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RESEARCH ARTICLE

Evaluating the Economic Feasibility of Agrivoltaic Systems: A Case Study of Solar Park Gambang

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ABSTRACT

Solar energy is a cornerstone of global decarbonization efforts, but its large land footprint creates a tradeoff between clean energy generation and competing land uses. Malaysia's growing commitment to renewable energy has prompted exploration into land efficient technologies like agrivoltaic systems, which combine solar power generation with agricultural production. With increasing land use competition and national solar capacity targets, optimizing economic returns from such dual use systems is both timely and strategic. However, most feasibility studies have been conducted in temperate regions, leaving a gap in context specific economic assessments for tropical climates like Malaysia. Therefore, this study evaluates the economic feasibility of implementing an agrivoltaic system at the Gambang Solar Park in Malaysia. The study employed comprehensive financial modelling by incorporating capital and operational expenditures alongside revenue from solar energy, agricultural output and environmental benefits. The results indicate that the agrivoltaic system generated higher revenue although incurred greater total production costs. Nevertheless, it achieved a higher net profit of 2.41 percent more than the conventional configuration. In addition, the system demonstrated a stronger return on investment at 25 percent, a shorter payback period of 4.01 years, and an internal rate of return of 24.61 percent. These findings suggest that the agrivoltaic system offers a financially attractive and sustainable dual

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use land strategy within Malaysia's renewable energy landscape.

Contribution/Originality: This study contributes to the existing literature by analysing AVS economic feasibility compared with conventional solar farms using cost structure analysis as methodology. The paper's primary contribution is finding that AVS offer greater profitability, diversified income, and improved financial resilience. Thus, supporting their large-scale adoption.

1. Introduction

The global shift towards renewable energy is driven by the urgency of reducing greenhouse gas emissions and mitigating climate change, has intensified the development of large-scale solar farms. In Malaysia, initiatives such as the Large-Scale Solar (LSS) program and the National Renewable Energy Policy aim to accelerate solar deployment to achieve a 20% renewable energy capacity mix by 2025 (Sustainable Energy Development Authority, n.d). However, the expansion of solar infrastructure often competes with agricultural land use, particularly in densely populated or agriculturally productive regions. This is resulting in land-use conflicts and food security concerns (Hu, 2023).

Therefore, Agrivoltaic Systems (AVS) which integrate photovoltaic (PV) technology with agricultural production on the same land, have emerged as a dual-use solution to address these challenges. From the past literature, suggests that AVS offers ecological and land-efficiency benefits while diversifying revenue streams for farmers and solar investors (Agostini et al., 2021; Torma & Aschemann-Witzel, 2023). However, despite its potential, AVS adoption remains limited due to several challenges. This is including economic concerns over economic feasibility (Kabir & Kumar et al., 2018), high capital costs (Torma & Aschemann-Witzel, 2023) and uncertain returns (Dupraz et al., 2011; International Renewable Energy Agency, 2012), particularly in the Malaysian context.

In conclusion, most existing studies emphasize technical feasibility or small-scale implementations, leaving a significant gap in understanding AVS cost structures and financial outcomes at utility scale. Therefore, this study aims to evaluate the economic value of implementing an agrivoltaic system at a large-scale solar farm by analyzing capital investment, operational costs and potential revenue streams. Using Gambang Solar Park as a case study, this research provides empirical insights into the financial feasibility of AVS to inform sustainable energy investment and policymaking in Malaysia.

2. Methodology

This study adopts a cost structure analysis framework to evaluate the economic feasibility of implementing an agrivoltaic system (AVS) by classifying and analysing cost elements into several categories. The structured approach provides a comprehensive understanding of costs outflows associated with dual-use land systems. This is including capital expenditure, operation expenditure, earning cost, profitability ratios, payback period analysis, net present value (NPV) and internal rate return (IRR). The methodology is guided by established cost accounting principles (Kaplan & Atkinson, 1989; Horngren et al., 2012) and extended to the renewable energy-agriculture

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integration context based on existing literature (Agostini et al., 2021; Alam et al., 2022; Trommsdorff et al., 2023).

2.1. Boundary of Study

This study is limit to a 1-hectare plot within Gambang Solar Park, Pahang, that accommodate approximately of 1,680 solar panels. Additionally, the analysis focuses on the combined production of solar electricity and aubergine (eggplant) cultivation as the test crop. This defined boundary provides a balanced framework for exploring the economic potential of agrivoltaics in a real-world solar farm context.

2.2. Capital Expenditure

In this study, capital expenditure (CAPEX) for the agrivoltaic system is following the framework proposed by Agostini et al. (2021). CAPEX refers to all expenditures related to the installed capacity of the photovoltaic (PV) system, measured in watts. This includes the cost of PV modules installation, technical services and administrative and financial expenses related to project execution. This classification allows for a clearer assessment of capital cost distribution and supports more accurate financial modelling for comparing conventional solar farms with agrivoltaic systems (Agostini et al., 2021).

2.3. Operation Expenditure

Operational expenditure refers to the recurring costs required to operate and maintain the system over time. Then, it will be categorized into three main components which is fixed costs, variable costs, and mixed costs. Fixed costs refer to costs that remain constant in total within a relevant range of activity but may vary on a per-unit basis as production levels change. Meanwhile, variable cost is directly proportional to changes in activity levels, meaning they increase or decrease in total as production or sales volumes fluctuate based on energy generation and crop production levels, affecting the overall cost-efficiency of the system (Alam et al., 2022). Lastly, mixed costs contain both fixed and variable components, meaning they change in total but not proportionately with changes in activity levels (Alam et al., 2022).

2.4. Earning cost

This earning cost presents the economic returns generated from the operation of both conventional solar farms and solar with agrivoltaic systems on a one hectare scale. It includes an overview of total revenue, which comprises income from solar energy generation, crop production and intangible benefits such as carbon credit earnings. In addition to revenue, the section evaluates the resulting net profit after deducting all operational and capital costs.

2.5. Profitability ratios

Three additional profitability indicators were computed to evaluate financial efficiency and return performance:

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2.5.1. Profit Over Production Cost

The Profit Over Production Cost ratio measures amount of profit is generated for every ringgit spent on total production costs. It is a useful indicator for assessing the efficiency and profitability of an investment relative to its operational expenses. The ratio is calculated using the equation (1).

$$\text{Profit over Production Cost} = \frac{\text{Annual Profit}}{\text{Total Production Cost}} \tag{1}$$

2.5.2. Profit Over Sales (Revenue)

The profit over sales ratio (also known as profit margin) measures each ringgit earned in revenue translates into actual profit. It is a key indicator of financial efficiency and operational performance as shown in the formula (2).

$$\text{Profit over Sales} = \frac{\text{Annual Profit}}{\text{Total Annual Revenue}} \tag{2}$$

2.5.3. Average Return on Investment (ROI)

The Return on Investment (ROI) is a standard metric used to evaluate the efficiency and profitability of an investment by comparing the net profit to the initial capital expenditure. It provides insight to measures the effective of invested capital is being utilized to generate earnings using the formula applied in (3).

$$\text{ROI} = \frac{\text{Net Profit}}{\text{Capital Investment}} \tag{3}$$

2.6. Payback Period Analysis

The payback period is a financial metric used to determine the time required for an investment to recover its initial capital cost, based on annual net cash inflows. A shorter payback period generally indicates a more attractive investment, particularly in renewable energy projects where upfront capital expenditure (CAPEX) is substantial. For this analysis, the payback period is calculated using the formula in (4).

$$\text{Payback Period} = \frac{\text{CAPEX}}{\text{cash flow}} \tag{4}$$

2.7. Net Present Value (NPV)

The Net Present Value (NPV) is a core financial metric used to evaluate the profitability of an investment by considering the time value of money. It reflects the present value of expected future cash flows over the project's lifetime, minus the initial capital investment. A positive NPV indicates that the investment is likely to generate more value than its cost, making it financially viable.

The discount rate of 6% is applied in this study to reflect a realistic, policy-aligned cost of capital for renewable energy projects in Malaysia. This value aligns with the reports by the Sustainable Energy Development Authority (SEDA) Malaysia, which apply 6% as a baseline discount rate in evaluating feed-in-tariff (FiT) and Net Energy Metering (NEM) project scenarios. While, a 20-year project horizon (n = 20) is adopted based on the expected operational lifespan of solar PV systems installed at Solar Park Gambang itself. The formula used in (5).

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$$\text{NPV} = \text{Cash Flow (PUIFA i, n)} - \text{Initial Outlay} \quad (5)$$

Where:
Cash Flow = Annual profit
PUIFA i,n = Present value of a uniform income series (annuity factor), based on discount rate *i* and period *n*
Initial Outlay = Total capital investment
Given: **i = 6%, n = 20 years**, hence **PUIFA = 11.470**

2.8. Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) is a key investment appraisal metric used to evaluate the profitability of a project. It represents the discount rate at which the Net Present Value (NPV) equals zero. In other words, the rate of return at which the present value of cash inflows equals the initial investment outlay. A higher IRR indicates a more profitable and attractive investment, provided it exceeds the project's cost of capital. For this analysis, the payback period is calculated using the formula in (6).

$$\text{IRR} = \left(\frac{\text{FV}}{\text{PV}}\right)^{\frac{1}{\text{n}}} - 1 \quad (6)$$

Where:
FV = Future Value
PV = Present Value
n = periods

3. Result

3.1. Solar Farm Cost for 1 Hectare

Table 1 summarizes the major costs associated with operating a one-hectare solar farm at Gambang Solar Park, with a total estimated cost of RM331,690.92. The largest capital expenditures include solar panels (1,680 units at RM800 each, totaling RM67,200.00) and infrastructure costs, annualized at RM126,363.64 over a 20-year lifespan. Key electrical components such as the inverter (RM22,500.00) and two transformers which is 0.36/33kV (RM3,500.00) and 33/132kV (RM47,500.00) are essential for grid compatibility. Additional costs include switchgear units (RM950.00 each), operation and maintenance (RM13,090.92 annually) and regulatory charges such as NEM application fees (RM10,000.00), TNB commissioning fees (RM10,000.00), and ST license (RM818.18). Land-related obligations, including land tax (RM25,454.55) and assessment tax (RM1,363.64), reflect the ongoing financial commitment tied to land use in Malaysia. All core equipment has an average lifespan of 15–25 years (Mekhilef et al., 2012), ensuring long-term system functionality.

Table 1: General Solar Cost for 1 hectare

Solar cost	Quantity	Cost/unit (RM)	Total cost (RM)
Solar panels*	1680 unit	800.00	67,200.00
Infrastructure costs*		2,527,273.00	126,363.64
Inverter DC to AC*	1 unit	450000.00	22500.00
0.36/33kV transformer*	1 unit	70000.00	3500.00

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RE switchgear*	1 unit	19000.00	950.00
GBLS switchgear*	1 unit	19000.00	950.00
33/132kV transformer*	1 unit	9500000.00	47500.00
Signboard	one time payment	2,000.00	2,000.00
Annual operation and maintenance cost	monthly	1,090.91	13,090.92
Other cost:			
ST license	one time payment	818.18	818.18
NEM application fees	one time payment	10000.00	10000.00
TNB Metering and Commissions fees	one time payment	10000.00	10000.00
Land tax	annually	25454.55	25454.55
Assessesment Tax	annually	1363.64	1363.64
Total cost			331,690.92
*depreciation value (20 years)			

Source: UiTM (n.d.)

3.2. Crop Cost for 1 Hectare

Table 2 presents the estimated annual cost of cultivating aubergine on a one-hectare plot under an agrivoltaic system, totaling RM44,905.00. This figure reflects inputs for two cropping seasons per year and includes four main cost categories which is development, raw materials, labor, and operational expenses. The development cost (RM2,840.00) covers land preparation and irrigation system depreciation. The largest share is attributed to raw materials (RM33,475.00), including seeds, fertilizers (chicken manure and organic), pesticides, and essential farming materials such as plastic mulch, baskets, and supporting woods (RM13,200.00). Labor cost is estimated at RM7,270.00 annually, covering activities across the crop cycle from seedbed preparation to harvesting that based on prevailing wage rates (Ministry of Human Resources Malaysia, 2023). Finally, fuel costs for operating machinery contribute RM1,320.00. These inputs represent a typical cost structure for small-scale vegetable farming under dual land-use conditions in Malaysia, as guided by Jabatan Pertanian Malaysia standards.

Table 2**:** General Crop Cost for 1 Hectare (Aubergine)

Crop cost	**Quantity needed**	**Price/unit (RM)**	**Price/season (RM)**	**Price/year (RM)**	**Total (RM)**
(A) Development cost:					
Soil preparation					
i. Mini tractor	1 unit	1750	1750	1750	1750
ii. Shovel	1 unit	40	40	40	40
iii. Sickle	1 unit	30	30	30	30
iv. Scoop	1 unit	20	20	20	20
Irrigation systems*		5000	500	1000	1000

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Total (A)					2840
(B) Raw material cost					
Seed	0.4 kg	400	160	320	320
Germination					
i. Nursery media	5 bags	35	175	350	350
ii. Seed Tray	70 unit	3	210	420	420
Agriculture lime (GML)	3.0 tons	600	1800	3600	3600
Fertilizer:					
Chicken manure	5.0 tons	120	600	1200	1200
Organic fertilizer	3.0 tons	1000	3000	6000	6000
Pesticides					
i. Insecticides	4.8 L	50	240	480	480
ii. Fungicides	3.0 kg	35	105	210	210
iii. Herbicides	3.4 L	50	170	340	340
Other Tools					
i. Plastic basket	20 unit	70	1400	2800	2800
ii. Silvershine plastic 4'	25 unit	80	2000	4000	4000
iii. Raffia string	10 unit	15	150	300	300
iv. Supporting woods**	6600 unit	2	6600	13200	13200
v. Scissor	1 unit	5	5	5	5
vi. Agriculture knapsack sprayer	1 unit	250	250	250	250
Total (B)					33475
(C) Labor input cost (per day)					
Soil dan seedbed preparation	Contract	230	230	460	460
Smoothing and repairing seedbed	12 days	15	180	360	360
Germination	5 days	15	75	150	150
Transplanting	12 days	15	180	360	360
Irrigation maintenance	10 days	15	150	300	300
Fertilizing	12 days	15	180	360	360
Weeding	12 days	15	180	360	360
Pest and disease control	25 days	15	375	750	750
Pruning	16 days	15	240	480	480
Build wood support	3 days	15	45	90	90
Harvesting	120 days	15	1800	3600	3600

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Total (C)					7270
(D) Other cost:					
Fuel	300 L	2.2	660	1320	1320
Total (D)					1320
Overall total (A + B + C + D)					44905

* Irrigation system can be used up to 5 years, Depreciation value: RM 5000/5 = RM 1000

**Supporting woods can be use for 2 harvesting season (1 year = 2 season)

Source: Jabatan Pertanian Malaysia (n.d.)

3.3. Comparison of Economic Cost Analysis

Based on the Table 3, the economic comparison between a conventional solar farm and a solar farm integrated with an agrivoltaic system (AVS) reveals notable differences in cost structures and financial performance. The AVS model incurs a higher total production cost of RM376,595.93 per hectare annually compared to RM331,690.92 for the conventional system. This increase is primarily due to higher variable costs (RM54,900.92) related to agricultural inputs such as fertilizers, pesticides, labour and fuel. While the conventional solar farm incurs only RM13,090.92 in variable costs, mostly for basic operation and maintenance. Fixed costs for both systems are similar whereas RM297,781.82 for the conventional solar farm and RM300,876.83 for the AVS system. In comparison, the slight increase in AVS attributed to farming equipment like irrigation systems and tools. Both systems share the same mixed costs (RM20,818.18), which include regulatory and grid connection fees such as licensing, metering, and application charges.

In terms of capital expenditure, the AVS requires RM294,896.82, marginally higher than the RM291,781.82 needed for the conventional solar farm. Despite the increased costs, the AVS demonstrates greater revenue-generating potential, achieving a total annual revenue of RM450,078.95 compared to RM401,718.82 for the solar-only model. This advantage is driven by the inclusion of crop sales and carbon credit earnings from both energy generation and sustainable agricultural practices. Consequently, the AVS yields a higher net profit of RM73,483.02 compare to RM70,027.95 for the conventional solar farm.

Profitability ratios further reflect the financial viability of both systems, with the AVS showing a return on investment (ROI) of 0.25, which is slightly higher than the 0.24 recorded for the conventional solar farm. This means that for every RM 1 of invested in the solar farm, there is a net return of RM 0.25 or a 25% return on the capital annually for solar farm with agrivoltaics and on the contrary for solar farm without agrivoltaic system. This result also indicates improved capital efficiency. However, in profit over production cost, shows conventional solar farm (0.21) is slightly higher than solar farm with agrivoltaic system (0.20). Additionally, the consistent result also shows in the profit over revenue whereas conventional solar farm is slightly higher than agrivoltaic system with result 0.17 and 0.16 respectively.

Next, the payback period for the solar farm with agrivoltaic system is shorter, at 4.01 years, compared to 4.17 years for the conventional solar farm. This means the solar farm with agrivoltaic system recovers its initial investment faster, despite the higher capital

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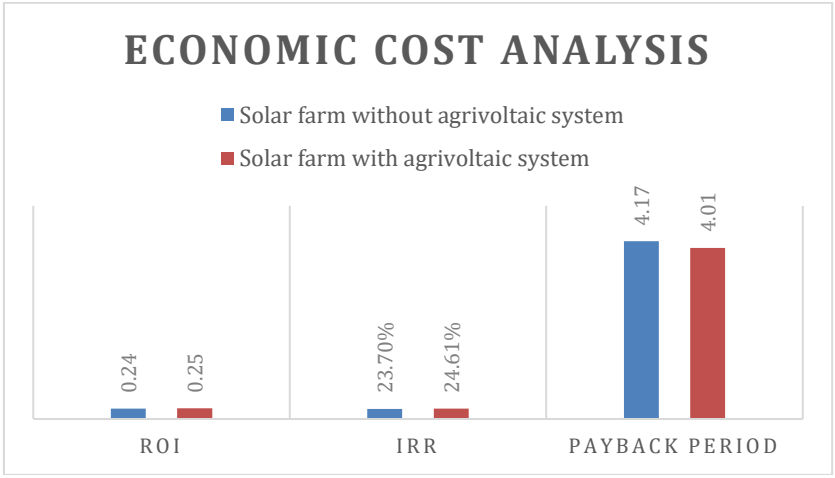
outlay. The Net Present Value (NPV) and Internal Rate of Return (IRR) also reinforce the solar farm with agrivoltaic system's economic advantage, with an NPV of RM547,953.42 and IRR of 24.61%, outperforming the conventional solar farm system's NPV of RM511,438.77 and IRR of 23.70%.

Table 3: Economic Cost Analysis

Item	Solar farm without agrivoltaic system	Solar farm with agrivoltaic system
Operation Expenditure:		
1. Fixed Cost	RM 297781.82	RM 300876.83
2. Variable Cost	RM 13090.92	RM 54900.92
3. Mixed Cost	RM 20818.18	RM 20818.18
4. Total Production Cost	RM 331690.92	RM 376595.93
CapitalExpenditure	RM 291781.82	RM 294896.82
Earning Cost		
i. Total Revenue	RM 401718.82	RM 450078.95
ii. Net Profit	RM 70027.95	RM 73483.02
Profitability Ratios		
i. Profit over Production Cost	0.21	0.20
ii.Profit over Sales	0.17	0.16
iii. ROI	0.24	0.25
Payback Period	4.17	4.01
NPV	RM 511438.77	RM 547953.42
IRR	23.70%	24.61%

Figure 1: Comparison of Economic Cost Analysis



4. Discussion

The comparative economic evaluation of a one-hectare solar farm with and without an agrivoltaic system (AVS) highlights critical insights into cost structures, revenue streams and investment performance. The integration of AVS leads to an increase in the total production cost, from RM331,690.92 in the conventional model to RM376,595.93, primarily driven by a substantial rise in variable costs. These variable costs which comprise agricultural inputs are necessary for enabling crop cultivation under solar

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panels. This aligns with findings that AVS systems impose additional operational expenditures, whereas vital for sustaining dual land-use functionality and enhancing land productivity (Agostini et al., 2021). Next, although the AVS model accounts for additional irrigation infrastructure and tool depreciation (Trommsdorff et al., 2023) the fixes cost remain comparable for both systems as the majority of infrastructure cost are consistent. Followed by mixed costs that comprising regulatory and metering charges show an equal amount for both systems, reflecting standard licensing and grid-integration expenses (Sustainable Energy Development Authority, 2024).

Furthermore, the initial investment for solar farm with agrivoltaic system (RM 294,896.82) is higher compared to conventional solar farm (RM 291, 781.82). Despite higher initial investment, agrivoltaic system generates higher revenue (RM450,078.95) contrast to conventional solar farm (RM401,718.82). This enhanced earning capacity is attributed to diversified income streams, which include electricity sales via Feed-in Tariff mechanisms, carbon credits from clean energy generation and crop revenue which is known for its short growth cycle and market demand in Malaysia (Alam et al., 2022; Mekhilef et al., 2012). The inclusion of intangible revenue streams of elevated solar panels further strengthens the financial case for AVS adoption (Ravilla et al., 2024). Consequently, the AVS system yields a higher net profit (RM73,483.02) than the conventional model (RM70,027.95), reflecting its capacity to optimize land utility and generate multiple revenue channels.

While, from a profitability perspective, profit over production cost (0.20) and profit over sales (0.16) for agrivoltaic system are marginally lower than their conventional counterparts. These differences are offset by agrivoltaic's system better long-term value metrics. However, the Return on Investment (ROI) slightly favors AVS (0.25) over the conventional system (0.24), underscoring improved capital productivity. On the other hand, the payback period for the AVS model is shorter (4.01 years) than the conventional system (4.17 years), indicating faster recovery of capital outlay. This result highlight that in AVS systems, despite higher upfront costs, achieve quicker break-even points due to their cumulative earnings potential (Pascaris et al., 2021; Agostini et al., 2021; Feuerbacher et al., 2022).

Lastly, the Net Present Value (NPV) and Internal Rate of Return (IRR) figures strongly support AVS feasibility. The AVS outperforming the conventional solar farm at RM547,953.42 (NPV) and 24.61% (IRR) compared to RM511,438.77 and 23.70%, respectively. These metrics affirm that AVS projects are not only bankable but also economically resilient, offering higher future cash flow relative to investment (Barron-Gafford et al, 2019; Agostini et al., 2021; International Renewable Energy Agency, 2021; Feuerbacher et al., 2022). This outcome corroborates earlier studies, which advocate for agrivoltaic deployment in regions with land scarcity and high solar irradiance, such as Malaysia (Torma & Aschemann-Witzel, 2023; International Renewable Energy Agency, 2021).

5. Conclusion

In conclusion, the study demonstrates the economic feasibility of integrating agrivoltaic systems (AVS) into solar farm infrastructure in Malaysia, using a one-hectare analysis at Gambang Solar Park as a reference. Although the AVS model incurs higher initial capital and variable operational costs due to the addition of agricultural activities, it simultaneously generates higher total revenue and net profit compared to the

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conventional solar farm. These gains are driven by diversified income streams through solar energy generation, crop cultivation and carbon credit opportunities, which enhance land productivity and financial resilience.

Moreover, investment performance indicators such as Net Present Value (NPV), Internal Rate of Return (IRR) and a shorter payback period further reinforce the attractiveness of AVS as a sustainable and profitable model. The findings reveal that agrivoltaic systems not only improve return on investment but also provide a strategic solution to address land-use conflicts, particularly in regions facing agricultural and energy land competition. Additionally, agrivoltaic systems offer a compelling case for dual land-use optimization by enhancing food-energy co-production, accelerating capital recovery and supporting climate adaptation strategies which align with the objectives under the National Renewable Energy Policy and Paris Agreement 2024. Their implementation should be supported through policy incentives, stakeholder engagement and scalable pilot projects to accelerate the transition toward a low-carbon, resource-efficient economy in Malaysia and similar regions.

Ethics Approval and Consent to Participate

This study received ethical approval from the Research Ethics Committee of Universiti Teknologi MARA (UiTM). All procedures involving human participants were conducted in accordance with the ethical standards of the institutional research committee. Informed consent was obtained from all participants prior to their participation.

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Conflict of Interest

The authors reported no conflicts of interest for this work and declare that there is no potential conflict of interest with respect to the research, authorship, or publication of this article.

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