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Pre-feasibility analysis of powering a remote research facility under arid conditions in Kazakhstan

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Abstract. This study evaluates the feasibility of using photovoltaic solar cells and solar water heating in a remote off-grid research facility for scientists in the steppe of Kazakhstan. The objective of the facility is to observe wildlife in this region, especially saiga antelope, whose population has been drastically reduced in recent years. The analysis is conducted using RETScreen software and includes energy, cost, emissions, and financial assessment. The proposed energy model is compared with a traditional base case scenario (based on a diesel boiler and reciprocating engine). Despite the challenges and constraints, the project pays off within its lifespan. It eliminates greenhouse gas emissions and reduces human interference with local wildlife.

1 Introduction

In 2015, a mass die-off of the endangered saiga antelope occurred in three regions of Kazakhstan: North, West and Central Kazakhstan. More than 100,000 saigas (62% of the world's saiga population) died over a 2-week course. This caused a massive response in the scientific community worldwide and brought researchers from all over the world to Kazakhstan to investigate this phenomenon [1]. The largest population of saigas and corresponding casualties was recorded near the Amangeldy District in the Kostanay region of Kazakhstan (Fig. 1).

A feasibility study that involves providing accommodation in this area for a group of scientists (about five people) who will study saiga behavior is proposed. To be close enough to the natural habitat of saigas, the shelter shall be located in the steppe and far from populated areas. With no access to the electricity grid, off-grid energy solutions are necessary. This type of project is characterized as a remote area power supply (RAPS) project, which typically utilizes renewable energy sources [2]. In this project, a pre-feasibility analysis of a solar water heater system for water heating and photovoltaic (PV) solar cell technology for electricity generation is run at the location of the study. The effectiveness and viability of these methods are to be assessed and compared with base case scenarios.

2 Methodology

The objective of the project is to assess the financial feasibility of a solar energy based RAPS in the defined area (Fig. 1). The solar energy must cover electricity and water heating needs, and the simulation is compared to traditional power systems (generator and boiler). Environmental benefits are discussed as well.

2.1 Generalities

The project is divided in two independent parts: "Heating" and "Electricity" parts. "Heating" is concerned with hot water production for domestic use and this system uses solar collectors to heat water during sunny hours. "Electricity" refers to production of electricity and utilizes solar PV panels alongside with battery pack to compensate intermittent nature of solar energy.

The performances of these two parts are evaluated separately. Evaluations include simulating each system performance during its lifetime, the financial aspects, and the CO_2 emissions analysis. The RETScreen software (software supported by the Government of Canada) is used to evaluate the financial viability of the project in the preliminary stage. This software is able to compare renewable versus conventional technologies, savings potential from energy efficiency, CO_2 emission reductions and financial risk. By changing the parameters of the system, users are able to observe its impact on the final results depending on the load and climatic conditions [4].

First, a solar thermal heating collector is compared with a diesel boiler used only to heat water (heating). Two different cases of hot water usage are evaluated: standard water consumption and reduced water consumption.

Then, a comparative study is performed on the electricity part. PV panels are compared with a reciprocating diesel engine for producing electricity.

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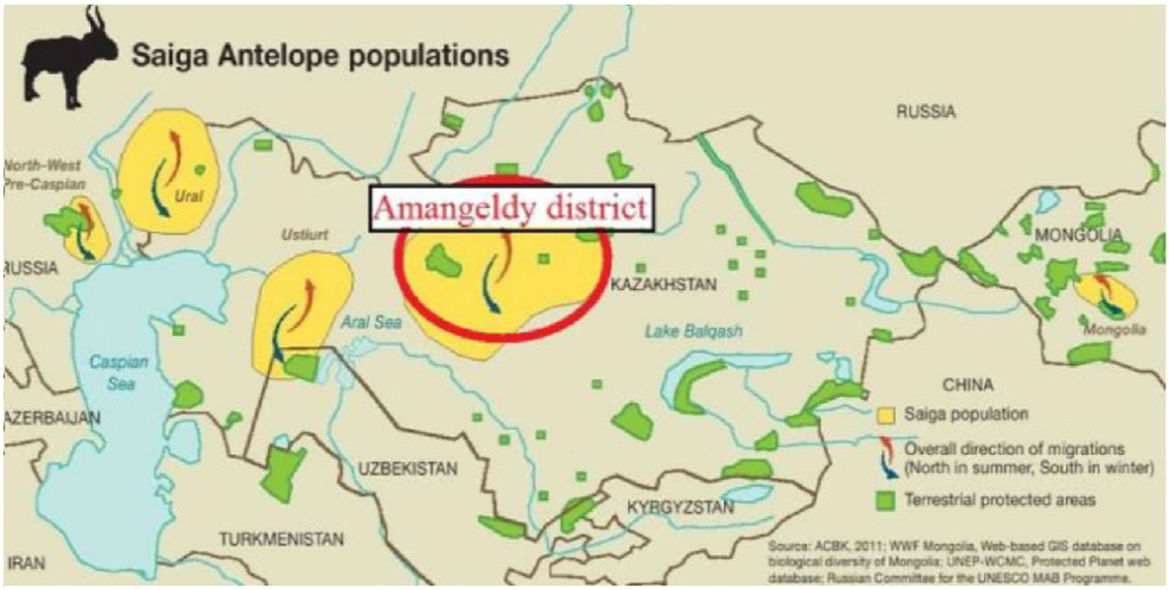

Fig. 1. Saiga population, Amangeldy District [3].

Finally, the two systems are gathered into one combined electricity-and-heating system and its financial performance is evaluated.

2.2 Financial analysis

The analysis was performed using recent economic data from the financial market, including: price of fuel, escalation rate of fuel, discount rate, and any possible incentives applicable to Kazakhstan. The Kazakhstani government provides subsidies for the installation of renewable energy equipment covering 50% of all necessary installation and equipment costs, except for value added tax (VAT) [5]. As an off-grid system, this project is not subject to income taxes.

Considering the evolution of the discount rate for the past 10 years, it is set at the value of 6.5%. Regarding the fuel escalation rate: the high volatility of fuel prices makes predictions difficult, an average inflation rate of 5% is assumed following official estimations [6]. The suggested value for the inflation rate (except fuel) is 3%.

The financial analysis will be performed using all previously mentioned assumptions. The feasibility of a particular option will be evaluated based on the following three financial indicators: Internal Rate of Return (IRR, rate at which present value of all cash flows is equal to zero), Net Present Value (NPV, total value of the system adjusted with discount rate to encourage early benefits), and payback period (time necessary to get a positive cash flow).

Note than a high IRR means that the system is financially attractive.

3 Results

3.1 Influence of using a solar thermal water system (heating part)

The objective is to heat water for domestic purposes. A comparison between a solar thermal collector component and a diesel-based boiler is made. This section investigates the benefits of using solar thermal collectors by looking at performance figures produced by RETScreen.

3.1.1 Load estimation – hot water

Hot water demand is estimated for five people. Two hot water consumption cases are studied: "standard", and "reduced".

Standard hot water consumption figures are calculated by RETScreen based on how much hot water will be used: 3 days per week per person in the original configuration (1092 L per person per week). Reduced water consumption is obtained by dividing the standard consumption by a factor of four (273 L per person per week) due to decreased comfort conditions in the shelter. This assumption is based on the fact that hot water will not be used for cloth washing, dishwashing, and prolonged shower sessions in the proposed system. We assume that the optimal temperature for storing hot water is 60 °C.

In the base case scenario, the cost of the boiler is estimated at 1000 USD (noted $ in the next occurrences). The efficiency of the boiler is 70% and the cost of the diesel is 0.445 $/L. The maintenance cost is estimated at 100 $ per year.

3.1.2 Proposed case – hot water

The system consists of a glazed flat panel solar water collector with a slope of 45°. From the RETScreen product database, the Skyline 20-01 from Americas Clean Resource Solar International is selected. One collector has an aperture area of 1.72 m^2, which indicates an effective surface for heating water. In order to determine the number of collectors needed to satisfy hot water demand, an iterative study was performed in RETScreen. The initial input value was a number of collector suggested by the program itself. Then we increased this value with an increment of one until the solar fraction of energy reached

Table 1. Performance indicators for standard and reduced water consumptions for the solar thermal system simulation.

Performance parameters	Standard water consumption	Reduced water consumption
NPV ($)	−3183	−364
IRR	−16.8%	−0.2%
CO_2 savings (t/year)	1.2	1.2
Payback time (years)	>Project life	>Project life

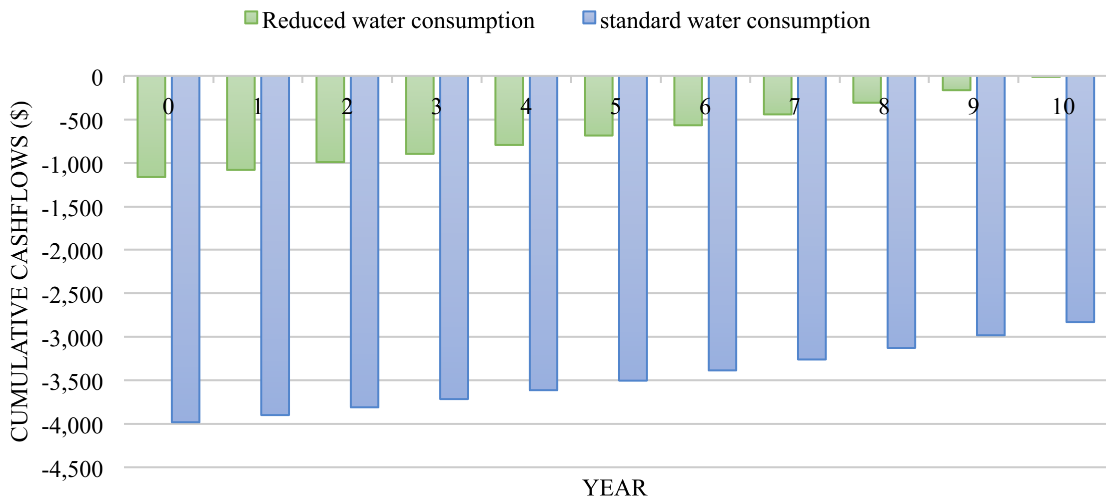

Fig. 2. Cumulative cash flow graph for the heating part (reduced and standard hot water loads).

100%. For the standard hot water consumption case this number turned out to be 8 collectors, and 2 for the reduced water consumption scenario. The boiler used in the base case simulation has a standard efficiency of 70%. Because the proposed system does not require a boiler to compensate for collector deficiencies, its price (1000 $), is deducted from cost analysis (indeed, RETScreen considers by default a boiler in the proposed case as a backup system, so we remove its value in our case). Miscellaneous losses of the system were assumed to be low since the tubing system is short. One collector costs $895; other expenses such as feasibility study, development, engineering and construction works will be taken as standard values provided by RETScreen and are equal to $200, $225 and $1000 respectively [7]. Knowing the number of collectors used in each case and adding 5% of the project cost for contingencies, the initial cost of solar thermal heating system becomes $3376 for the reduced water consumption case and $9014 for the standard one. Notice that the parameters are calculated by comparing with the same base case (diesel boiler and standard water consumption).

The comparison between the solar thermal system with standard hot water load (assuming that the usage of hot water is equivalent to the usage in a typical household) and with the reduced hot water load revealed how beneficial the system becomes when needs are decreased. The results for these two cases are presented in Table 1. The reduced water consumption drastically improves all the financial indicators. The NPV increases (from $−3183 to $−364) and the IRR also shows growth (from −16.8% to −0.2%) compare to a standard hot water consumption. The installation could prevent 1.2 t of CO_2 to be emitted (note that this number does not change between the two simulations as both standard and reduced consumption simulations are compared to the base case: standard consumption with diesel boiler).

Reducing the water consumption is then necessary to have a NPV close to the base case.

Figure 2 shows side-by-side comparison of the annual cash flows throughout lifetime of the project for reduced and standard water usages. This clearly shows preeminence of the modest water consumption, and how non-competitive the implementation of solar thermal collectors would be without moderate water usage. Combining moderate water consumption and solar thermal collectors makes the system competitive against a diesel boiler with standard water consumption.

3.2 Influence of using solar PV panels (electricity part)

In this simulation, solar PV panels are used for power production to cover all electricity needs of facility residents, which includes various electric appliances.

3.2.1 Load estimation – electricity

Here, a comparison is made between the diesel reciprocating engine and PV panels, named "Electricity". The energy demand for the accommodation was estimated by assuming all the necessary equipment on site, including household objects that are essential for living and working

Table 2. Load estimation for household appliances.

Description	Intermittent resource-load correlation	Loads (W)	Hours of use per day (h/d)	Daily consumption (kWh)
Water pump	Positive	40	0.7	0.0272
Kettle	Zero	2000	0.15	0.3
Lights	Negative	125	4	0.5
Radio	Zero	50	3	0.15
Climate control	Positive	1000	8	8
Fridge	Zero	250	24	6
Laptop computer	Zero	100	8	0.8
Single burner electric hotplate	Zero	1000	2	2
Satellite internet	Zero	40	4	0.16
			Total	17.9

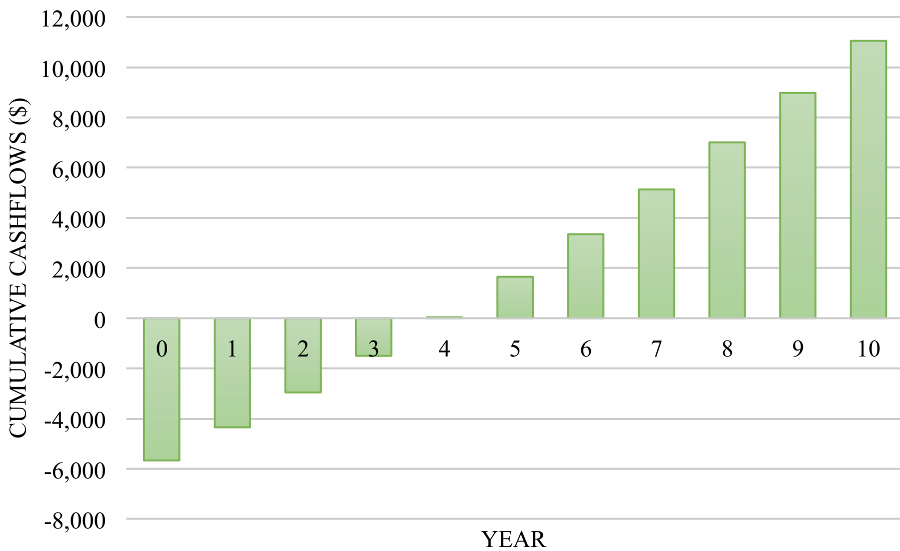

Fig. 3. Cumulative cash flow for the electricity part of the project (PV panels).

(Tab. 2). Each piece of equipment has an intermittent resource load correlation that dictates whether the equipment is directly powered through PV panels (positive correlation), batteries (negative correlation) or a combination of PV panels and batteries (no correlation). Assuming the typical loads of these devices and the estimated hours of use per day, we obtain a daily electricity demand of 17.9 kWh and a peak load of 3.6 kW.

In the base case scenario, the onsite electricity is generated from a diesel-powered generator (reciprocating engine). The heat rate of this generator is 13,000 kJ/kWh (28% efficiency). Combined with the fuel rate of 0.445 $/L (diesel price for 1 L of fuel), the electricity rate (ER) is 0.442 $/kWh [6]. Thus, the annual electricity cost can be calculated using (1); considering an annual electricity consumption (YC) of 2.74 MWh, this value is equal to $1214.

$$\text{Annual cost} = \text{ER}\,\text{YC}. \tag{1}$$

In addition, the annual operation and maintenance cost for such a diesel generator is estimated to be $800 [8].

3.2.2 Proposed case – electricity

For off-grid stand-alone PV cell systems, the recommended array output should be greater than (or equal to) 120% of the maximum monthly load [4]. In this case, using the peak load of 3.6 kW, the recommended output is 120% of this value, so 4.32 kW. The selected PV cells are the Suntech mono-Si-STP175s-24 with a capacity of 175 W per unit and 13.7% efficiency. These panels can operate in the temperature range of −40 to 85 °C. At elevated temperatures, the maximum power output slightly deteriorates. The frontal area of one panel is 1.28 m^2 [9]. If fixed panels with a 45° slope are employed, the optimal number of panels is calculated by RETScreen and yields to 28 PV panels and a total area of 36 m^2. At this level of power, an auxiliary power system for peak load is not required. At $1.143 per watt or $200 per panel, the PV system costs $5600. As in the heating part, the cost of the diesel generator ($2500) is deduced from the initial cost of the system since it is not used anymore to cover deficiencies.Using one-axis or two-axis solar tracking

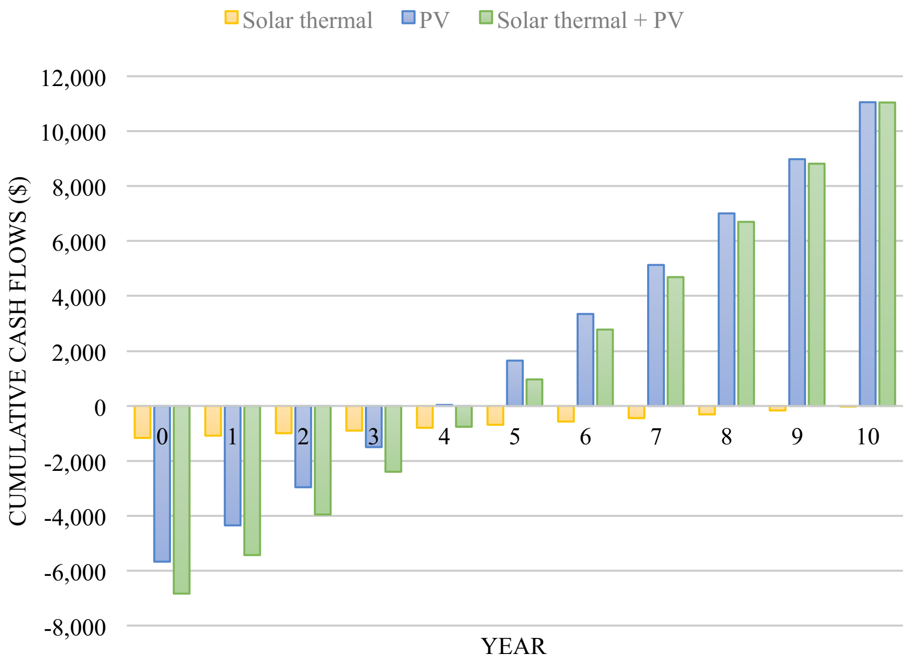

Fig. 4. Cumulative cash flows for the heating part (solar thermal), electricity part (PV), and solar thermal + PV.

Table 3. Performance indicators for the electricity part (PV panels).

Performance indicators	PV
NPV ($)	6045
IRR	24%
CO_2 savings (t/year)	2.5
Payback time (years)	4

systems would reduce the number of panels; however, the final cost would exceed the cost of the fixed-panel system. Considering increased maintenance requirements for solar trackers, fixed panels are chosen. The area of the panels (36 m^2) is not a concern since the site does not contain other buildings or obstructions; thus, the panels can be placed on the ground. Other components of an off-grid system include a battery and an inverter. In our case, the battery is designed to provide a minimum of 2 days of autonomy. At 80% efficiency and a maximum depth of discharge of 50%, the required battery capacity calculated by RETScreen is 2284 Ah. The inverter is designed for a peak load of 3.6 kW at 90% efficiency. The efficiencies for the batteries and the inverter are suggested by RETScreen. The combined cost of the inverter and batteries is $3768 (this value is obtained from the RETScreen product database).

The financial feasibility of using solar panels over diesel generator is shown in Figure 3. Other important parameters are summarized in Table 3. NPV and IRR are both positive, which is good for the financial feasibility. Moreover, the installation prevents the emission of 2.5 t of CO_2 every year.

3.3 Combined solar thermal and PV panels

In order to take a look at the overall performance of the system, the two aforementioned cases are combined. It includes electricity and hot water production by the means of solar PV panels and solar thermal collectors respectively. As the PV panels produce electricity only, and solar thermal project deals with water heating only, they are financially independent. Thus, the NPV and the CO_2 savings of both can simply be added.

Figure 4 compares all three cases alongside in terms of yearly cash flows. This gives a clear picture of the financial impact of each system impacts the financing. Table 4 summarizes all the indicators for the 3 cases. The NPV of the combined system is lower than for the electricity part only; however it is still largely positive: the electricity part can then easily finance the small deficit of the heating part.

In order to investigate the influence of each parameter on the NPV, a sensitivity analysis is performed for both PV and solar thermal systems. Figure 5 indicates which variation of each financial parameter has the greatest impact on the NPV. A negative magnitude shows that an increase of the corresponding parameter has a negative impact on the NPV, and vice versa for positive magnitude. The magnitude is proportional to the influence.

The initial cost and diesel fuel cost are the two most influential parameters for both systems. An increase in the initial or in O&M (operation and maintenance) costs cause a decrease in the NPV since it generates negative cash flow; an increase in fuel cost causes an increase in the NPV because it makes the system more competitive against the base case.

3.4 Local environmental benefits analyses

For this project, non-emission of greenhouse gases is not the main benefit. The most important point is the reduced level of disturbance for the natural environment. A diesel

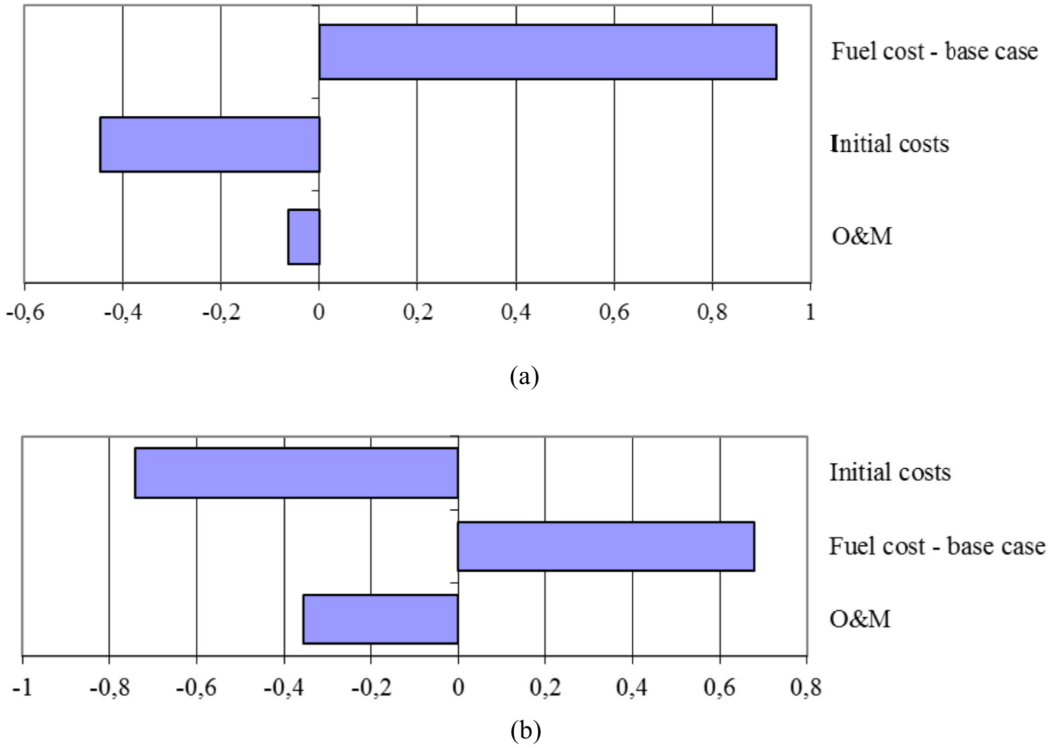

Fig. 5. Impact on NPV for (a) PV system (electricity part) and (b) solar thermal system (heating part).

Table 4. Performance indicators.

Indicators	Solar thermal	PV	PV + solar thermal
NPV ($)	−364	6045	5681
IRR	−0.2%	24%	23%
CO_2 savings (t/year)	1.2	2.5	3.7
Payback time (years)	>Project life	4	5

generator produces loud noise and smoke while working, which will frighten off saigas and hinder observation. Another interaction is the supply of diesel to the site by land or air transport, which will increase the noise in the nearby area and frighten the animals too. PV and solar thermal panels do not make noise, do not require a chain of fuel supply and do not emit any odorous byproducts, which will minimize disruptions and facilitate the observation of wildlife.

4 Conclusion

The initial feasibility study demonstrates that installing PV panels with a battery pack system to produce electricity is economically efficient, while solar thermal system alone shows relatively poor financial performance. However, combining both alternatives results in an economically feasible alternative with a NPV greater than zero and a payback time after 7 years of project initiation. Besides its solid financial performance, this project can generate other benefits. These benefits include reduced interactions with wildlife and less impact on the natural environment. Minimizing noise and air pollution are some of the environmental advantages of such solar energy systems.

Solar water heaters combined with reduced water consumption associated with solar PV panels are both economically and environmentally competitive, and technically feasible. This configuration is highly recommended for such a situation to replace traditional energy systems (boiler and generator).

Since this study is only a pre-feasibility analysis, future recommendations include testing the use of a detailed assessment of components and energy-saving equipment: solar pump and fridge, solar cooking or cooking with gas.

Glossary

ER	electricity rate
IRR	internal rate of return
PV	photovoltaic
NPV	net present value
RAPS	remote area power supply

O&M	operation and maintenance
YC	annual electricity consumption
VAT	value added tax

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