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Economic evaluation of a wind and solar energy hybrid electric sightseeing boat in Laemsak, Krabi Province, Thailand

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Abstract: This research aims to analyze the economic evaluation of using hybrid wind and solar energy with a diesel-engine long-tail boat in the Laemsak tourism community, Krabi province, Thailand. It is a quantitative research study that collects and estimates the costs and expenses of developing hybrid wind turbine and solar panels with diesel-engine long-tail boat, including initial development costs, operational and maintenance costs, and depreciation costs, and also estimates the benefits of using the developed boat, such as revenue from boat services, fuel savings, and carbon offset savings. The economic feasibility is analyzed using the Cost-Benefit Analysis (CBA) method by calculating the Payback Period (PP), Net Present Value (NPV), Benefit Cost Ratio (BCR), and Internal Rate of Return (IRR), as well as analyzing the Sensitivity of some uncertain factors. The analysis of the project over a 10-year period indicates PP of approximately 3-4 years, positive NPV, BCR greater than 1.0, and IRR much higher than the Interest Rate. These figures demonstrate that the project is highly economically viable and suitable for investment.

Keywords: *Diesel engine long-tail boat, Economic evaluation, Hybrid electric sightseeing boat, Laemsak tourism community, Solar energy, Wind energy.*

1. Introduction

The average global surface temperature has continuously increased over the past 100-200 years, in the phenomenon known as global warming. In 2023 (to October), it was found that the Earth's mean near-surface temperature had increased by 1.40±0.12°C compared to the pre-industrial era (1850-1900) [1]. Without serious and urgent intervention, it is predicted that the Earth's temperature will rise by up to 4.0°C in the 21st century [2], which will lead to increasingly severe and catastrophic disasters. The escalation of global warming has severe implications for the health and well-being of humans worldwide [3]. The primary cause of global warming stems from human activities that lead to an increase in carbon dioxide (CO_2) emissions, a significant greenhouse gas (GHG) which pays a key role in crucial for trapping heat in the atmosphere [4]. The Paris Agreement (2015), which succeeded the Kyoto Protocol (enforced in 2005), has set global cooperation to maintain the global average temperature increase below 2°C and strives to limit the temperature increase to 1.5°C [5].

Tourism is a significant contributor to climate change, with approximately 8% of global carbon emissions attributed to tourism activities [6]. Given the projected growth of the tourism industry, carbon emissions from tourism could reach around 6.5 gigatons by 2025, accounting for about 13% of

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global emissions, representing a 44% increase from 2013. Travel and transportation are the primary sources of carbon emissions in tourism, accounting for approximately 49% of the total [7].

Krabi province is one of Thailand's key tourism destinations. In 2018, it ranked 4th among the country's 77 provinces in terms of tourism revenue [8]. Known for its stunning coastal attractions, Krabi boasts world-renowned beaches such as Railay beach, voted the 9th most beautiful beach in the world in 2023 [9]. The province also features community-based tourism highlighting a rich cultural heritage and abundant natural beauty both on land and at sea. For instance, the Laemsak tourism community has received multiple Thailand Tourism Awards from the Tourism Authority of Thailand in 2017, 2019, 2021, and 2023 [10].

Krabi has prioritized reducing GHG emissions, aligning with Thailand's policies outlined in the National 20-Year Strategy (2018-2037), the 13th National Economic and Social Development Plan (2023-2027), and the Master Plan to Support Climate Change (2015-2050). These plans include strategies to develop a low-emission economy in the long term, with targets to reduce GHG emissions by 30% from the projected business-as-usual (BAU) level by 2030, achieve carbon neutrality by 2050, and net zero emissions by 2065 [11-13]. Despite Thailand's low contribution of only 0.95% of global emissions in 2020 [14], the country remains committed to working collaboratively to keep global average temperatures from exceeding 1.5°C as per the Paris Agreement. Krabi places great emphasis on sustainable development. Various sectors have collaborated to outline sustainable tourism strategies for the province through the Krabi Green Tourism Declaration in 2015, along with the establishment of the "Krabi Go Green" initiative as both a guideline and a goal for the province's tourism. This vision was further solidified with the Krabi Vision 2020 and the Krabi Tourism Development Plan for the 5-year period of 2023-2027 [15]. These plans underscore Krabi's commitment to environmentally friendly tourism practices for sustainability. A key aspect of these plans is the reduction of fossil fuel energy consumption and the promotion of renewable energy use to reduce pollution and GHG emissions [16].

Renewable energy sources such as solar, wind, hydro, biomass, and geothermal energy are widely available and can be replenished continuously without depletion over time. They are crucial due to their capacity to offer a sustainable and environmentally friendly energy alternative, unlike fossil fuels [17]. The potential of renewable energy sources for sustainable energy production and their pivotal role in the decarbonization of the energy sector are significant [18]. While renewable energy has numerous advantages, such as reducing GHG emissions, it also has some disadvantages, such as reliance on weather conditions and variability in energy production, as well as low energy efficiency and limited electricity generation capacity, all of which pose challenges [19]. However, the use of hybrid renewable energy systems, which combine multiple types of renewable energy, can mitigate the stability issues of renewable energy resulting from intermittent weather and changing seasons [20].

The scope of this research includes using wind turbine and solar cells in a hybrid configuration for a diesel engine long-tail boat in the Laemsak tourism community, Krabi province. The selection of the long-tail boats in this study is motivated by their unique prevalence in Krabi and the Andaman coast provinces (Phuket, Ranong, Phang Nga, Krabi, Trang, and Satun). They are widely used for tourism. Laemsak tourism community is chosen as the study area because it is a tourism community that has emerged from the collaboration of the local people in Laemsak sub-district who jointly manage tourism in the community themselves. It has a clear direction in responsible tourism for sustainability. The main activity of tourism in this community is taking long-tail boat tours to appreciate nature (Figure 1.1). These boats are powered by internal combustion engines, burning fossil fuels such as diesel, which continuously emit carbon into the atmosphere during tourism operations. Additionally, there are problems of noise pollution, odours, and oil spills in the sea.

As for the renewable energy to be used, solar energy using solar cells and wind energy using wind turbines in a hybrid configuration with diesel engines can be considered suitable. This choice is supported by the operational patterns of sightseeing boats, which predominantly operate during the middle of the day and remain in continuous motion, enabling consistent energy capture from sunlight

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and wind throughout the day. It was also found that using hybrid renewable energy, such as wind, fuel cell and solar energy ensures energy stability, resulting in efficient boat propulsion [21].

The objective of this research is to analyze the economic evaluation of developing wind turbine and solar cells in a hybrid system with a diesel engine long-tail boat used in the Laemsak tourist community, Krabi province, Thailand.

Figure 1.
Tourism route utilizing the long-tail boats in the Laemsak tourism community.

2. Materials and Methods

The research framework depicted in Figure 2.1 outlines the development of a 23-frame long-tail boat capable of carrying up to fifteen passengers under normal conditions. This vessel provides a general tourism service in Krabi province and the Andaman region. The boat has been retrofitted into a hybrid system, integrating an internal combustion diesel engine with a regenerative energy system that stores energy from 3.96 kW solar panels. The solar panels are strategically installed on the roof of the boat and can be partially folded for user convenience. Additionally, a 6.00 kW vertical-axis wind turbine has been installed to capture wind from all directions. Energy is stored using Gel Deep Cycle batteries, supporting an electrical power capacity of 10 kW. These batteries drive a 10 kW induction motor, which operates in conjunction with a 85 Hp diesel engine, providing a total electrical power output of 63.38 kW. The system features a switch gear to alternate between energy sources, as illustrated in Figure 2.2.

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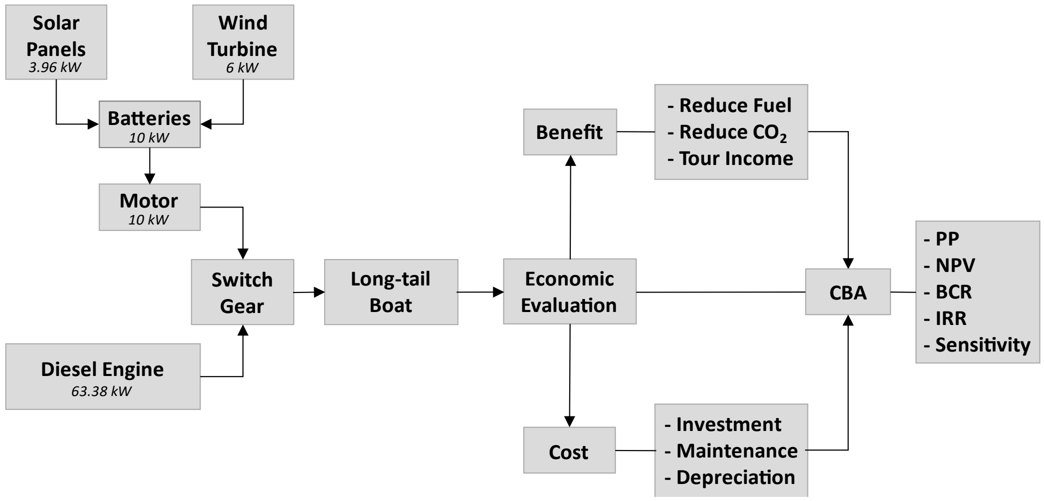

Figure 1.
Research framework based on wind and solar energy that supported boat.

Figure 2.
Hybrid electric boat development framework.

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This research is a quantitative study aimed at analyzing the economic evaluation by using Cost-Benefit Analysis (CBA), which is highly beneficial in decision-making for both business and public policy projects [22]. The costs for CBA include estimations for developing the wind and solar energy hybrid system with the diesel engine long-tail boat, as well as the annual operation and maintenance expenses and depreciation. Meanwhile, fuel consumption of the pre-developed boat along the 17 km tourism route in the Laemsak tourism community as illustrated in Figure 1.1 has been recorded and utilized to calculate carbon emissions. The fuel savings realized through the use of wind and solar energy as substitutes in the case of the developed boat, alongside the savings in carbon offsetting costs incurred by the use of the developed boat, constitute the project's benefits. Meanwhile, the other primary benefit is the revenue from services provided by the developed boat for tourist excursions. The data obtained will be analyzed for economic evaluation by calculating various values as follows:

Payback Period (PP) refers to the time required to recover the benefits to offset the investment costs, and effectively denotes the breakeven point. It is calculated by accumulating the net cash flows (cash inflows minus cash outflows) for each year. The year when the cumulative cash flow equals zero or turns positive is considered the payback year [23].

Net Present Value (NPV) represents the disparity between the present value of cash inflows and outflows over a specified period. It is computed using a Discount Rate, often referencing an Interest Rate as the minimum acceptable rate of return. NPV is a crucial factor in assessing the present value of cash flows. As long as the Interest Rate remains positive, present money holds greater value than future money. A positive NPV signifies that projected revenues exceed anticipated costs [24]. The formula for NPV calculation is as follows:

$$NPV = \sum_{t=0}^{n} \frac{Rt}{(1+i)^t} \tag{1}$$

Where: t represents the time period of the cash flow (year 0, 1, 2, ... up to n).

Rt is the net cash flow (cash inflow - cash outflow) at time t.

i is the discount rate.

Benefit Cost Ratio (BCR) is a comprehensive analysis of the relationship between benefits and costs. It is determined by dividing the present value of all benefits over a specified period by the present value of all costs during the same period. A BCR exceeding 1.0 indicates a profitable project [25]. The formula for BCR calculation is as follows:

$$BCR = \frac{\sum_{i=0}^{n} \frac{Bt}{(1+i)^t}}{\sum_{i=0}^{n} \frac{Ct}{(1+i)^t}} \tag{2}$$

Where: t represents the time period of the cash flow (year 0, 1, 2, ... up to n).

Bt is the net cash inflow at time t.

Ct is the net cash outflow at time t.

i is the discount rate.

Internal Rate of Return (IRR) is a financial indicator used to assess the profit potential of an investment. It represents the Discount Rate at which the Net Present Value of all cash flows equals zero, indicating the return on investment when the project reaches its breakeven point [26]. The formula for calculating IRR is as follows:

$$NPV = \sum_{t=0}^{n} \frac{Rt}{(1+r)^t} = 0 \tag{3}$$

Where: t represents the time period of the cash flow (year 0, 1, 2, ...up to N).

Rt is the net cash flow (cash inflow - cash outflow) at time t.

r is the IRR to be calculated.

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Sensitivity Analysis is a method used to analyze the effects of variables resulting from changes in independent or input variables, providing an understanding of factors influencing outcomes. This analysis leverages other formulas such as PP, NPV, BCR, and IRR [27]. In this analysis, various input variables such as the developed boat service fees, and fuel prices are altered to evaluate the changes in PP, NPV, BCR, and IRR.

2.1. Costs of the Project

This research focuses on the development of a solar panels and wind turbine hybrid system with a diesel engine boat through the conversion of an existing long-tail boat used for sea-sightseeing tourism in the Laemsak tourism community. The associated costs are outlined as follows:

1. Refurbishment of a 23-frame long-tail boat:
   1.1 Structural repairs, involving the replacement of the wooden structure and the implementation of a leak-proof system, amounting to 60,000 Thai baht for materials and 40,000 baht for labor, totalling 100,000 baht.
   1.2 Installation of a 85 Hp diesel engine as a replacement for the original engine, costing a total of 30,000 baht.
2. Installation of solar and wind energy on the boat:
   2.1 Installation of 36 Mono Crystallize solar panels, each measuring 0.51 m x 1.20 m, with a capacity of 110 W, 12 V, 5.5 A, mounted on the roof of the boat, providing a total electric power output of 3.96 kW, which costs 150,000 baht.
   2.2 Installation of a vertical-axis wind turbine capable of capturing wind from all directions, 1.00 m diameter, 1.60 m high, positioned at the bow of the boat, providing 6 kW of electricity, with costs of 100,000 baht.
   2.3 Electric vehicle (EV) systems include batteries, inverters, motors, and gearboxes, with costs of 300,000 baht.
3. Operation and Maintenance (O&M):
   3.1 O&M of the boat structure, including inspections, cleaning, leak-proof system maintenance, and anti-corrosion painting, is estimated at 2,000 baht per month, totalling 24,000 baht per year.
   3.2 The O&M cost is approximately 1 US dollar or 36 Thai baht per hour of operation for a 50 kW diesel engine [28]. This research uses a 64 kW diesel engine, with the maximum estimated usage being 3 hours per trip, 200 trips per year. Therefore, the total annual O&M cost is calculated as 36 x (64/50) x 3 x 200 amounting to 27,648 baht per year.
   3.3 O&M of the solar panels is generally minimal, consisting mainly of regular cleaning and inspections. However, it is assumed that there is a cost equivalent to 2% of the initial system cost per year [29], which therefore, amounts to 150,000 x (2/100) = 3,000 baht per year.
   3.4 O&M of the wind turbine is estimated at 2% of the initial investment cost per year [30], which amounts to 100,000 x (2/100) = 2,000 baht per year.
   3.5 The EV system requires minimal maintenance. However, to extend the lifespan of the EV system, especially the battery, it is necessary to check the electrolyte levels, maintain cleanliness, and store properly when not in use [31]. This research sets the O&M cost for the EV system at 500 baht per month or 6,000 baht per year.
4. Depreciation:
   4.1 Depreciation of the boat structure is calculated at a fixed rate. With an average lifespan of 20 years, the annual depreciation rate is 5% of the initial investment cost, which amounts to 100,000 x (5/100), totalling 5,000 baht per year.
   4.2 Depreciation of the diesel engine is also calculated at a fixed rate. With an average lifespan of 15,000 hours under normal operating conditions [32], and an estimated maximum usage of 3 hours per trip, 200 trips per year, thus, the engine's lifespan is approximately 25 years.

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Therefore, the annual depreciation rate is 4% of the initial investment cost, totalling 30,000 x (4/100) = 1,200 baht per year.

4.3 Depreciation of the solar panels is calculated at a fixed rate. With an average lifespan of 25 years [33], the annual depreciation rate is 4% of the initial investment cost, totalling 150,000 x (4/100) = 6,000 baht per year.

4.4 Depreciation of the wind turbine is also calculated at a fixed rate. With an average lifespan of 20 years [30], the annual depreciation rate is 5% of the initial investment cost, totalling 100,000 x (5/100) = 5,000 baht per year.

4.5 Depreciation of the EV system is calculated at a fixed rate. With an average battery lifespan of 10 years [34-35], the annual depreciation rate is 10% of the initial investment cost, totalling 300,000 x (10/100) = 30,000 baht per year.

The costs associated with the development of the hybrid electric boat in this research are detailed in Table 1.

Table 1
The various costs involved in developing a hybrid electric long-tail boat.

Description	Amount (baht)
Boat modification	
Structural repair cost	100,000
85 Hp diesel engine cost	30,000
Installation of hybrid renewable energy	
Solar panels	150,000
Wind turbine	100,000
EV system	300,000
O&M cost (per year)	
Boat structure	24,000
Diesel engine	27,648
Solar panels	3,000
Wind turbine	2,000
EV system	6,000
Depreciation (per year)	
Boat structure, lifespan 20 years	5,000
Diesel engine, lifespan 25 years	1,200
Solar panels, lifespan 25 years	6,000
Wind turbine, lifespan 20 years	5,000
EV system, lifespan 10 years	30,000

2.2. Benefits of the Project

The benefits of developing the hybrid electric boat in this research include:

1. Revenue from sightseeing boat services along the coastal tourism routes of the Laemsak tourism community, spanning approximately 17 km. Each trip costs 1,500 baht, with a deduction of 500 baht for the boat driver, resulting in a net income of 1,000 baht per trip. With an estimated 200 trips per year, the revenue from services after deducting expenses is 200,000 baht per year.
2. This research aims to develop the use of wind and solar energy to generate electricity for powering the boat instead of using diesel fuel. A diesel engine is installed as a backup in case of emergencies where renewable energy cannot be utilized. From data collected on boat usage before development along the route shown in Figure 1.1, it was found that 15 litres of diesel fuel were used. With the selling price of diesel fuel in Krabi province at 33 baht per litre, this project achieves saving on diesel fuel costs, amounting to 15 x 33 x 200 = 99,000 baht per year.

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3. Not using diesel fuel avoids carbon emissions, eliminating the need to pay for carbon offsetting for environmentally friendly tourism. Diesel fuel consumption releases 2.7406 $kgCO_2eq$ per litre [36], so it is possible to reduce carbon emissions by 15 x 2.7406 x 200 = 8.222 tCO_2eq per year, and the cost of carbon offsetting is approximately 166 baht per tCO_2eq [37]. Therefore, this project saves on the purchase of carbon offsetting credits, amounting to 8.222 x 166 = 1,365 baht per year.

The benefits of developing the hybrid electric boat in this research are as shown in Table 2.

Table 2.
The various benefits of developing a hybrid electric long-tail boat.

Description	Amount (baht/year)
Tourist boat service fees, net of expenses	200,000
Diesel fuel savings	99,000
Carbon offsetting savings	1,365

This research is set for the duration of a 10-year project, aligning with the minimum operational lifespan for the EV system of hybrid electric boat development. The Interest Rate is fixed at the Minimum Retail Rate (MRR) offered by Krung Thai Bank as of March 22nd, 2024, which stands at 7.57% [38].

3. Results and Discussions

The results of the Cost-Benefit Analysis in this study are indicated in Table 3.

Table 3
Cost-Benefit Analysis of developing a hybrid electric long-tail boat.

Description	Amount
Payback period (PP)	3.57 years
Net present value (NPV)*, **	623,553 baht
Benefit cost ratio (BCR)*, **	1.69
Internal rate of return (IRR)*	25.01 %

Note: *Project duration 10 years
**Interest rate 7.57%.

From Table 3, it can be seen that the payback period is 3.57 years, which is considered relatively short. The NPV is 623,553 baht, indicating a positive value. The BCR is 1.69, which is much greater than 1.00, and the IRR is 25.01%, which is much higher than the interest rate of 7.57%. These results demonstrate that the project is economically viable and suitable for investment.

The uncertainty surrounding certain factors can influence the outcomes presented in Table 3 This study will conduct a sensitivity analysis to assess the economic viability under various scenarios. Specifically, variations of -10%, and +10% will be applied to the revenue from boat services, and the price of diesel fuel.

By analyzing the sensitivity using these adjustments, the economic evaluation of the project will vary, as detailed in Table 4.

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Table 4.
Economic evaluation resulting from changes in various factors.

Description		
Tourist boat net service fees change	-10%	+10%
Payback period (PP)	3.99 years	3.23 years
Net present value (NPV)*, **	486,709 baht	760,397 baht
Benefit cost ratio (BCR)*, **	1.57	1.80
Internal rate of return (IRR)*	21.50 %	28.42 %
Diesel price change	-10%	+10%
Payback period (PP)	3.76 years	3.39 years
Net present value (NPV)*, **	555,816 baht	691,291 baht
Benefit cost ratio (BCR)*, **	1.63	1.74
Internal rate of return (IRR)*	23.29 %	26.71 %

Note: *Project duration 10 years
**Interest rate 7.57%.

Table 4 illustrates that a 10% increase in revenue from boat services or a 10% increase in diesel prices would result in a shorter payback period (PP), indicating a faster return on investment. Additionally, the NPV, BCR, and IRR would increase, indicating greater economic feasibility. Conversely, a 10% decrease in revenue or a 10% decrease in diesel prices would result in a PP of 3.99 and 3.76 years, respectively, indicating an admittedly longer payback period but one which is still relatively short. The NPV, BCR, and IRR would decrease slightly, but these measures would still indicate a high level of economic viability.

4. Conclusions

Boats are primary vehicles of transportation in marine tourism areas. The use of renewable energy sources instead of fossil fuels such as diesel, can help reduce environmental pollution, particularly carbon emissions, thus mitigating the causes of climate change. However, the use of renewable energy may face challenges related to the stability and consistency of the energy sources. Hybrid renewable energy systems, such as solar panels and wind turbines, combined with diesel engines, can address these challenges. Developing renewable energy systems for tourist boats involves investment costs, along with operational and maintenance costs. The Cost-Benefit Analysis conducted over a 10-year period on the integration of wind turbine and solar cells in a hybrid system with a diesel engine long-tail boat used in the Laemsak tourism community reveals promising results. The Payback Period (PP) is estimated to be approximately 3-4 years, which is considered relatively short, with a positive Net Present Value (NPV), a Benefit-Cost Ratio (BCR) is much greater than 1.0, and an Internal Rate of Return (IRR) is much higher than the interest rate. These findings indicate that the project is highly economically viable. Moreover, the implementation of this hybrid system can contribute to the reduction of carbon emissions, thereby addressing the issue of global warming and promoting environmentally friendly tourism. Nevertheless, it is recommended to conduct stakeholder satisfaction assessments for the operation of hybrid electric tourist boats. This will provide valuable insights for further improving the efficiency and suitability of renewable energy use in marine tourism.

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