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A comparison between the wind energy system and the solar energy system in feeding areas isolated from the grid in terms of economic feasibility.

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Abstract

Remote areas often lie in difficult-to-reach locations, such as mountainous or rugged terrains, which makes extending electricity infrastructure both costly and challenging. The sparse population and distance from economic hubs further deter investments, as the return on investment is typically low. This research deals with the economic feasibility analysis of two solar and wind energy projects over 20 years, focusing on calculating a set of financial factors such as monthly revenues, operating costs, monthly and cumulative cash flows, and taxes due on revenues and the capital payback period for each project was also calculated in addition to their Net Present Value (NPV) and the monthly cash flows were calculated through the revenues resulting from the sale of energy generated from solar and wind systems, in addition to calculating the operating costs that include maintenance and operation. Revenues and costs were adjusted annually using the inflation factor (3%), which reflects the economic reality and the results of the financial analysis showed that solar energy is the most economically viable option compared to wind energy.

Keyword: solar energy - wind energy -Economic feasibility - Isolated areas.

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مقارنه بين نظام طاقة الرياح ونظام الطاقة الشمسية في تغذية مناطق معزولة عن الشبكة من حيث الجدوى الاقتصادية

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الملخص

غالبًا ما تقع المناطق النائية في مواقع يصعب الوصول إليها، مثل التضاريس الجبلية أو الوعرة، مما يجعل تمديد البنية التحتية للكهرباء مكلفًا وصعبًا. كما أن قلة السكان والبعد عن المراكز الاقتصادية يثبطان الاستثمارات، حيث يكون العائد على الاستثمار منخفضًا عادةً. يتناول هذا البحث تحليل الجدوى الاقتصادية لمشروعين للطاقة الشمسية وطاقة الرياح على مدى 20 عامًا، مع التركيز على حساب مجموعة من العوامل المالية مثل الإيرادات الشهرية وتكاليف التشغيل والتدفقات النقدية الشهرية والتراكمية والضرائب المستحقة على الإيرادات وتم أيضًا حساب فترة استرداد رأس المال لكل مشروع بالإضافة إلى القيمة الحالية الصافية (NPV) وتم حساب التدفقات النقدية الشهرية من خلال الإيرادات الناتجة عن بيع الطاقة المولدة من أنظمة الطاقة الشمسية وطاقة الرياح، بالإضافة إلى حساب تكاليف التشغيل التي تشمل الصيانة والتشغيل. تم تعديل الإيرادات والتكاليف سنويًا باستخدام عامل التضخم (3%)، مما يعكس الواقع الاقتصادي وأظهرت نتائج التحليل المالي أن الطاقة الشمسية هي الخيار الأكثر جدوى اقتصاديًا مقارنة بطاقة الرياح.

الكلمات المفتاحية: الطاقة الشمسية – طاقة الرياح – الجدوى الاقتصادية – المناطق المعزولة.

1. Introduction

Providing energy to off-grid areas presents a significant challenge for countries pursuing sustainable development goals, as they seek to secure stable, reliable electricity supplies to promote economic and social progress in these regions. Renewable energy solutions, specifically wind and solar energy systems, present viable alternatives to fossil fuel-based power systems and both systems utilize readily available natural resources, making them suitable and

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sustainable options that contribute to environmental conservation, energy independence, and cost reduction over the long term [1]. However, the economic feasibility and efficiency of wind and solar systems vary based on a range of factors, including installation costs, operational expenses, energy production stability, environmental impact, and the longevity of each system. A thorough economic feasibility study is essential to assess these factors, particularly for off-grid applications and one of the primary considerations in selecting between wind and solar energy systems is the initial capital cost and wind energy systems generally require a higher upfront investment due to the complex infrastructure needed for installation and this includes the cost of turbines, support towers built to heights that capture optimal wind speeds, and robust foundations to withstand variable weather conditions and these requirements elevate the costs significantly, especially in remote, hard-to-access areas, where transporting materials and setting up large-scale equipment can be both challenging and costly and by contrast, solar energy systems typically have lower initial costs [2]. Solar panels are relatively easy and quick to install, and they demand minimal infrastructure, making them adaptable to various terrains, which is particularly advantageous in off-grid and rural settings and this affordability and flexibility enhance the economic attractiveness of solar energy systems for regions with high solar potential [3].

Operational and maintenance costs are critical in assessing long-term economic feasibility. Solar energy systems have a distinct advantage in terms of lower maintenance expenses. Solar panels, due to their stationary nature, require minimal upkeep, mainly limited to routine cleaning to maintain performance and this lack of moving parts reduces the risk of mechanical failure, extending the system's operational life and decreasing maintenance costs and wind energy systems, however, are more maintenance-intensive and turbines consist of mechanical components subject to wear and tear due to continuous movement, requiring periodic maintenance of parts such as blades and gearboxes [4]. In remote areas, these maintenance requirements lead to higher costs since transporting specialized equipment and technicians to isolated locations can be logistically demanding and expensive and production efficiency and the stability of power generation are key factors influencing the choice between wind and solar systems and wind energy systems depend heavily on local wind conditions; in regions with consistent,

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strong winds, these systems can achieve high efficiency and stable production. However, the variability of wind speeds can lead to fluctuations in energy output, necessitating the use of storage systems or backup generators to ensure a consistent power supply and this variability may introduce added costs and logistical challenges in maintaining stability [5]. In contrast, solar energy systems offer relatively steady production levels during daylight hours in sunny areas. While production halts at night or during cloudy weather, battery storage systems provide a solution to bridge these periods, maintaining a balanced energy supply and though storage adds to the initial costs, it enhances continuity and reliability, making solar energy a viable option in regions with ample sunlight and the environmental impact and lifespan of each system also contribute to economic feasibility and wind energy systems typically require large areas of open land to avoid interference with natural ecosystems. While they produce clean energy, the presence of turbines can introduce noise pollution and potentially affect local wildlife, particularly bird populations, necessitating careful planning and potentially raising project costs [6]. Solar energy systems, on the other hand, have a relatively low environmental footprint during operation, as they are silent and stationary. However, at the end of their useful life, solar panels require responsible disposal and recycling due to the materials involved, which may present environmental and economic considerations. Both systems offer long operational life spans, though wind systems often require more complex and frequent maintenance, increasing long-term costs [7].

Investing in wind or solar energy systems for off-grid areas can yield substantial economic and social returns. Both systems contribute to energy security and reduce dependency on imported fossil fuels, resulting in long-term savings and price stability. Additionally, renewable energy systems can stimulate local economic activity by creating job opportunities in construction, maintenance, and potential future expansions. For rural and isolated communities, access to reliable electricity can drive local industry, improve healthcare and education facilities, and enhance overall quality of life. Moreover, as these systems produce clean energy, they play a significant role in reducing greenhouse gas emissions, helping nations meet climate targets while improving air quality and public health in surrounding areas [8].

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In conclusion, the choice between wind and solar energy systems for off-grid regions hinges on a comprehensive analysis of economic and engineering factors.

2. Literature Review

Many studies addressing this research are summarized in TABLE 1.

Table 1. Summary of prior's studies.

Criterion	Solar Energy	Wind Energy	References
Initial Cost	High (Cost of solar panels, devices, and installation)	High (Cost of wind turbines and installations)	[1 , 2]
Operating and Maintenance Cost	Low (Minimal maintenance, but panel replacements may incur costs)	Higher (Requires regular maintenance for wind turbines)	[3 , 4]
System Efficiency	High in areas with consistent solar radiation	Depends on wind continuity in the area	[1 , 7]
Production Predictability	Predictable with high solar radiation regions	Less predictable due to wind variability	[6 , 16]
Environmental Sustainability	Low emissions, helps reduce reliance on fossil fuels	Reduces carbon emissions, but may impact local ecosystems	[3 , 15]
Return on Investment (ROI)	Returns appear after a long period (5-10 years, depending on conditions)	Faster returns in regions with consistent winds	[5 , 17]
Environmental Impact	Very low environmental impact	Impact on wildlife, especially birds and small animals	[15 , 16]
Resource Availability	Depends on geographical location (better in sunny regions)	Depends on average wind speed (better in regions with continuous winds)	[1 , 8]

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Criterion	Solar Energy	Wind Energy	References
Grid Independence	Suitable for off-grid areas	Suitable for off-grid areas if wind is sufficient	[7 , 14]
Economic Advantages	Long-term fuel and maintenance savings	More cost-effective in regions with consistent wind	[8 , 10]

3. Methodology

The economic comparison between solar and wind energy systems requires a step-by-step methodology that encompasses the entire process, from project initiation through energy production and finally, to economic analysis.

1- Defining Energy Requirements.
2- Solar Energy System Design.
3- Wind Energy System Design.
4- Cost Estimations.
5- Energy Yield Calculation.
6- Net Present Value (NPV).
7- Levelized Cost Of Energy (LCOE).

4. Calculation process

Step 1: Defining Energy Requirements: To begin the design, it is necessary to define the total energy requirement for the project and the total energy required is calculated as the product of the average power demand and the time duration for which the energy is needed:

$$E = P_{load} * T \qquad (1)$$

Where: E is the total energy required in kWh, P_{load} is the average power demand in kW, and T is the time duration in hours [9].

Step2: Solar Energy System Design In this section, solar panel capacity and solar panel area are calculated as,

- Solar Panel Capacity

To determine the capacity of the solar panel system required to meet the total energy demand, the following formula is used, taking into account the efficiency of the solar panels and the average solar irradiance:

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$$\mathbf{P_{solar}} = \frac{\mathbf{E}}{(\eta_{\mathbf{solar}} * \mathbf{G})} \quad (2)$$

Where: P_{solar} is the required capacity of the solar panels in kW, E is the total energy required in kWh, η_{solar} is the efficiency of the solar panels, and G is the average solar, taking into account irradiance in kW/m² [10].
To calculate the total area required for the solar panels, the following equation is used:

$$A_{solar} = \frac{P_{solar}}{(\eta_{solar} * G)} \quad (3)$$

Where: A_{solar} is the total area of the solar panels in square meters, $\mathbf{P_{solar}}$ is the required solar panel capacity in kW, η_{solar} is the efficiency of the solar panels, and G is the solar irradiance in kW/m².

Step 3: Wind Energy System Design, the output of wind turbine power and the total number of turbines are calculated as,* Wind Turbine Power Output.
The energy output of a wind turbine is calculated based on the wind speed, the swept area of the turbine blades, and the efficiency of the turbine and the formula for wind the efficiency of the solar power generation is:

$$P\_wind = 0.5 * \rho * A * v\_wind\hat{}3 * C p \quad (4)$$

Where: P_{wind} is the power output of the wind turbine in watts (W), ρ is the air density in kg/m³, A is the swept area of the turbine blades in m², v_{wind} is the wind speed in m/s, and C_p is the power coefficient of the wind turbine [11].

- Number of Wind Turbines

To calculate the number of wind turbines required to meet the total energy demand, we use:

$$\mathbf{N_{turbines}} = \frac{\mathbf{E}}{(\mathbf{P_{wind}} * \mathbf{CF_{wind}})} \quad (5)$$

Where: $N_{turbines}$ is the number of wind turbines required, E is the total energy demand in kWh, P_{wind} is the power output per wind turbine in kW, and CF_{wind} is the capacity factor of the wind turbines

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(typically between 0.3 and 0.4).

Step 4: Cost Estimations, in electrical projects determines the financial resources required for completion within budget and schedule constraints.

- Capital Expenditure for Solar System

The capital expenditure for the solar energy system includes the costs of solar panels, inverters, batteries (if applicable), installation, and other necessary components and the total capital expenditure (CapEx) is calculated as:

$$\mathbf{CapEx_{solar}} = \mathbf{C_{panels}} + \mathbf{C_{inverters}} + \mathbf{C_{batteries}} + \mathbf{C_{installation}} + \mathbf{C_{other_{components}}} \quad (6)$$

Where: C_{panels} is the cost of solar panels per kW, $C_{inverters}$ is the cost of inverters, $C_{batteries}$ is the cost ofbattery storage (if applicable), $C_{installation}$ is the installation cost, and $C_{other_{components}}$ is the cost of additional components (e.g., wiring, monitoring systems) [12].

- Capital Similarly, for the wind energy system, the capital expenditure is calculated using:

$$\mathrm{CapEx_{wind}} = C_{turbines} + C_{inverters} + C_{batteries} + C_{installation} + C_{other_{components}} \quad (7)$$

Where: $C_{turbines}$ is the cost of each wind turbine, $C_{inverters}$ is the cost of inverters, $C_{batteries}$ is the cost of battery storage (if applicable), $C_{installation}$ is the installation cost, and $C_{other_{components}}$ includes additional infrastructure costs such as foundations Wind System, electrical connections, and control systems [13].

- Operating Expenditure for Solar System

The operating monitoring and other ongoing operational costs:

$$\mathrm{OpEx_{solar}} = C_{maintenance} + C_{monitoring} \quad (8)$$

Expenditure (OpEx) for the solar system includes maintenance, where$C_{maintenance}$is the annual maintenance cost of the solar panels and related components, and $C_{monitoring}$ is the cost of monitoring and managing the system's performance.

- Operating Expenditure for Wind System

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For the wind energy system, the operating expenditure is calculated as:

$$\mathrm{OpEx}_{\mathrm{wind}} = C_{\mathrm{turbine}_{\mathrm{maintenance}}} + C_{\mathrm{monitoring}} \quad (9)$$

Where: $C_{\mathrm{turbine}_{\mathrm{maintenance}}}$ is the annual maintenance cost of the wind turbines, and $C_{\mathrm{monitoring}}$ is the cost of monitoring and system management.

Step 5: Energy Yield Calculation, in electrical projects critically determines the expected energy output, considering efficiency, environmental condition, and technical losses.
The energy yield from the solar and wind systems is affected by the system's efficiency and the capacity factor and the energy yield can be calculated using the following formula for each system [14].

- Energy Yield for Solar System

For the solar energy system, the energy yield is given by:

$$\mathrm{EY}_{\mathrm{solar}} = P_{\mathrm{solar}} * T * \mathrm{CF}_{\mathrm{solar}} \quad (10)$$

Where: $\mathrm{EY}_{\mathrm{solar}}$ is the energy yield in kWh, P_{solar} is the installed solar capacity in kW, T is the operational time in hours, and $\mathrm{CF}_{\mathrm{solar}}$ is the capacity factor for solar energy, which typically ranges between 0.15 and 0.25.

- Energy Yield for Wind System

For the wind energy system, the energy yield is calculated using:

$$\mathrm{EY}_{\mathrm{wind}} = P_{\mathrm{wind}} * T * \mathrm{CF}_{\mathrm{wind}} \quad (11)$$

Where: $\mathrm{EY}_{\mathrm{wind}}$ is the energy yield in kWh, P_{wind} is the power output per wind turbine in kW, T is the operational time in hours, and $\mathrm{CF}_{\mathrm{wind}}$ is the capacity factor for wind energy, typically between 0.3 and 0.4.

Step 6: Net Present Value (NPV)
The Net Present Value (NPV) is an essential factor in assessing the economic viability of both systems. It is calculated by discounting the future cash flows:

$$\mathrm{NPV} = \sum \left(\frac{C_t}{(1 + r)^t} \right) \quad (12)$$

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Where: C_t is the net cash flow at time t, r is the discount rate, and t is the time period. A positive NPV indicates that the project is financially feasible [15].

Step 7: Levelized Cost of Energy (LCOE)

The Levelized Cost of Energy (LCOE) is another important metric to compare the cost-effectiveness of LCOE.

$$\mathrm{LCOE} = \frac{(\mathrm{CapEx} + \mathrm{OpEx})}{\mathrm{EY}} \qquad (13)$$

Where: CapEx is the capital expenditure, OpEx is the operating expenditure, and EY is the total energy yield in kWh over the lifetime of the system.

LCOE helps to determine the cost per unit of energy generated by the system, which is useful for comparing solar and wind energy costs and this extended methodology involves multiple engineering calculations to design, cost, and analyze the feasibility solar and wind energy systems and by taking into account the energy requirements, system design, capital and operating expenditures, energy yield, and financial metrics such as NPV and LCOE [16], it is possible to make a thorough and accurate economic comparison of the two energy systems and this approach ensures that the selected of both different energy sources. It is calculated as: energy system is not only technically viable but also financially sustainable, maximizing energy production while minimizing costs over the system's lifespan and the economic comparison between solar and wind energy systems involves evaluating various parameters across the entire project lifecycle, from energy requirements to design considerations, capital and operating expenditures, energy yield, and financial viability metrics like NPV and LCOE.

In Table 2, we begin by defining the energy requirements for both systems. For this example, both the solar and wind energy systems require 5000 kWh of total energy, with an average power demand of 5 kW and a time duration of 1000 hours and this common energy requirement forms the basis for further calculations in both energy systems [17].

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TABLE 2. Energy Requirements Comparison

Parameter	Solar Energy System	Wind Energy System
Total Energy Requirement (E)	5000 kWh	5000 kWh
Average Power Demand (P_{load})	5 Kw	5 kW
Time Duration (T)	1000 hours	1000 hours

Moving to the design phase, Table 3 details the design parameters for the solar energy system and the required capacity of the solar panels is 10 kW, calculated based on the energy demand and average solar irradiance and the area required for the solar panels is 100 m², determined by the solar panel efficiency and the average daily solar irradiance of 5 kWh/m²/day and the efficiency of the solar panels (η_{solar}) is set at 0.18, reflecting typical performance.

TABLE 3. Solar Energy System Design Parameters

Parameter	Value	Description
Solar Panel Capacity (P_{solar})	10 kW	Required capacity of solar panels (Equation 2)
Solar Panel Area (A_{solar})	100 m²	Area of solar panels (Equation 3)
Solar Panel Efficiency (η_{solar})	0.18	Efficiency of solar panels
Solar Irradiance (G)	5 kWh/m²/day	Average daily solar irradiance

In comparison, Table 4 outlines the design parameters for the wind energy system and the power output per wind turbine is 5000 W (or 5 kW), calculated using the wind speed, air density, and turbine efficiency factor (C_p) and the number of wind turbines required is one, as calculated by the energy demand and the power output of a single turbine and the air density is assumed to be 1.225 kg/m³, which is the standard value at sea level, and the wind speed is assumed to be 6 m/s and the power coefficient (C_p) of the turbine is set at 0.35, which is typical for modern turbines.

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TABLE4. Wind Energy System Design Parameters

Parameter	Value	Description
Wind Turbine Power Output (P_{wind})	5000 W (5 kW)	Power output per turbine (Equation 4)
Number of Wind Turbines (N_turbines)	1	Number of turbines (Equation 5)
Air Density (ρ)	1.225 kg/m³	Air density at sea level
Wind Speed (v_{wind})	6 m/s	Average wind speed
Power Coefficient (C_p)	0.35	Efficiency factor of the wind turbine

Once the system designs are completed, the next phase involves calculating the capital expenditure (CapEx) for each system. As detailed in Table 5, the capital costs for the solar energy system include the cost of solar panels (4,870 LYD/kW), inverters (24,350LYD), batteries (9,740LYD), installation costs (4,870LYD), and other components (2435LYD) and the total capital expenditure for the solar system amounts to 36,525LYD. For the wind energy system, the capital expenditure is higher, totaling 43,830LYD, with costs allocated for the turbines, inverters, installation, and other components, but no battery storage costs are included.

TABLE 5. Capital Expenditure (CapEx) Comparison

Parameter	Solar Energy System	Wind Energy System
Solar Panels Cost (C_{panels})	4870LYD/kW	N/A
Inverters Cost $(C_{inverters})$	24,350LYD	24,350LYD
Batteries Cost $(C_{batteries})$	9,740LYD	0LYD
Installation Cost $(C_{installation})$	4870LYD	14,610LYD
Other Components $(C_{other_{components}})$	2,435LYD	4870LYD
Total CapEx $\left(\frac{CapEx_{solar}}{CapEx_{wind}}\right)$	36,525LYD	43,830LYD

Following the capital costs, Table 6 outlines the operating expenditures (OpEx) for both systems and the solar energy system incurs an annual maintenance cost of 2,435LYD and a monitoring and management cost of 974LYD, leading to a total OpEx of 3,409LYD per year. In contrast, the wind energy system has higher operating costs, with annual maintenance costs of 4,870LYD and

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monitoring costs of 1,461LYD, leading to a total OpEx of 6,331 LYD per year.

TABLE 6. Operating Expenditure (OpEx) Comparison

Parameter	Solar Energy System	Wind Energy System
Annual Maintenance ($C_{maintenance}$)	2,435LYD	4,870LYD
Monitoring & Management ($C_{monitoring}$)	974LYD	1,461LYD
Total OpEx $\left(\frac{OpEx_{solar}}{OpEx_{wind}}\right)$	3,409LYD/year	6,331LYD/year

In Table 7, the energy yield for both systems is calculated. For the solar system, the energy yield is 4000 kWh, considering the solar capacity factor (CF_{solar}) of 0.18 and the wind energy system, with a capacity factor (CF_{wind}) of 0.35, yields the same amount of energy, 4000 kWh, based on the system's power output and operational time.

TABLE 7: Energy Yield Comparison

Parameter	Solar Energy System	Wind Energy System
Solar Energy Yield (EY_{solar})	4000 kWh	N/A
Wind Energy Yield (EY_{wind})	N/A	4000 kWh
Capacity Factor (CF_{solar})	0.18	N/A
Capacity Factor (CF_{wind})	N/A	0.35

Finally, Table 8 presents the financial analysis, comparing the Net Present Value (NPV) and Levelized Cost of Energy (LCOE) for both systems and the NPV for the solar energy system is 487,000 LYD, while the wind energy system's NPV is slightly lower at 438,300 LYD and the LCOE for the solar system is 0.7305 LYD/kWh, indicating that solar energy is slightly more cost-effective than wind energy, where the LCOE is 0.8766LYD/kWh.

TABLE 8. Financial Analysis (NPV and LCOE)

Parameter	Solar Energy System	Wind Energy System
Net Present Value (NPV)	487,000LYD	438,300LYD

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Parameter	Solar Energy System	Wind Energy System
Levelized Cost of Energy (LCOE)	0.7305LYD/kWh	0.8766LYD/kWh

This comprehensive analysis across different stages and parameters shows that while both solar and wind energy systems can meet the energy requirements of the project, the solar system tends to be more cost-effective in terms of capital expenditure, operating costs, and levelized cost of energy. However, the final decision may depend on site-specific factors such as geographic location, solar and wind availability, and long-term sustainability considerations.

5. Result

The analysis performed by the work is an economic feasibility analysis of two solar and wind energy projects over a period of 20 years and the work is based on calculating a set of financial factors that include monthly revenues, operating costs, monthly and cumulative cash flows, and taxes that must be paid based on the resulting income and the payback period of the investment capital for each project is also calculated, as well as the Net Present Value (NPV) for each of them and this section deals with calculating the net cash flow resulting from the solar energy project and the wind energy project on a monthly basis, the monthly cash flow and revenues resulting from the sale of electricity generated from both systems (solar energy and wind energy), and calculating the monthly operating costs paid to operate the two systems and this includes expenses such as equipment maintenance and operation in addition to taxes that must be paid based on the net revenues resulting from the projects after deducting operating expenses. In the work, an inflation factor is added to adjust costs and revenues annually based on the annual inflation rate (3%), which affects cash flows and reflects the economic reality. After deducting all costs and taxes, the monthly cash flow is calculated as follows:

$$\text{Cash flow} = \text{Revenues} - \text{Operating costs} - \text{Taxes} \quad (14)$$

These values are used to analyze the financial performance of the project on a monthly level as shown in the Figure 1.

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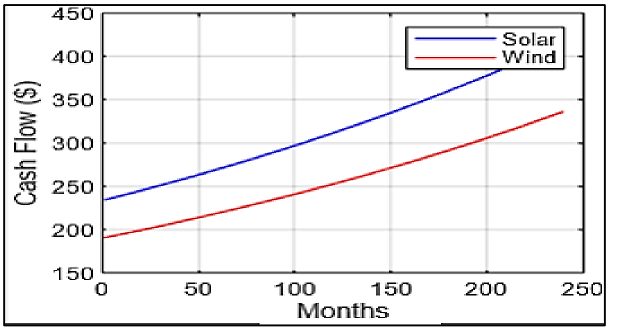

Figure 1. Monthly cash flows for solar energy and wind energy.

Revenue is calculated from the sale of energy generated by solar and wind systems. Revenue is based on the yield from the sale of Kilo Watt-hours (kWh) as well as environmental factors such as the capacity factor of both systems (solar and wind). In this work, solar energy production is calculated using the capacity of solar panels and the capacity factor (which reflects the actual efficiency of the system in generating energy) and wind energy production is calculated using the capacity of wind turbines and their capacity factor and the energy production is multiplied by the selling price of electricity per kWh (0.974LYD) to determine the monthly revenue and the calculations take into account inflation which is increasingly applied to monthly revenues and this is shown in Figure 2.

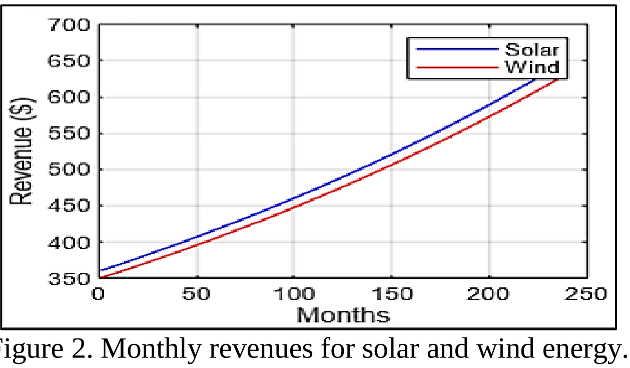

Figure 2. Monthly revenues for solar and wind energy.

Whereas Figure 3, shows the monthly operating costs associated with running solar and wind systems. Costs include maintenance and operation, and vary between systems depending on their characteristics.
In this example:

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- Solar operating costs = 3,409LYD per year (prorated monthly).
- Wind operating costs = 6,331LYD per year (prorated monthly).
- Operating costs are adjusted for annual inflation in the code to become larger over time.

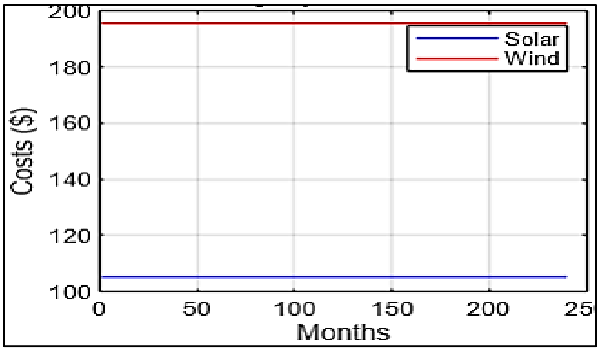

Figure 3. Monthly Operating Costs for Solar and Wind.

While Figure 4, the accumulated cash flow over time is displayed on a monthly basis. All monthly cash flows are added together to calculate the cumulative total of cash flows and this allows the total profitability of each project to be determined over the months and this figure shows how profits accumulate from the first month to the last month of the project life (20 years) and this method is important for analyzing the overall profitability of the project.

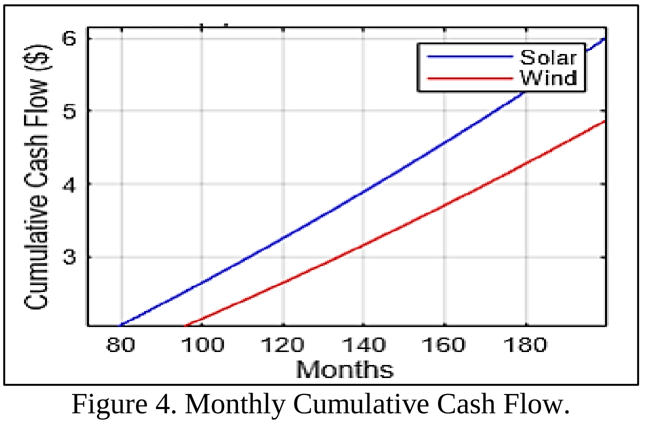

Figure 4. Monthly Cumulative Cash Flow.

The cost payback period for each project (solar and wind) is calculated, which indicates the length of time it takes for the project to recover the initial investment (CAPEX) using the accumulated

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cash flows in this figure5 and the month in which the full investment cost is recovered is determined using:

$$\text{Initial Investment} = \text{Capital Cost (CAPEX)for solar or wind.} \quad (15)$$

The first month (month 1) in which the cumulative cash flow becomes greater than or equal to the capital cost of the project is found and this is considered the cost payback period and this period is displayed in the form of a bar chart showing the cost payback period for solar and wind projects as Figure 5.

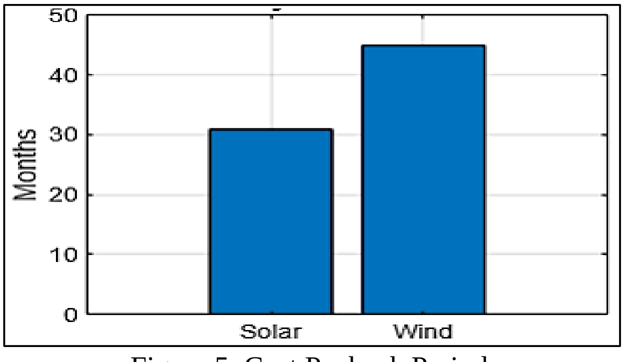

Figure 5. Cost Payback Period.

The monthly cash flows are converted to annual cash flows by representing the cumulative cash flow for each year, where Figure 6, shows the financial performance of the project over the years. Annual cash flow is calculated by taking the accumulated values at the end of each year and these values are shown in a linear fashion, where each point represents the total accumulated cash flow at the end of the year.

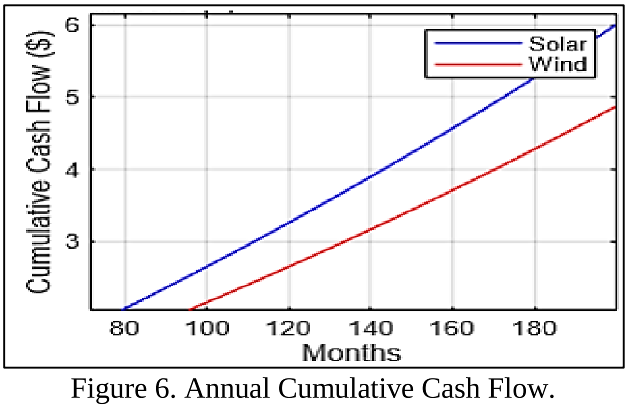

Figure 6. Annual Cumulative Cash Flow.

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As for the payback period, the results show that the payback period for solar energy is 31 months, which means that after 31 months (less than 3 years), the project will be able to recover the initial investment allocated to develop the project and the short payback period indicates that solar energy generates positive cash flows faster and is therefore a faster option for recovering the investment compared to other energy sources.
As for the payback period for wind energy, it was 45 months, meaning that the project takes 45 months (about 3 and a half years) to recover its initial investment and this is longer than the payback period for solar energy, indicating that profitability comes more slowly compared to solar energy in this case and this may be due to higher capital costs, lower energy production, or other factors such as equipment maintenance or lower turbine capacity in some circumstances and the Net Present Value (NPV) for solar energy was: 55,021.8931LYD, which indicates that the solar energy project is profitable in the long run. A positive net present value shows that the project will generate financial returns that exceed the initial cost of investment over time, including future returns adjusted for inflation and the higher the NPV, the more profitable the project is. In this case, the NPV indicates that the project will generate a good profit after recovering the initial investment cost and for wind energy, it was 44,619.7679LYD, meaning that the wind energy project also shows a positive NPV, meaning that it is also profitable. However, compared to the solar energy project, the wind project shows a lower NPV of 10,402.1252LYD and this may indicate that the profitability of the wind project is lower, which is consistent with the longer payback period.
As for the comparison analysis between solar energy and wind energy in terms of faster cash flow, solar energy generates larger and faster cash flows compared to wind energy and this is due to the lower operating costs of solar energy and the increased production capacity in the first months of the project and the longer profitability of wind energy is positive, but the longer payback period means that the project may have a harder time attracting investment quickly compared to a solar project. Also, the final profit is lower for wind energy, which may make some investors prefer solar energy if the goal is to recover capital quickly and as for the factors influencing the choice between projects in terms of initial cost, it was found that the cost of developing a solar energy project is less than the cost of

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developing a wind energy project, which leads to achieving a faster payback of capital.

Also, the monthly operating costs of solar energy are lower than those of wind energy, which promotes a faster flow of money into solar energy.

Solar energy may be more productive due to environmental factors such as sun hours in the selected locations, which contributes to a shorter payback period compared to other energy sources.

Figure 7 shows four key economic indicators for comparing solar and wind energy,

Return On Investment (ROI) As shown in Figure 7(A), the Return On Investment (ROI) for solar is 50.64%, while it is 1.80% for wind energy. ROI is a measure of the profitability of an investment, and is calculated as a percentage of the return compared to the initial investment. A higher ROI indicates that the project is more profitable. Solar energy has a much higher ROI than wind energy, indicating that it is a more efficient and profitable investment. In contrast, the ROI for wind energy is much lower, indicating that the wind energy project has a lower return on investment and Benefit-Cost Ratio (BCR) As shown in Figure 7(B), the Benefit-Cost Ratio (BCR) for solar energy is 1.51, while it is 1.02 for wind energy and the benefit-cost ratio represents the ratio of the benefits generated to the costs incurred in a power project. A BCR greater than 1 indicates that the project is economically viable, as the benefits exceed the costs. Solar has a higher BCR, meaning it provides more value per dollar than wind, which has a BCR of just over 1 and this suggests that while wind is still economically viable, it provides a relatively marginal return for its costs and the Annual Economic Net Present Value (AENPV) is shown in Figure 7(C) where the Annual Economic Net Present Value (AENPV) for solar is 6,462.8309LYD per year and for wind is 5,240.9966LYD per year and the annual economic net present value is the annual value of the net cash flows from a project, adjusted for the time value of money. A higher annual economic net present value indicates a greater annual economic return from the project. A higher economic net present value for solar indicates that it generates a greater annual financial value than wind, making it a more attractive financial option for investors.

Levelized Cost Of Energy (LCOE) As shown in Figure. 7,(D), the LCOE for solar is \$0.0498/kWh, while that for wind is \$0.0833/kWh and the LCOE represents the cost per unit of energy

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produced over the life of the power system. A lower LCOE indicates a more cost-effective energy source. Solar has a lower LCOE, meaning that it costs less to produce one kilowatt-hour of energy than wind and this makes solar a more cost-efficient energy source, providing cheaper energy production overall.

After the process of financial analysis of the economic feasibility of solar and wind projects, it was found that solar energy is the most economically feasible option compared to wind energy, as the results showed that the capital payback period for the solar energy project is less than that of wind energy and that calculating the Net Present Value (NPV) of solar energy It was higher than wind energy, and the data showed that the annual operational costs of the solar energy project are lower than its counterpart in wind energy and this difference in costs reflects the higher efficiency of solar energy in terms of resource consumption and time in maintenance. Based on these results, it can be concluded that solar energy is the most suitable option. Financially and engineering efficient for long-term investment. Although wind energy may be more suitable in some areas with strong, continuous winds, solar energy remains the best option in terms of cost and quick returns in most cases.

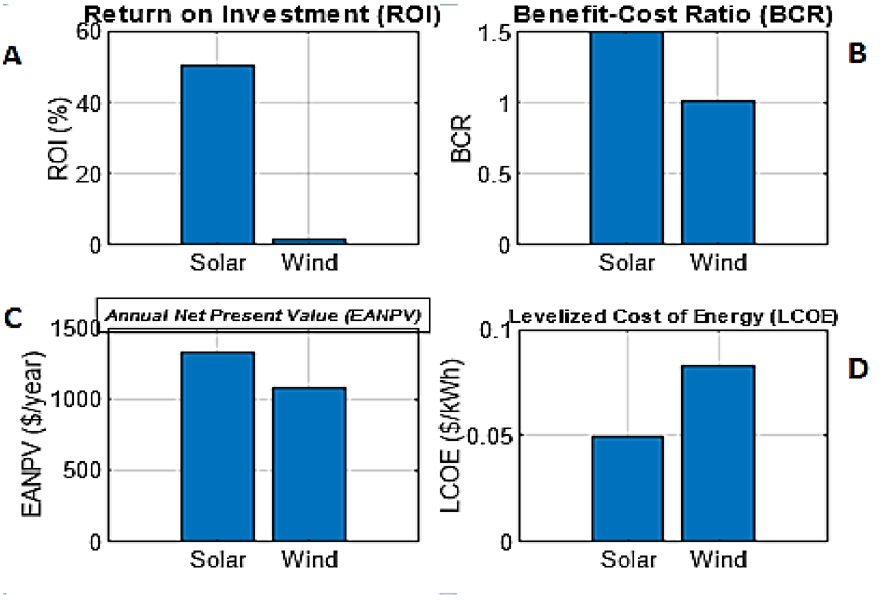

Figure7. Return On Investment (ROI)(A)-Benefit-Cost Ratio (BCR)(B) - Annual Economic Net Present Value (AENPV)(C) -Levelized Cost Of Energy (LCOE)(D).

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6. Conclusions

In conclusion the results showed that the capital payback period for the solar energy project is 31 months, which means that the project recovers its costs faster compared to the wind energy project, which had a payback period of 45 months and the calculations also showed that the net present value of the solar project was 55,021.89 LYD while that of wind was 44,619.77 LYD, reflecting the higher profitability of solar energy. Other economic indicators were used such as the Return On Investment (ROI) which was 50.64% for solar energy compared to 1.80% for wind energy and the Levelized Cost Of Energy (LCOE) for solar energy was 0.2425 LYD per kWh, while that of wind energy was 0.4057 LYD per kWh, reflecting the lower production cost of solar energy. Based on these results, it can be concluded that solar energy represents an effective financial and engineering option for long-term investment, making it the preferred choice for investors seeking quick capital recovery and stable and sustainable profits.

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