Journal of Sustainable Bioenergy Systems, 2025, 15(1), 1-16
https://www.scirp.org/journal/jsbs
ISSN Online: 2165-4018
ISSN Print: 2165-400X

Technical and Economic Pre-Feasibility Study for a Micro-Hydro Plant and Solar Photovoltaic System for the Eco-Tourist Village of Mandraka

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How to cite this paper: Ouedraogo, A.L., Bonkoungou, D., Simonguy, E., Korsaga, E., Palm, S.F., Kam, S., Ravoninjatovo, A.O. and Bathiebo, D.J. (2025) Technical and Economic Pre-Feasibility Study for a Micro-Hydro Plant and Solar Photovoltaic System for the Eco-Tourist Village of Mandraka. *Journal of Sustainable Bioenergy Systems*, **15**, 1-16.
https://doi.org/10.4236/jsbs.2025.151001

Received: December 10, 2024
Accepted: January 23, 2025
Published: January 26, 2025

Abstract

Madagascar is well endowed with energy resources, particularly renewable energies. These include watercourses for hydropower, solar irradiation for photovoltaic solar energy, wind for wind power, as well as exploitable surfaces for bioenergy, although these are currently little exploited. What's more, the electricity distribution network covers only a small part of the national territory, which excludes most rural areas. As a result, the population continues to consume fossil fuels, while gradually turning to solar energy (autonomous installation). Rural electrification should be totally oriented towards renewable energies, making the most of hydroelectric sites, solar energy, wind power and biomass, so that production costs are low, enabling us to offer a tariff adapted to subscribers' purchasing power and promote production activities. The aim of this project is to carry out a technical and economic pre-feasibility study of a micro-hydropower plant and a photovoltaic system to supply the village of Mandraka. Initially, field surveys were carried out to establish the consumption profile and estimate household energy expenditure. Next, a sizing, financial pre-analysis and system simulation were carried out to assess the economic interest of the installation. The results of the pre-feasibility study gave a power of 24.64 kW for the micro-hydro plant and 1.58 kW for the solar photovoltaic system, which we oversized to 1.76 kW to compensate for unforeseen circumstances. Finally, a technical-economic study enabled us to obtain a positive NPV for a minimum cost of 1040 Ar, thus concluding that the project is feasible. The results of this study show that most households in this village can afford the cost of electricity consumption.

Keywords

Pre-Feasibility Study, Sizing, Micro-Hydropower Plant, Photovoltaic System, Investment Cost

1. Introduction

The use of fossil fuels in developed and developing countries is leading to the progressive depletion of their resources, which, on the one hand, are becoming increasingly scarce and, on the other, produce greenhouse gases that pollute the atmosphere. In addition, the high cost of dependence on fossil fuels and environmental considerations have been a powerful driver for exploiting the potential of renewable energies over the past decade [1]-[5]. Village electrification using locally available hybrid renewable energy sources is a viable option for eradicating energy poverty [6]. One of the greatest challenges facing the world today is to ensure access to a secure and affordable supply of electricity [7]. Like other developing countries, Madagascar is experiencing difficulties in terms of energy self-sufficiency. The country is well endowed with energy resources, particularly renewable energies. It has a hydraulic potential of some 1500 sites throughout the country. The island has a solar potential of 2000 kWh/m^2·year and an annual sunshine duration of around 2800 hours over the entire country, particularly high in the western and southern regions. Solar radiation exceeds 5500 W/m^2/day. Wind power potential is substantial, estimated at 2000 MW with an average wind speed of 6 to 9 m/s at 50 m above ground level in the northern and southern regions. There are also a number of geothermal energy sources and biomass recovery from agro-industrial waste [8]. Despite the country's enormous potential for renewable energy, the energy sector is still partly dependent on external sources, as most power plants are fuelled by non-renewable resources, mainly heavy fuel oil, the price of which is constantly fluctuating in response to unpredictable changes in the market price of oil.

Mandraka, a tourist village, is unable to satisfy its population and the many tourists who visit. As in other parts of the country, the village has a wealth of renewable energy potential, including watercourses and a significant solar energy deposit. To improve living conditions for the local population and make the village more attractive to tourists, the village needs to be electrified. In this context, rural electrification should be totally oriented towards renewable energies, making the most of hydroelectric sites such as solar and wind power to reduce environmental impacts. This will help reduce the cost of production and enable us to offer a tariff adapted to subscribers' purchasing power and promote production activities.

The hybrid hydroelectric/photovoltaic system makes an effective contribution to alleviating the area's electricity shortage. The combination of hybrid renewable energy and conventional energy resources is more efficient and cost-effective than single-source power systems [9] [10].

The main objective of this project is to carry out a technical and economic pre-feasibility study of a micro-hydro power plant and photovoltaic system for the Mandraka eco-tourism site, using available energy resources. This project will provide this rural population with electrical energy, giving them a better daily and professional life.

2. Overall System Dimensioning

2.1. Sizing the Hydroelectric Micro-Power Station

The hydro condition that can be used as an electricity-generating resource is one that has a particular flow and head capacity, as the electricity generated by micro-hydro is also highly dependent on the height of the waterfall and the water flow.

A visit to the site of the Ecole Supérieure des Sciences Agronomiques (ESSA) enabled us to measure the geographical coordinates of the future hydroelectric power station and the flow rate of the Mandraka river.

Depending on the river flow, small hydropower is often a profitable source of renewable energy.

Figure 1 shows the principle of a micro-hydropower plant.

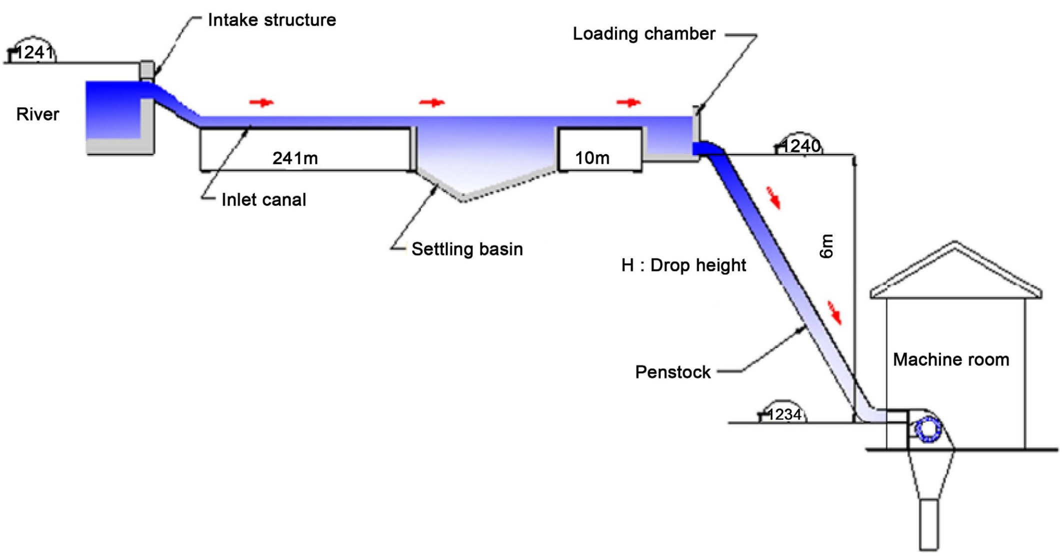

Figure 1. Schematic diagram of the micro-hydropower plant.

It should be noted that the machine room houses several items of equipment, including the hydraulic turbine, the electric generator, the alternator, the electrical cabinet and the transformer, among others.

The geographical coordinates of the components of the hydroelectric micropower station to be installed are summarized in the following Table 1.

From this table, we can calculate the head of the micropower station and determine the main components of the layout.

For this purpose, the opening height H of the water intake is defined by (1).

Table 1. Geographical coordinates of the hydroelectric development.

Location	Latitude	Longitude	Altitude
Barrage	S 21˚53'00", 1	E 47˚26'09", 2	1241 m
Loading chamber	S18˚54'41", 9	E 47˚54'53", 1	1240 m
Factory	S18˚54'41", 9	E 47˚54'53", 5	1234 m

$$H = r + y \tag{1}$$

where r is the freeboard and y is the height of water in the section.

Water velocity in a section of the feeder channel [11]-[13] is given by Chezy's formula (2):

$$V = C\sqrt{R_h \times I} \tag{2}$$

where C is the proportionality coefficient, Rh is the hydraulic radius and I is the longitudinal slope of the channel.

The loading chamber is given by the following equation:

$$S_{chamber} = \frac{V_{cbas} \times S_{duct}}{V_{chamber}} \tag{3}$$

Here $S_{chamber}$ is the cross-sectional area of the charging chamber, S_{duct} is the cross-sectional area of the penstock, $V_{chamber}$ is the velocity at the inlet to the loading chamber et V_{cbas} is the velocity at the outlet from the loading chamber.

The internal diameter of the penstock is deduced from the Hazen-William formula [14]:

$$Q_{\max} = 0.2785 \times \left(\frac{\Delta H}{L}\right)^{0.54} \times C_1 \times D_{in}^{2.63} \tag{4}$$

$$D_{in} = \left(\frac{Q_{\max}}{0.2785 \times \left(\frac{\Delta H}{L}\right)^{0.54} \times C_1}\right)^{\frac{1}{2.63}} \tag{5}$$

where $Q_{\max}$ is the maximum flow carried by the section, L the length of the section, ΔH the difference in altitude between the two ends of the section and C_1 the coefficient of friction of the material used.

The pressure drop equation is as follows:

$$Pd = J \times L \tag{6}$$

where Pd is the pressure drop, J is the pressure drop per metre, L is the length of penstock

The theoretical power available from hydropower can be calculated from the flow rate, water density, net head and local acceleration due to gravity [15]-[17]:

$$P = \eta_{TG} \times \rho \times g \times Q \times H \tag{7}$$

where η_{TG} is the efficiency of the turbine and generator, Q is the flow rate in m^3/s, H_n is the Net height in m.

The specific speed of the turbine is given by (8):

$$n_s = \frac{0.2626 \times N \times P^{1/2}}{H_n^{5/4}} \tag{8}$$

where P is the effective power (kW) of the wind turbine and N is its rotation speed (rpm).

Depending on the values of n_s, the type of turbine best suited to the configuration will be selected.

2.2. Photovoltaic System Sizing

2.2.1. Evaluation of Average Monthly Irradiation in the Study Area

Figure 2 shows the evolution of average monthly irradiation in the village of Mandraka.

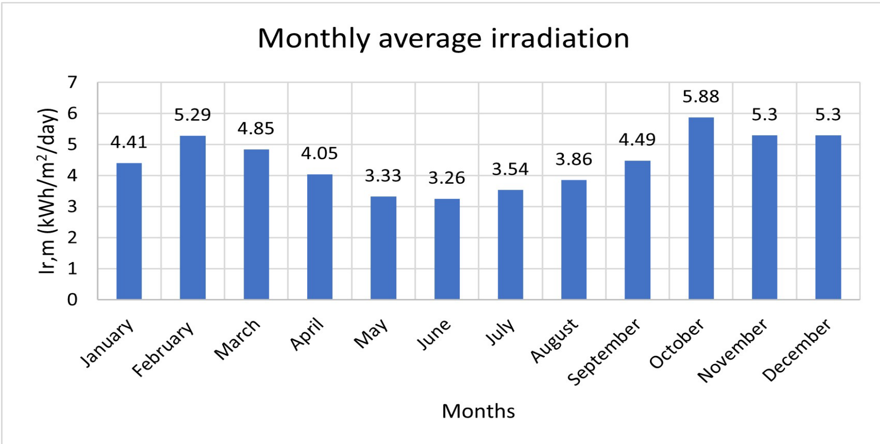

Figure 2. Average monthly irradiation in Mandraka.

This figure provides information on the least sunny month of the year, in particular June, with solar irradiation of 3.26 kWh/m²/day. This value will be used to size the photovoltaic generator.

2.2.2. Determining Photovoltaic System Components

The peak power of the PV system is described by Equation (9):

$$P_c = \frac{C_j}{K \times E_i} \tag{9}$$

where C_j is the daily energy consumption, E_i the sunshine of the place and K a coefficient varying between 0.5 and 0.7.

The numbers of modules in series and in parallel are given respectively by (10) and (11):

$$N_s = \frac{U}{U_{\text{mod}}} \tag{10}$$

$$N_p = \frac{P_c}{N_s \times P_{\text{mod}}} \tag{11}$$

where U is the requested voltage and P_{mod} the unit power of the module.

The number of panels required is given by the following equation:

$$N = N_s \times N_p \tag{12}$$

The capacity of the accumulator battery is defined by the following relationship:

$$C_b = \frac{N_j \times C_j}{R_{bat} \times U_{bat} \times DM} \tag{13}$$

where N_j is the number of days of autonomy, DM is the depth of discharge (%) and R_{bat} is the battery efficiency (between 75% and 90%). For the purposes of this study, the number of days of autonomy considered is 2 days.

Knowing C_b, we can determine the number of batteries in series and in parallel.

3. Economic study

3.1. Hypothesis

The economic hypotheses for this study are:

- The project has a 20-year life [18].
- The discount rate considered is 18%.
- Cash flow and operating costs are assumed to be constant over the life of the project.

3.2. Determining the Cost of Production in kWh

It's important to note that the profitability of the project will depend on the selling price of the kilowatt-hour (kWh) of electricity. The production cost per kWh of electricity generated by the plant is given by the overall discounted cost formula (14):

$$C_{kWh} = \left(\frac{\sum_1^n I + \sum_1^n D_a}{\sum_1^n E_a} \right)_{discounted} \tag{14}$$

where n is the year number (equal to the project deadline), I the investment, D_a annual spending (equal to 5% of investment) and E_a the average annual power production.

C_{kWh} calcul gives:

$$C_{kWh} \approx 1040\,\text{Ar/kWh}$$

Note that the Internal Rate of Return (IRR) and the Profitability Index (PI) of the project depend only on the ability of users to pay electricity.

3.3. Determination of Net Present Value (NPV)

The Net Present Value of a project is difference between net flow of cash and investment. The project is profitable if NPV is greater than or equal to zero. It is given by the following equation [17]:

$$\text{NPV} = -I + \sum_{i=1}^{n} \frac{CF_i - C_i}{(1+a)^i} \tag{15}$$

where CF_i: Represent the cash-flows from year 1 to year n, C_i: The operating cost from year 1 to year *n*, *a*: The discount rate and *I*: The initial investment.

4. Results and Discussion

4.1. Assessment of Energy Requirements

Surveys of the various categories of electricity users at the Saha Maintsoanala station have enabled us to estimate the site's electrical requirements. The figures below show the hourly variations in demand for the different categories of Mandraka users.

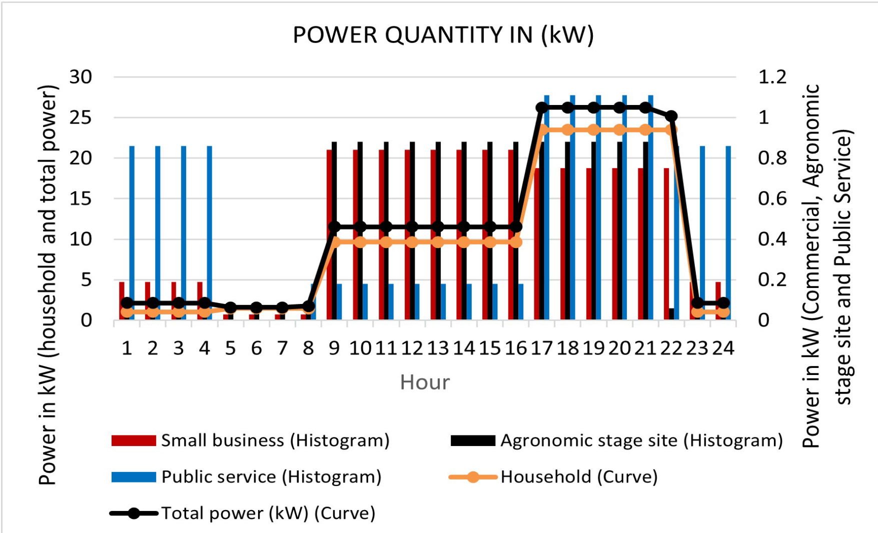

Figure 3. Users power consumption curves.

Peak consumption is reached between 5 pm and 9 pm and corresponds to a total power of 26.22 kW (Figure 3). The overall power generation system will therefore need to produce a total power equal to 26.22 kW to meet the electricity demand of the village of Mandraka.

Table 2 shows the sizing results for the micro-hydropower plant.

Table 2. Components of the micro-hydropower plant.

Designation	Value	Designation	Value
Water intake		Total height H (m)	1.66
Flow rate (m^3/s)	0.807	Length L (m)	3.15
Flow rate coefficient (m)	0.5	Width l (m)	1
Width of the orifice (m)	1	Surface area available for settling S (m^2)	3.15
Water height on the section (m)	0.51	Settling speed (m/s)	0.004467513
Revenge (m)	0.2	Coefficient k	25
Height of the orifice (m)	0.71	Slope a1 (in degrees)	18.75˚
Water velocity over section (m/s)	1.57	Slope a2 (in degrees)	34.18

Continued

Lead channel		Loading chamber	
STRICKLER's coefficient k	50	Chamber width $l_{chamber}$ (m)	1
Channel width (m)	1.2	Chamber length $L_{chamber}$ (m)	0.91
Height h of channel off-revenge (m)	0.8	Chamber height $H_{chamber}$ (m)	1.04
Upstream dimension (m)	1240	Loading chamber exit velocity V_{cbas} (m/s)	10.85
Downstream dimension (m)	1239.5	Drop height H_{drop} (m)	6
Channel length (m)	241	Loading chamber inlet velocity $V_{chamber}$ (m/s)	1.33
Channel slope (m/m)	0.0021	Penstock cross-section S_{duct} (m^2)	0.11
Revenge (m)	0.25	Chamber section (m^2)	0.912
Total channel height Ht (m)	1.05	**Penstocks**	
Crest width (m)	2.602	Minimum penstock diameter (m)	0.38
Angle of inclination in (degrees)	56.31	Inlet velocity (m/s)	7.24
Wetted hydraulic cross-section Sh (m^2)	1.387	Exit velocity (m/s)	13.04
Wetted hydraulic perimeter Ph (m)	3.124	Pressure drop (m)	1.55
Hydraulic radius Rh (m)	0.444	Penstock length (m)	15
Proportionality coefficient C	43.673	**Turbine and hydraulic power**	
Water velocity in the channel (m/s)	1.326	Net height of fall (m)	4.45
Decantation pond		Turbine speed (rpm)	720
Horizontal height h1 (m)	0.95	Specific speed ns (m/s)	180.89
Slope height h2 (m)	0.71	**Electric power (kW)**	**24.64**

As the calculated specific speed is between 60 m/s and 420 m/s, we'll be choosing a Banki-Michell type turbine.

It should be noted that the power produced by the micro-hydropower plant (24.64 kW) does not meet user demand (26.22 kW), so a solar photovoltaic system is essential. These photovoltaic generators will power the Ecole Primaire Publique (EPP), the administrative department, the workroom and the street lighting equipment in the village of Mandraka.

Table 3 shows the energy requirements for photovoltaic energy.

Table 3. Energy requirements for photovoltaics.

Types	Number of units	Unit power (W)	Total power (W)	Operating time in hours/day	Energy consumption Wh/day
			Public Service		
Light bulb	3	15	45	4	180
Computer	1	60	60	8	480
Sound system	1	250	250	1	250
Total			**355**		**910**

Continued

Work Room					
Light bulb	3	15	45	3	135
Computer	1	60	60	2	120
Sound system	1	250	250	2	500
Total			**355**		**755**
Mandraka School (Epp)					
Light bulb	6	15	90	3	270
Computer	1	60	60	8	480
Total			**150**		**750**
Eclaireage Pubique					
Light bulb	15	60	**900**	9	**8100**
Total			**1760**		**10515**

Total daily consumption EjEj, calculated for the four subscriber categories (administrative office, workroom, public elementary school (EPP) and public lighting), amounts to 10,515 Wh/d, or 3838 kWh/year, with a power of 1760 W.

The sizing based on this calculated power is appropriate, as the difference between the total power obtained (26.22 kW) and that of the hydraulic power plant (24.64 kW) is 1.76 kW, or 1760 watts. This slight oversizing is also recommended to ensure reliable consumption for users.

Having carried out the sizing calculations for the photovoltaic system, the results obtained are as follows.

Table 4 shows the results for the size of PV system components needed to produce the additional power required to meet consumer demand.

Table 4. Photovoltaic system components.

Designation	Administrative office	Work room	Mandraka public primary school	Public lighting
Daily consumption (Wh/d)	910	755	750	8100
Peak power (Wc)	480	398	396	285
PV system voltage (V)	24	24	24	24
Battery voltage (V)	24	24	24	24
Number of PV panels required	5 of 100 Wc	4 of 100 Wc	4 of 100 Wc	1 of 300Wc
Storage capacity (Ah)	155.6	129.1	128.2	92.3
Selected battery capacity (Ah)	200	150	150	100
Number of batteries required	1	1	1	1
Intensity between regulator and subscribers (A)	13	10.5	10.4	8
Intensity between panel and regulator (A)	22	18	18	13

Continued

Load power (W)	355	355	150	60
Inverter power (W)	444	444	188	75
Field area (m^2)	1.55	1.29	1.28	0.92

This table shows the results for the technical characteristics of each energy consumer group. It also specifies the number of solar panels required for each consumer group.

4.2. Investment Cost

The realization of the project to supply the village with electricity through the renewable energy system requires an investment of 227,626,018 Ariary (Ar) or 63229.5 Euros. The operating cost amounts to 29,152,668 Ar or 8098 Euros. Note that the current Euro is equal to 3600 Ar. Table 5 gives the system's investment budget estimate.

Table 5. Total system investment cost (1 Euro = 3600 Ar).

Designation	Number	Amount (Ar)	Subtotal (Ar)
Intangible asset			
Software		800,000	800,000
Hydroelectric microcentral			
Tangible asset			
Planning		400,000	400,000
Materials and tools (ft)			200,000
Civil engineering work			119,231,500
Mechanical and hydraulic equipment			13,850,000
Electrical equipment			28,250,000
Photovoltaic System			
Materials and tools			200,000
Solar panels	28		49,300,000
Regulators	18		2,065,000
Batteries	18		6,850,500
Converters	18		1,557,750
Electrical wiring (ml)	35		198,800
Metal supports (ml)	4		2,740,000
Communication materials	2		200,000
Office equipment and furniture			150,000
Computer equipment			500,000
Other Deposits (5%)	Ft		1,132,468
General Total (Ar)			**227,626,018**

We'd like to point out that the profitability of hydroelectric power plant infrastructures is spread over a period of more than 15 to 20 years, depending on the scale of the infrastructure to be installed. So, for this case, it is essential that we study two different cases, *i.e.,* the case where the NPV is positive and the case where the NPV is Negative.

Case 1: If the NPV is positive, *i.e.,* the project is interesting, we need to calculate the corresponding price per kWh.

Thus, if the NPV is positive, the price per kWh is greater than Ar 1040.

Second case: Negative NPV, *i.e.,* the project is no longer worthwhile.

Thus, if NPV Negative, the price per kWh is less than Ar 1040.

So, if the selling price per kWh of electricity is greater than Ar 1040, the project is profitable.

Table 6 shows the influence of the kWh selling price on the payback period.

Table 6. Influence of the kWh sale price.

Profitability indicators	Price per kWh (Ar/kWh)	DRIC
NPV positive	1040	4 years 11 months 27 days
	2500	3 years 7 months 27 days

For the current project:

$$\text{NPV} = 157036279 \text{ Ar}$$

Since the NPV is positive, the project is profitable.

Table 6 shows that, if the price per kilowatt-hour (kWh) is 1040 Ar, the period required to amortize the investment is 4 years, 11 months and 27 days. However, when the price reaches 2500 Ar, this period is reduced to 3 years, 7 months and 27 days.

4.3. Assessment of Households' Ability to Pay for Energy

We conducted a survey to estimate the household monthly expenditure of substitutable energy by electricity. To achieve this, we have taken into account the needs of existing households in the village and estimate the current expenditure in energy that they are used to making per month according to their financial means, for the operation of their equipment and for enlightenment. These expenses relate to the use of cells, batteries, candles, lighting gas and kerosene. To this end, households have been subdivided into three categories, according to their standard of living: low-income, middle- income and well-off households. The results of these surveys show that most households in the village of Mandraka, already spend a part of their monthly income to meet their basic energy needs (Figure 4).

Figure 4 shows that low-income, middle-income and well-off households spend respectively 18,700, 26,000 and 32,300 Ar per month for their energy supply.

Figure 4. Household energy expenditure in Mandraka.

4.4. Assessment of the Ability to Pay Energy of Other Electricity Consumers

Another survey was conducted to assess the monthly substitutable energy expenditure of other categories of energy consumers in Mandraka village (**Figure 5**).

Figure 5. Energy expenditure of other consumers in Mandraka.

It emerges from this work that users of restaurants, grocery stores, lodges and public service spend respectively 38,400, 16,500, 56,740 and 40,400 Ar per month for their energy supply.

4.5. Comparative Study of Consumer Energy Expenditure

We conducted a socio-economic survey among the population of the village of Mandraka, in order to make a comparative study of expenditure on electric energy and substitutable energies by the use of cells, batteries, candles, lighting gas, kerosene. These surveys take into account the needs of the inhabitants in order to estimate the energy expenditure they usually make per month, to operate their equipment and for lighting, before and after supplying the village with electricity through the renewable energy system. For this purpose, consumers have been classified by type of activity. The results are shown in **Figure 6** and **Figure 7**.

Figure 6 and **Figure 7** show that, in general, supplying the village with electricity through the renewable energy system greatly reduces the monthly energy expenditure of consumers.

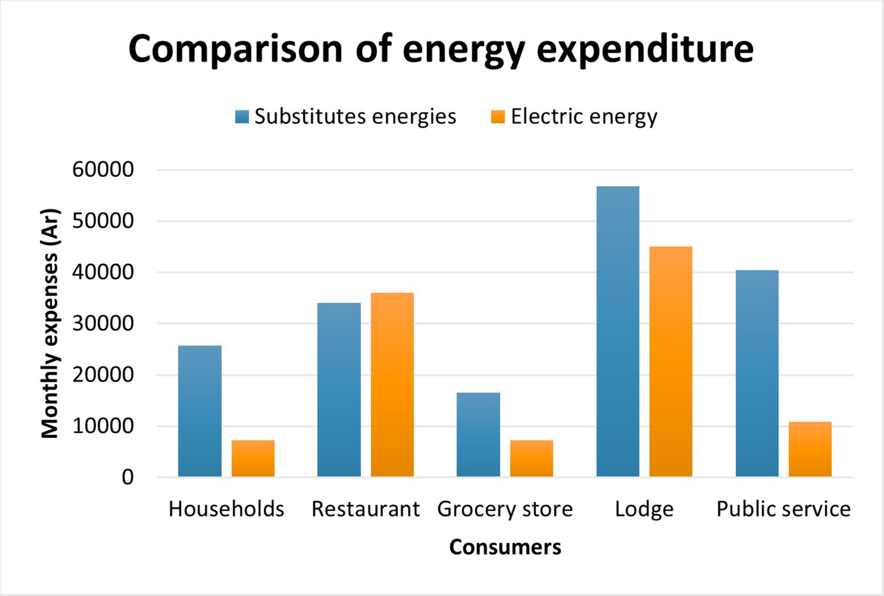

Figure 6. Comparison between substitute energy and electricity expenditures.

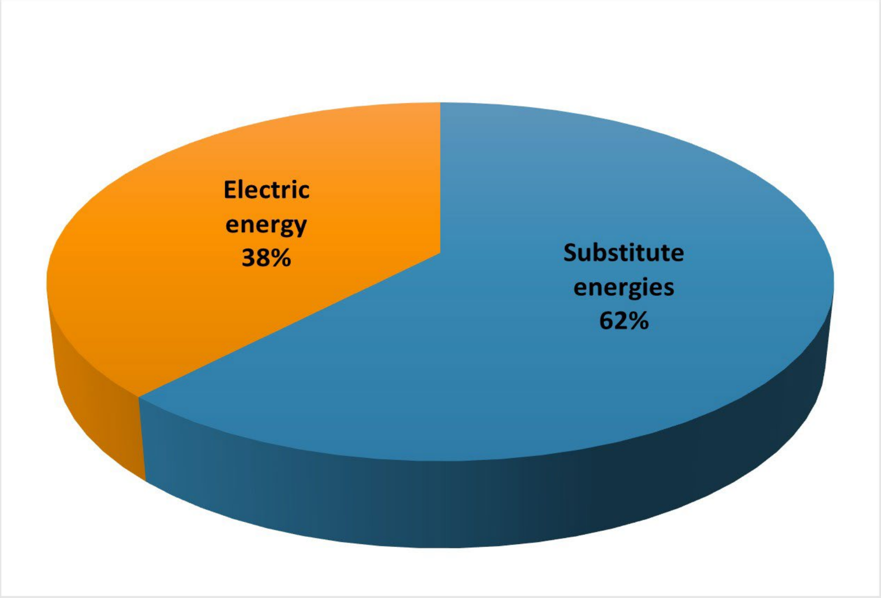

Figure 7. Comparison of energy expenditure for all consumers.

Figure 6 and Figure 7 show that, overall, supplying the village with electricity from the renewable energy system greatly reduces consumers' monthly energy costs.

The installation of the micro-hydro plant and the solar photovoltaic system is also a significant asset for the local population, as the electricity generated by these resources will obviously be an engine for economic development, enabling them to combat the area's isolation, the lack of information and communication, and the reduction or elimination of poverty through the practice of income-generating activities.

The investment required to bring this project to fruition amounts to Ar 227,626,018 or 63229.5 euros, with a cost of Ar 29,152,668 or 8098 euros, and the payback period (DRCI) and/or financial profitability of such an infrastructure with a high initial investment range from 15 to 20 years or even more.

Access to electricity will mark a decisive turning point in the region's development, promoting the integration of New Information and Communication Technologies (NICT). The creation of cybercenters will improve access to information, erasing the image of a "landlocked area". Literacy will increase, and the computerization of administration will eliminate bureaucratic delays, accelerating local development.

Leisure facilities (auditoriums, video games, karaoke, nightclubs) will energize social life and combat idleness, also attracting tourists. Electricity will encourage greater affluence, thanks in particular to the region's rich natural resources. ESSA's student hostel will also be able to welcome tourists, boosting local revenues. The restaurant, which currently serves around 550 customers a month, will see its clientele triple, prompting the construction of new gargotes and chalets to meet growing demand.

Small shops and local businesses will thrive, improving the standard of living for local residents. Finally, a year-round RN2 will facilitate inter-municipal trade in agricultural produce and charcoal, strengthening the regional economy.

5. Conclusions

In this article, a techno-economic pre-feasibility study of a micro-hydropower plant coupled with a photovoltaic system, intended to produce electricity for an isolated site (Mandraka village) was presented. First, the various components of the system were sized. After sizing, we found that the micro-hydro plant could only produce a maximum power of 24.64 kW, whereas the power required by users is 26.22 kW. We therefore sized a 1.76 kW photovoltaic system to back up the micro-hydropower plant.

We then carried out a series of surveys: the first showed us that most households in Mandraka already spend a significant proportion of their monthly income on meeting their basic energy needs. The second showed that users of substitutable energy sources pay more for their energy consumption than those using electricity. These surveys show that, depending on the socio-professional category of the population, the inhabitants of this village can pay for their electricity consumption.

The availability of these energy resources will not only meet the needs of the various consumers in the village of Mandraka but will also provide young people with opportunities to reduce the exodus and promote village development.

Acknowledgements

The authors would like to express their deep gratitude to the National Center for Industrial and Technological Research (CNRIT) in Antananarivo (Madagascar) for invaluable logistical and technical support during data collection, and to the Joseph KI-ZERBO University (UJKZ) for its scientific and institutional support.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Rehman, S., Al-Hadhrami, L.M. and Alam, M.M. (2015) Pumped Hydro Energy Storage System: A Technological Review. *Renewable and Sustainable Energy Reviews*, **44**, 586-598. https://doi.org/10.1016/j.rser.2014.12.040

[2] Kaldellis, J.K. and Zafirakis, D. (2007) Present Situation and Future Prospects of Electricity Generation in Aegean Archipelago Islands. *Energy Policy*, **35**, 4623-4639. https://doi.org/10.1016/j.enpol.2007.04.004

[3] Ma, T. and Javed, M.S. (2019) Integrated Sizing of Hybrid Pv-Wind-Battery System for Remote Island Considering the Saturation of Each Renewable Energy Resource. *Energy Conversion and Management*, **182**, 178-190. https://doi.org/10.1016/j.enconman.2018.12.059

[4] Javed, M.S., Song, A. and Ma, T. (2019) Techno-Economic Assessment of a Stand-Alone Hybrid Solar-Wind-Battery System for a Remote Island Using Genetic Algorithm. *Energy*, **176**, 704-717. https://doi.org/10.1016/j.energy.2019.03.131

[5] Lin, S., Ma, T. and Shahzad Javed, M. (2020) Prefeasibility Study of a Distributed Photovoltaic System with Pumped Hydro Storage for Residential Buildings. *Energy Conversion and Management*, **222**, Article ID: 113199. https://doi.org/10.1016/j.enconman.2020.113199

[6] Parida, A. and Chatterjee, D. (2019) Remote Area Power Supply through Suitable Solar PV Augmented Micro-hydro Generation: A Case Study. *International Transactions on Electrical Energy Systems*, **30**, 1-12. https://doi.org/10.1002/2050-7038.12247

[7] Hatata, A.Y., El-Saadawi, M.M. and Saad, S. (2019) A Feasibility Study of Small Hydro Power for Selected Locations in Egypt. *Energy Strategy Reviews*, **24**, 300-313. https://doi.org/10.1016/j.esr.2019.04.013

[8] Zomers, A.N. (2001) Rural Electrification, Utilities' Chafe or Challenge? Twente Univ. Press, 321.

[9] Al-Ghussain, L., Ahmed, H. and Haneef, F. (2018) Optimization of Hybrid Pv-Wind System: Case Study Al-Tafilah Cement Factory, Jordan. *Sustainable Energy Technologies and Assessments*, **30**, 24-36. https://doi.org/10.1016/j.seta.2018.08.008

[10] Niringiyimana, E., WanQuan, S. and Dushimimana, G. (2022) Feasibility Study of a Hybrid Pv/Hydro System for Remote Area Electrification in Rwanda. *Journal of Renewable Energy*, **2022**, Article ID: 4030369. https://doi.org/10.1155/2022/4030369

[11] Dubois, J. (1998) Comportement hydraulique et modélisation des écoulements de surface. Laboratoire de Constructions Hydrauliques Ecole Polytechnique Fédérale de Lausanne, 200.

[12] Muhtar, B. and Albayati, M.M.A. (2016) Determination of Chezys and Mannings Coefficient for Different Aggregate Bed Using Different Notches in Hydraulic Bench. *International Journal of Scientific & Technology Research*, **5**, 167-175. https://www.ijstr.org

[13] Boukhari, I. (1945) Contribution Par la C.R.C (Méthode de la Conduite De Référence Connue) Au Calcul De l'écoulement Permanant Uniforme Pour Des Différents Canaux Ouverts. BadjiThèse de doctorat, Mokhtar Annaba University Université Badji Mokhtar, 145.

[14] Pioge, P. (2007) Bernoulli's Theorem and the Hazen-Williams Equation. 1-7.

[15] Mandefro, Y. (2017) Feasibility Study of Small Hydropower/PV/Wind Hybrid System for Off-Grid Electrification of Liben and MedaWoulabu Villages. University of Cavle, 100.

[16] Bitar, Z., Khamis, I., Alsaka, Z. and Jabi, S.A. (2015) Pre-Feasibility Study for Construction of Mini Hydro Power Plant. *Energy Procedia*, **74**, 404-413. https://doi.org/10.1016/j.egypro.2015.07.638

[17] Elie Bertrand, K.S., Hamandjoda, O., Nganhou, J. and Wegang, L. (2017) Technical and Economic Feasibility Studies of a Micro Hydropower Plant in Cameroon for a Sustainable Development. *Journal of Power and Energy Engineering*, **5**, 64-73. https://doi.org/10.4236/jpee.2017.59006

[18] Syahputra, R. and Soesanti, I. (2020) Planning of Hybrid Micro-Hydro and Solar Photovoltaic Systems for Rural Areas of Central Java, Indonesia. *Journal of Electrical and Computer Engineering*, **2020**, Article ID: 5972342. https://doi.org/10.1155/2020/5972342