPAL-RT, and Sandia's Microgrid Design Toolkit (MDT). However, HOMER (hybrid optimization of multiple energy resources) Energy Plus has been the most widely used and documented tool for the design and analysis of microgrids [1–3]. It offers numerous functionalities, such as annual energy analysis, optimization, and economic analysis.

Using HOMER, we propose an economic comparison of two scenarios: one with the use of renewable energies and another without them. We conduct cost and efficiency assessments. It is important to highlight that HOMER also presents economic combinations of the simulated renewable energy systems, enabling comparison and decision-making among various configurations. This provides a more robust approach to the optimal selection of energy solutions. The following section presents details of the methodology, experiments, results, and conclusions.

2. Theorical Framework

HOMER Pro (hybrid optimization of multiple electric renewable energies) is a tool that allows us to simulate various configurations in a system through its sensitivity analysis and optimization algorithms [5].

The software incorporates two optimization algorithms: the original grid search algorithm, which simulates all possible microgrid configurations within the search space, and a derivative-free algorithm that identifies the system with the lowest cost. After these algorithms complete their processes, HOMER generates a list of all feasible configurations, ranked by net annual cost or life cycle cost. Additionally, HOMER allows for sensitivity analysis, where the user can define sensitivity variables as inputs, and the software will initiate the optimization process for each of the entered sensitivity variables [6,7].

Depending on the number of variations, HOMER systematically explores all possible combinations and optimizes them. In this specific study, sensitivity variables were not included.

2.1. Levelized Cost of Energy (LCOE)

The levelized cost of energy is a key economic performance metric, enabling us to estimate the cost of electricity production for each evaluated case [3,8–10]. It represents the average cost per kWh of useful electricity produced by the grid.

The cost of electricity production can be computed as follows:

$$LCOE = \frac{C_y - C_b H_L}{E_L} \quad (1)$$

where C_y is total annualized cost per year (USD/year), C_b is Marginal boiler cost (USD/kWh), H_L is the total thermal load served per year (kWh/year), and E_L is the total electrical load served per year (kWh/year).

H_L is the portion of the annualized cost that results from serving the thermal load. In systems such as wind or photovoltaics, which do not serve a thermal load (H_L = 0), this term is zero.

2.2. Net Present Cost (NPC)

The net present cost (or life-cycle cost) of a component is the present value of all the costs of installing and operating the component over the project's lifetime, minus the present value of all the revenues that it earns over the project's lifetime. HOMER calculates the net present cost of each component in the system and of the system as a whole [5]. It is the monetary value of the difference between income and expenditure flows, subtracting the initial investment [11,12].

2.3. Operating Cost (OC)

The operating cost is the annual value of the sum of all costs and incomes excluding the capital cost. The objective of the optimization is to seek a reduction in the operating cost of the microgrid [13,14]. The operating cost equation is as follows:

$$OC = C_y - C_c \quad (2)$$

where C_c is the total annualized capital cost per year (USD/year). The total annualized capital cost is equal to the total initial capital cost multiplied by the capital recovery factor [10].

2.4. Initial Capital Cost

Total cost of installing each element at the beginning of the project. This includes equipment installation costs, equipment costs, materials, or auxiliary systems for installation.

3. Existing Resources

Thanks to Ecuador's strategic location and the presence of the Andes Mountain range, the country boasts significant photovoltaic potential [15–17].

Irradiance and wind data, along with climatic information, are directly obtained from NASA's website and via the HOMER software once the microgrid's design location is selected [17]. To validate this data, it employs historical ground-based measurement data from weather stations located in El Aromo and Villonaco; this data is available at meteo-scinergy.epn.edu.ec (accessed on 27 June 2023).

3.1. Solar Resource in El Aromo Microgrid

In Figure 1, it can be observed that the months with the highest irradiance in the El Aromo sector are January, March, April, and May, reaching an approximate average of 6 kWh/m^2/day. We can observe the data of global horizontal solar irradiance in the Aromo area for each month of the year, with an annual average irradiance of 4.82 kWh/m^2/day [18].

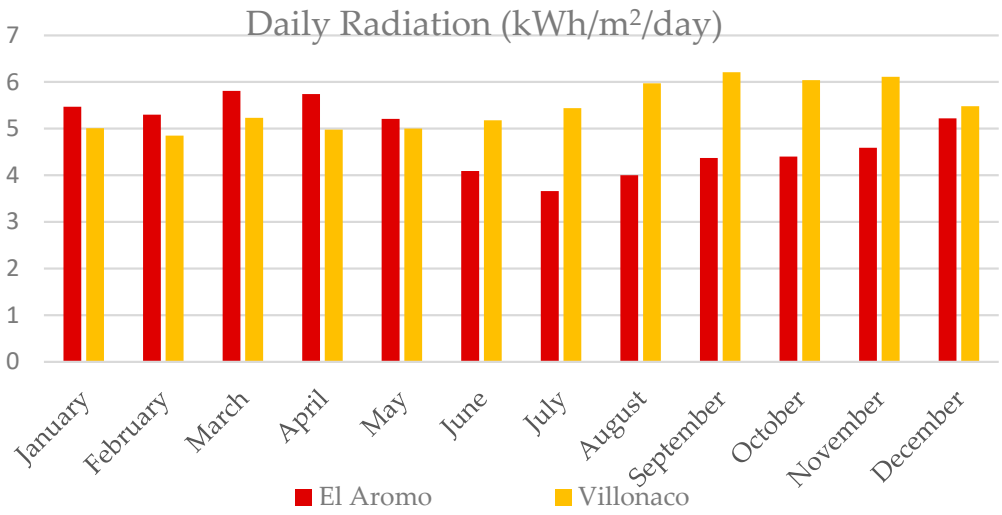

Figure 1. Daily average radiation in El Aromo and Villonaco.

In Villonaco, as shown in Figure 1, it can be observed that the months with the highest solar irradiation are August, September, October, and November, reaching average radiation levels of 6 kWh/m^2/day. As observed in the available resource data in Villonaco, there is an average annual irradiation higher than that in the Aromo sector. In Aromo, it is 4.82 kWh/m^2/day, meanwhile in Villonaco, it is 5.46 kWh/m^2/day.

3.2. Wind Resource in El Aromo and Villonaco Microgrid

From the NASA database, monthly average wind speed data are obtained. The graph shows the values for each month, giving an annual average wind speed of 2.78 m/s. Wind turbines start operating at 3–4 m/s and reach maximum power generation at 13–14 m/s. The integration of wind power in El Aromo may not be feasible, but results will be obtained through software optimization. In Figure 2, the months with the highest average wind speed are June to November, with speeds of 3 m/s.

The wind resource is also superior in Villonaco with an annual average wind speed of 3.02 m/s, while the average wind speed in Aromo is 2.78 m/s. In Figure 2, it can be observed that the months with the highest wind speeds in Villonaco are June, July, and August, surpassing average speeds of 3 m/s.

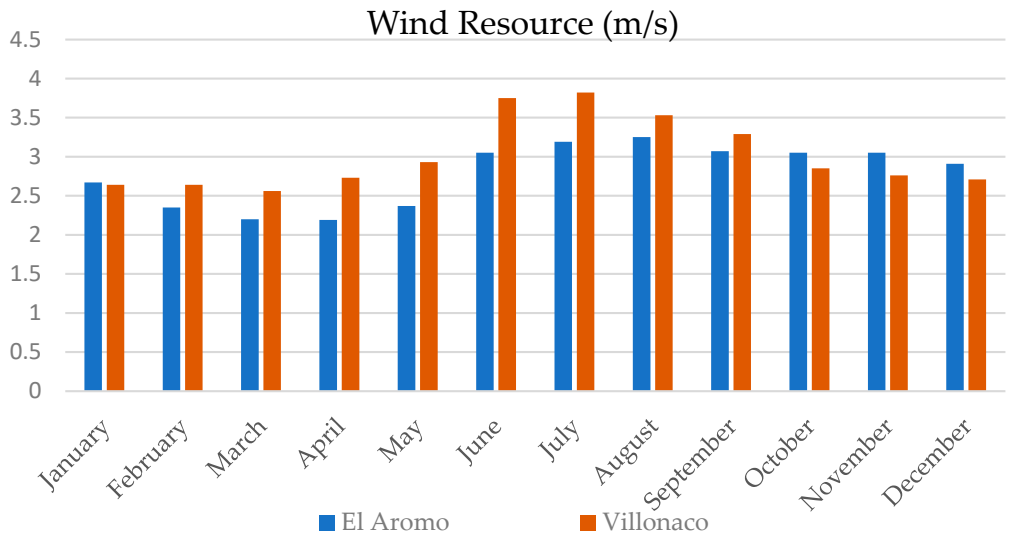

Figure 2. Wind resource in El Aromo and Villonaco.

4. Characteristics of Modules Used in the Design of Microgrids

Given that this is a comparative study between two different areas with different environmental resources, the microgrid designs will be carried out using modules with identical characteristics. This is to ensure an objective analysis focused primarily on the quantity of existing resources in each sector.

4.1. Grid

Distribution networks are a crucial component of power systems, because all the generated power needs to be distributed among users who are scattered across vast territories [16]. Residential loads are connected to the local grid through the grid module, as well as to the microgrid integrated with photovoltaic and wind generation, forming a hybrid system. The grid module allows us to incorporate real-time or scheduled energy purchases and sale rates. In this case, it has been configured using the simple tariff mode, enabling the input of constant energy purchases and sale prices, as well as the capacity to sell energy back to the distribution company or grid.

For the calculation and input of data in the simple tariff, an average value of the cost per kWh and the purchase cost based on the actual average tariff in Ecuador was estimated. The price of grid energy is USD 0.09/kWh and selling price to the grid is USD 0.07/kWh.

4.2. Photovoltaic Module (PV)

A photovoltaic module (PV) can convert solar energy into electrical energy, and the module allows us to input a matrix of photovoltaic panels and their complementary elements into the microgrid. HOMER's library provides a wide selection of panel brands and generic elements with different power generation capabilities. We use as inputs capital costs, replacement costs, and annual operation and maintenance costs for each of these elements. It is important to consider the costs associated with the photovoltaic system, which may include costs of photovoltaic panels, installation costs, wiring costs, additional accessories, and mounting costs, among others [19–22].

These additional costs may also include the power electronics parts such as, in this case, the DC-AC converter module, which has not been included in this case.

The specification of the selected solar module is shown in Table 1, and its mentioned reference costs have been tabulated in Table 2.

The nominal capacity of the photovoltaic array is 4.4 kW, which allows covering almost half of the demand.

Table 1. Properties of PV module Fromius Symo 4.5-3-S with generic PV.

Variable	Description
Type	Flat plate
Nominal capacity (kW)	4.4
Temperature coefficient	−0.41
Operation temperature (°C)	45
Efficiency (%)	17.3
Manufacturer	Fromius

Table 2. Costs of PV module Fromius Symo 4.5-3-S with generic PV.

Capacity (kW)	Capital (USD)	Replace (USD)	O&M (USD/year)
1	2200	2200	10

4.3. Storage Module

In photovoltaic systems, batteries are mainly used as energy storage systems due to the temporal displacement that may exist between generation periods (during the day) and consumption periods (during the night), allowing the operation of loads when the photovoltaic generator alone cannot generate sufficient power to supply consumption [23]. An idealized battery has been integrated into the photovoltaic system through the storage module, which allows for the independent configuration and sizing of energy and power. This type of battery operates based on a flat capacity curve.

The specification of the selected storage module is shown in Table 3, and its mentioned reference costs have been tabulated in Table 4.

Table 3. Properties of storage module RedT5kW-20kWh energy storage.

Variable	Description
Nominal voltage (V)	48
Nominal capacity (kWh)	20
Nominal capacity (Ah)	417
Round-trip efficiency (%)	75
Maximum charge current (A)	105
Maximum discharge current (A)	105
Service life (years)	25
Efficiency (kWh)	876,000

Table 4. Costs of storage module RedT5kW-20kWh energy storage.

Capacity (N°)	Capital (USD)	Replace (USD)	O&M (USD/year)
1	750	750	20

4.4. Converter Module

An important decision must be made regarding whether to establish power consumption in alternating current (AC) or direct current (DC), considering that the standard electrical grid operates on AC, sinusoidal at 60Hz in Ecuador, and the majority of consumer appliances and industrial equipment are designed to function with AC [24]. The converter module becomes imperative for systems necessitating the seamless integration of both AC and DC components, as is the case with integrating the photovoltaic array into the broader microgrid. This module empowers us to precisely define costs and fine-tune the parameters for both the inverter and rectifier, ensuring optimal performance and efficiency. The specifications of the selected converter module are shown in Table 5, and its reference costs have been tabulated in Table 6.

Table 5. Properties of converter module SolarX X3-hybrid5.

Variable	Description
Capacity (kW)	5
Efficiency (%)	97.7
MPPT Efficiency (%)	99
Minimum voltage of MPPT range (Vdc):	180
Maximum voltage of MPPT range (Vdc):	950

Table 6. Costs of converter module SolarX X3-hybrid5.

Capacity (kW)	Capital (USD)	Replace (USD)	O&M (USD/year)
5	400	400	10

4.5. Wind Turbine Module

In wind installations, particularly in smaller and medium-sized setups, achieving extremely high efficiency might not hold the same level of importance, given the freely available nature of wind energy (at least for now). However, optimal performance still holds significance as it facilitates the reduction of rotor diameter, leading to cost savings and addressing construction and mechanical complexities [23–25].

Within the microgrid context, a generic 3 kW wind turbine has been seamlessly integrated to cater to an additional segment of the energy demand. The specifications of the selected solar module are shown in Table 7, and its reference costs have been tabulated in Table 8.

Table 7. Properties of wind turbine module G3 3 kW.

Variable	Description
Capacity (kW)	3
Manufacturer	Generic

Table 8. Costs of wind turbine module G3 3 kW.

Capacity (kW)	Capital (USD)	Replace (USD)	O&M (USD/year)
3	18,000	18,000	180

Figure 3 illustrates the power characteristic curve generated in relation to wind speed for the chosen generator in the simulation.

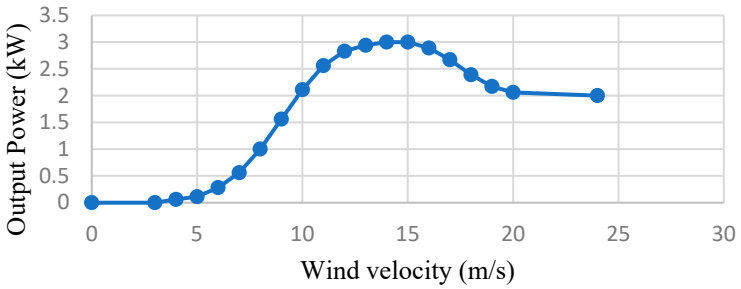

Figure 3. Power characteristic curve of wind turbine module G3.

5. Demand Characteristics

An important strength of this research on electrical consumption projections lies in its distinct seasonality. For electricity producers, understanding which months of the year experience higher or lower electricity consumption is crucial for scheduling maintenance activities on machinery [26].

There are three types of users, each with their own distinct characteristics: residential, commercial, and industrial [27].

The simulated demands will focus on the residential type, utilizing their characteristic load curve but based on the average electrical consumption data for each sector.

5.1. El Aromo's Demand

The grid-connected microgrid simulated in the El Aromo sector features a distinct primary residential load with a demand of 9.97 kWh/day. This demand value corresponds to the average residential demand on the Ecuadorian coast, including the approximate monthly consumption of 100 kWh for an induction cooker [27].

As illustrated in Figure 4, the daily residential load profile in El Aromo displays a distinct demand pattern, with pronounced peaks during the late afternoon and evening hours, coinciding with the times when most consumers are present in their households. This characteristic demand shape accurately mirrors the consumption behavior prevalent in this region.

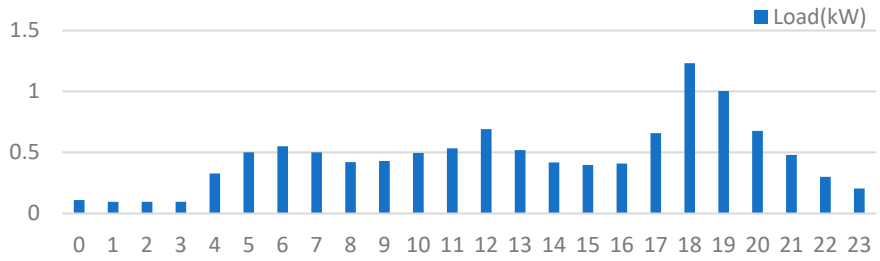

Figure 4. Daily load profile of El Aromo.

5.2. Villonacos's Demand

The demand profile in Villonaco showcases a distinct residential primary load with a daily demand of 8.40 kWh. This demand value aligns with the average residential consumption in the Ecuadorian highlands, encompassing an estimated 100 kWh/month usage from an induction cooker [27].

6. Results

Displayed in Figures 5 and 6 are schematic diagrams showcasing the simulated hybrid microgrid located within Ecuador's Manabí province, specifically in the El Aromo sector. This complex setup seamlessly integrates all the components. Furthermore, an analogous schematic diagram for Villonaco is provided, reflecting a similar configuration of elements. It's worth noting that the disparities primarily pertain to load characteristics and the distinct energy resources accessible in each respective area.

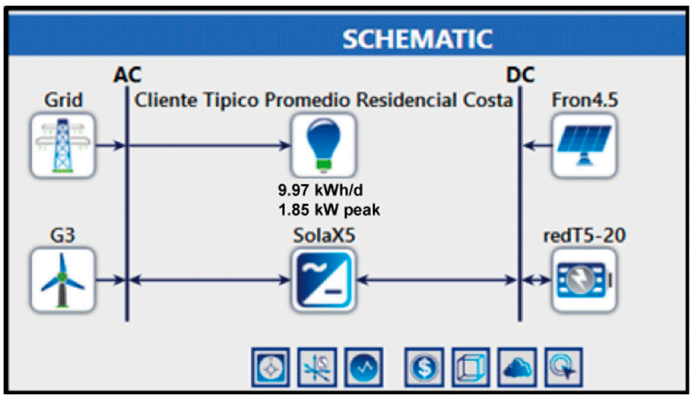

Figure 5. El Aromo microgrid configuration.

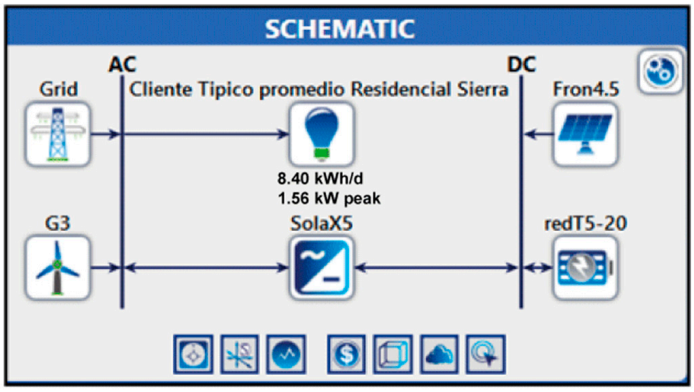

Figure 6. Villonaco microgrid configuration.

6.1. El Aromo Microgrid

The presented case involves a user solely connected to the electrical grid, with an initial capital requirement of USD 0. The annual cost, or the yearly expense that the user would pay to the distribution company for consumption amounts to USD 327.40, equivalent to a monthly fee of USD 27.28. This scenario does not consider the integration of any other type of power generation into the system. Below, in Table 9 is shown the data of sensitivity analysis of this case.

Table 9. Table of sensitivity analysis for El Aromo.

Grid (kW)	LCOE (USD)	NPC (USD)	Operating Cost (USD/year)	Initial Capital Cost (USD)
1	0.09	4,232,505	180	0

Optimization Results

As depicted in the optimization table shown in Table 10, the annual cost for energy consumption solely sourced from the grid amounts to USD 327.40, translating to a monthly payment of USD 27.28. For a residential load characterized as proposed, the most viable choice emerges in the third row. This selection involves integrating the grid with a 4.5 kW photovoltaic panel array (from 4.5 kW) and a 5 kW DC-AC SolarX5 converter. This integration necessitates an initial capital investment of USD 10,080 and yields a negative operational cost of USD −158.62, indicating surplus energy being sold back to the distribution entity. This configuration not only facilitates the long-term recovery of the initial investment but also encompasses the compelling environmental advantages associated with renewable energy utilization.

Table 10. Optimization analysis table displaying possible microgrid combinations for El Aromo sector.

From 4.5 kW	G3	redT5-20	Grid (kW)	SolarX5 (kW)	LCOE (USD)	NPC (USD)	Operating Cost (USD/yr)	Initial Capital (USD)
			1		0.09	4232.505	327.4028	0
		1	1	1	0.1217797	5752.891	356.0538	1150
1			1	1	0.0733681	8029.5	−158.6151	10,080
1		1	1	1	0.08226459	9020.611	−139.9641	10,830
	1		1		0.5696319	26,854.04	684.8985	18,000
	1	1	1	1	0.599184	28,374.42	713.5494	19,150
1	1		1	1	0.2764108	30,664.86	199.9506	28,080
1	1	1	1	1	0.2847995	31,655.97	218.6015	28,830

6.2. Villonaco Microgrid

The annual cost of energy consumption obtained solely from the electrical grid with a fixed rate of USD 0.09 per kWh in Villonaco amounts to USD 275.94, equivalent to a

monthly cost of USD 22.99. Below, in Table 11 is shown the data of sensitivity analysis of this case.

Table 11. Table of sensitivity analysis for Villonaco.

Grid (kW)	LCOE (USD)	NPC (USD)	Operating Cost (USD/year)	Initial Capital Cost (USD)
1	0.09	3567	275.94	0

Optimization Results

Analyzing Table 12, it can be concluded that the most viable configuration option integrates the electrical grid with the photovoltaic panel array from 4.5 kW and the DC-AC converter SolarX5 5kW, requiring an initial capital investment of USD 13,600 and resulting in a negative operating cost of USD -283.99.

Table 12. Optimization analysis table displaying possible microgrid combinations for Villonaco sector.

From 4.5 kW	G3	redT5-20	Grid (kW)	SolarX5 (kW)	LCOE (USD)	NPC (USD)	Operating Cost (USD/yr)	Initial Capital (USD)
			1		0.09	3567.219	275.94	0
		1	1	1	0.1276727	5087.612	304.5916	1150
1			1	1	0.0851245	9928.711	−283.9902	13,600
1		1	1	1	0.09345291	10,919.85	−265.3368	14,350
	1		1		0.6498159	26,081.54	625.1429	18,000
	1	1	1	1	0.6840639	27,601.94	653.7945	19,150
1	1		1	1	0.2724693	32,463.09	66.76398	31,600
1	1	1	1	1	0.2804584	33,458.66	85.75963	32,350

This implies that energy is being sold back to the distribution company, leading to a faster recovery of the initial investment cost in the long term compared to the El Aromo microgrid.

7. Conclusions

The optimal design for the proposed microgrids has been successfully accomplished, providing insightful outcomes that pinpoint the most cost-effective and energy-efficient configurations when integrated with the local distribution utility in each specific case.

The optimization results from HOMER lead us to a firm conclusion: the most optimal setup involves a grid integration strategy incorporating the from 4.5 kW photovoltaic panel array along with the SolarX5 (5kW) DC-AC converter. This optimal arrangement is consistent for both the El Aromo and Villonaco microgrid scenarios.

It can be deduced that the payback period for the initial investment cost, in the context of the proposed average residential consumption within the coastal and mountainous regions of Ecuador, spans around 20 years. However, it's crucial to note that this initial investment cost may pose a considerable hurdle for an average household. To reduce this payback period and promote the adoption of renewable energy, strategies such as government subsidies, accessible financing, public education, and large-scale projects can be implemented, along with improving energy efficiency to make the investment more attractive and profitable in both the short and long term.

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