Triangulating a Mixed-Method Approach to Design Sustainable a Solar Energy Decision-Making Framework: A Malaysian Residential Perspective

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ABSTRACT

Despite Malaysia's high solar potential and the availability of government incentives under programs like Net Energy Metering (NEM 3.0), the adoption of solar energy systems (SES) among household consumers remains significantly low. This study aims to develop a sustainable decision-making framework by triangulating qualitative insights and quantitative prioritization to better understand the key factors influencing SES adoption. A sequential mixed-method design was employed in two phases. In Phase One, thematic analysis of semi-structured interviews with SES adopters under NEM 3.0 revealed six major themes: financial viability, service capability, technology flexibility, company credibility, regulatory feasibility, and external influences.

Phase Two applied the Analytic Hierarchy Process (AHP) to these six themes, using pairwise comparisons conducted by SES users to quantify the relative importance of each criterion. The AHP findings revealed that Service Capability (26.07%) and Financial Viability (24.79%) were the most influential factors, while External Influences received the lowest weight. These quantitative results were found to be consistent with the qualitative insights from Phase One, indicating strong convergence between what users expressed narratively and how they prioritized factors when forced to make trade-offs.

Based on this triangulation process, a comprehensive SES decision-making framework was developed, reflecting both contextual lived experiences and structured data-driven rankings. This framework provides practical value to policymakers, solar providers, and end users by offering a clear roadmap for promoting residential SES adoption. Methodologically, the study demonstrates the strength of integrating thematic analysis with AHP. Practically, it contributes to Malaysia's renewable energy goals and supports Sustainable Development Goals 7 (Affordable and Clean Energy) and 13 (Climate Action).

Keywords: Solar Energy Systems (SES), Decision-Making Framework, Analytic Hierarchy Process (AHP), Thematic Analysis, Household Adoption

INTRODUCTION

In recent years, Malaysia has made notable strides in promoting renewable energy adoption, with solar energy positioned as a key driver toward achieving its sustainability targets under the Sustainable Development Goals (SDG 7 – Affordable and Clean Energy, and SDG 13 – Climate Action) (NRECC, 2024; SEDA, 2023). The nation's solar potential is vast, with average solar irradiation levels ranging between 4.0 to 4.9 kWh/m²/day, making it highly suitable for SES, particularly for rooftop installations on residential homes (MIDA, 2020; International Energy Agency, 2019). Despite this favourable environmental and technical landscape, the actual adoption rate of SES among household consumers remains modest, especially under the government's Net Energy Metering (NEM 3.0) program (GlobalData Energy, 2019; Chee, 2023).

While incentives and infrastructure are in place, household decision-making around SES adoption continues to be shaped by a complex mix of behavioural, financial, regulatory, and informational factors. Existing studies have highlighted various barriers to adoption, including high capital costs, lack of awareness, concerns about long-term performance, and limited trust in service providers (Ridauddin Daud, 2024; Azman et al., 2021).

Moreover, the adoption landscape is further complicated by fragmented findings from previous research, many of which examine influencing factors in isolation, failing to present a cohesive view of the interrelationships that govern consumer decisions (Balcombe et al., 2014; Cheah & Phau, 2022).

Given this context, this study seeks to investigate and integrate both qualitative and quantitative dimensions of household SES adoption in Malaysia. Drawing from a sequential mixed-method approach, the research explores lived consumer experiences through thematic analysis and prioritizes adoption criteria via the AHP (Braun & Clarke, 2006; Saaty, 2008). This triangulated methodology not only captures the nuanced personal and contextual motivations behind SES adoption but also quantifies the relative importance of key factors in consumer decision-making.

Ultimately, the study proposes a comprehensive and sustainable decision-making framework tailored to the Malaysian residential context. This framework is designed to guide households, policymakers, and service providers in fostering informed decisions, improving service alignment, and accelerating the national energy transition toward a greener future.

LITERATURE REVIEW

The adoption of SES in household contexts has been examined through numerous interdisciplinary lenses, such as economics, behavioral science, and policy studies. However, present a unified framework that combines these perspectives to capture decision-making in the real world, particularly in specific local settings like Malaysia.

Models of Technology Adoption

Several theoretical models have been proposed to understand the process of technology uptake. Diffusion of Innovation (DOI) theory, as outlined by Rogers (2003), describes the mechanism through which innovations spread in a population, dividing people into five adopter groups: innovators, early adopters, early majority, late majority, and laggards. However, DOI lacks the specificity to examine consumer-specific patterns of behavior in the SES context.

To address such barriers, the Technology Adoption Life Cycle (TALC) (Moore, 1991) presents the concept of a "chasm" between early adopters and the early majority that explains the adoption stagnation widely observed for solar technologies. At the same time, the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) (Venkatesh et al., 2012) adds to the discussion of adoption by including factors like performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, and habit. These behavioral constructs were particularly helpful in informing the decision-making framework in this study.

Adoption of SES in Malaysia

Malaysia has the advantage of stable solar irradiance and a maturing renewable energy policy landscape. Yet, household SES adoption is slower than expected as shown in Table 1 below. The NEM Rakyat Programme's cycle 3 allocation for household consumers is crucial in driving the adoption of SES among household consumers, particularly through its incentive structure. Despite the allocation of 250 MW, only 171.61 MW of applications have been submitted, of which 157.03 MW have been approved. The remaining 78.39 MW (31.36% of the total quota) highlights a shortfall in the adoption rate among household consumers to be completed by year end of 2024.

Table 1: NEM Rakyat Allocation and Take Up Rate

NEM Rakyat Programme	MWac
Total Allocation (NEM Rakyat)	250.00
Quota Applied	171.61

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Total Quota Approved	157.03
Quota Balance to the date 2024	78.39 (31.36%)

Source: SEDA (2024)

GlobalData (2019) shows that there are not many rooftops solar opportunities being tapped. Ridauddin Daud (2024) and Zahari et al. (2024) inform that despite various subsidy programs like NEM 3.0 and SolaRIS, household adoption is deterred by the high upfront capital investment, low awareness, and regulatory ambiguity. Based on Figure 1.1, Malaysia had a total of approximately 4.55 million buildings as of 2021 with an estimated total roof area of 720.6 km² available for solar installation (MyRER, 2021). Additionally, residential buildings contributes the highest percentage in terms of building type which taking up approximately 22.7 GW of potential, split between 3.9 million houses.

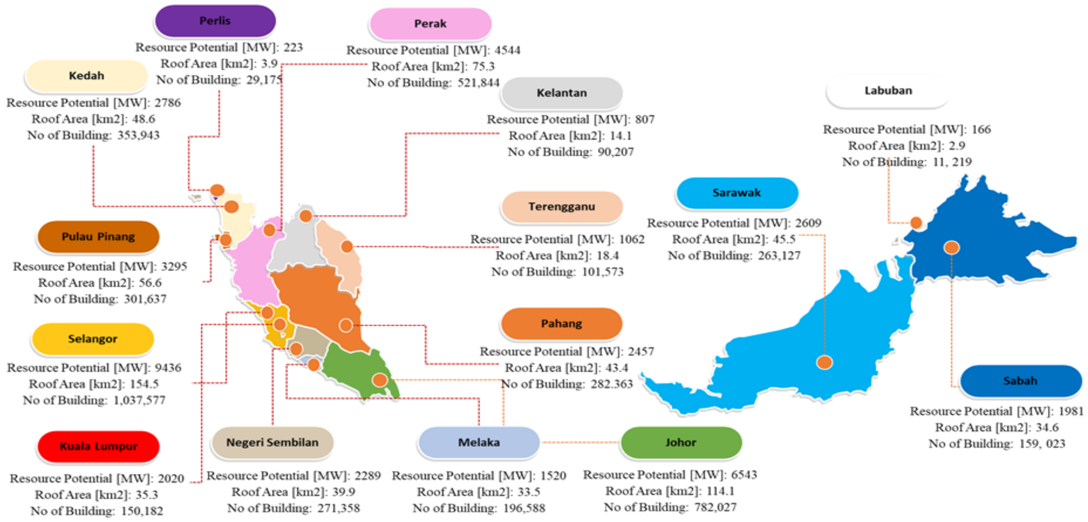

Figure 1: Summary of Building Assessed for Rooftop Solar PV

Source: MyRER,2021

Azman et al. (2021) discovered financial feasibility, with worries over payback periods and upkeep expenses, to be a main discouragement. Likewise, Bao et al. (2020) and Balcombe et al. (2014) recognized long-term return on investment (ROI) issues to be significant in domestic SES choices. Research conducted by Batel (2020) and Palm & Eriksson (2018) highlights the importance of social proof and provider credibility in shaping decision-making among households, thereby illustrating the prevailing trust deficit in the market. While some studies discuss SES adoption in the Asia-Pacific region (Sovacool, 2014), they do not delve specifically into Malaysian household-level results, particularly those under schemes like NEM 3.0.

Research Gap and Motivation

Despite the proliferation of solar energy initiatives in Malaysia, household adoption of SES has not progressed at the pace anticipated by national energy planners. As of 2024, participation in the NEM 3.0 Rakyat program remains critically low, with less than 17% of allocated household capacity fulfilled (SEDA, 2024). This shortfall threatens Malaysia's ability to meet its renewable energy mix target of 31% by 2025 and 40% by 2035 (Nik Nazmi, 2024). The underperformance indicates a deeper problem: SES adoption is not merely a matter of affordability or technical feasibility, but rather the result of complex decision-making processes shaped by household perceptions, behavioral patterns, service quality, and policy trust (Ridauddin Daud, 2024).

Most prior research has adopted either a techno-economic or behavioral lens, rarely integrating the two to reflect the nuanced decision-making pathways of real adopters. For example, financial concerns such as upfront capital and payback period are often studied in isolation from qualitative factors like service reliability or company reputation (Azman et al., 2021; Balcombe et al., 2014). This has led to fragmented findings that fail to offer a unified or actionable roadmap for stakeholders. Moreover, many models are intention-based (e.g., surveys of willingness to adopt) and are not grounded in the experiences of actual SES users, thereby limiting their predictive and prescriptive power (Chee, 2023; Cheah & Phau, 2022).

The theoretical frameworks traditionally used such as the DOI (Rogers, 2003), TALC (Moore, 1991), and UTAUT2 (Venkatesh et al., 2012) are useful in explaining general adoption trends, but they lack specificity in capturing Malaysia's regulatory and market conditions. Particularly, they do not account for the layered influence of national programs like NEM 3.0, nor the dual role of consumers as both energy users and micro-producers under net metering mechanisms.

Methodologically, there is a clear gap in studies that combine qualitative depth with quantitative structure. While qualitative interviews capture lived experiences and contextual subtleties, they lack the capacity to quantify the relative weight of decision factors. Conversely, purely quantitative approaches like Structural Equation Modelling (SEM) or regression analysis require predefined constructs and often ignore the rich narratives that shape consumer behavior. This research addresses that gap by triangulating thematic analysis (Braun & Clarke, 2006) with the AHP (Saaty, 2008), thereby integrating subjective meaning-making with objective prioritization.

The motivation behind this study lies in its potential to generate a holistic and operational decision-making framework for SES adoption among Malaysian households. By focusing on actual adopters under the NEM 3.0 scheme, the study contributes real-world insight into what factors matter most and in the adoption journey. This framework not only assists policymakers in aligning incentives with user needs but also helps solar service providers tailor their offerings to meet expectations in service delivery, technical support, and credibility. In doing so, the study contributes both methodologically and practically to Malaysia's clean energy transition, supporting national policy objectives and Sustainable Development Goals (SDG 7 and SDG 13).

METHODOLOGY

This study adopts a sequential exploratory mixed-method design grounded in pragmatism, aligning with the study's objective to develop a sustainable decision-making framework for SES adoption among Malaysian household consumers. The methodology is structured in mixed methods that separated into two distinct yet integrated phases: (1) qualitative exploration through thematic analysis, and (2) quantitative prioritization using the AHP.

Research Philosophy and Strategy

This study adopts a pragmatic epistemological stance, allowing for the integration of both subjective insights and objective evaluation (Lincoln & Guba, 1985; Creswell, 2024). The approach to theory development is inductive in the qualitative phase—aiming to explore themes emerging from participants' lived experiences—and deductive in the quantitative phase, where the derived themes are tested and ranked using structured comparisons (Peirce, 1958; Combemale et al., 2024).

An exploratory strategy was employed through semi-structured interviews, while a survey-based strategy guided the AHP instrument, both aligning with a mixed-method design (Creswell & Poth, 2018; Akotia et al., 2024). The study is cross-sectional in nature, capturing decision-making data at a single point in time (Braun & Clarke, 2006). For data collection and analysis, thematic analysis was applied in the qualitative phase, while the AHP structured the quantitative assessment, offering a dual lens understanding of SES adoption priorities (Saaty, 2008). The summary of this study is outlined in Table below.

Table 2: Research Approach

No	Properties	Approach Use for This Study		Reference(s)
		Qualitative	Quantitative	
1	Philosophy	Epistemology (Pragmatism)		Lincoln & Guba, 1985; Creswell 2024

2	Approach to Theory Development	Inductive	Deductive	Peirce, 1958; Fowler, 2014
3	Strategies	Explorative	Survey	Creswell & Poth, 2018).
4	Methodologies Choice	Mixed Method (Semi-Structure Interview)	Mixed Method (Pairwise Comparison Questionnaires)	Akotia et al., 2024
5	Time Horizon	Cross Sectional		Braun & Clarke, 2006
6	Technic and Procedure	Thematic Analysis	AHP Analysis	Saaty, 2008

Phase 1: Qualitative Design – Thematic Analysis

The qualitative phase of this study aimed to explore the lived experiences, perceptions, and contextual motivations influencing household adoption of SES under Malaysia's Net Energy Metering (NEM 3.0) program. Adopting a epistemological lens, the study sought to generate deep, user-centric insights that would inform the subsequent prioritization framework. A purposive sampling strategy was employed to select nine residential participants who met three specific criteria: (1) ownership of a landed property; (2) installation of rooftop SES under the NEM 3.0 scheme; and (3) completion of at least one full billing cycle. These inclusion criteria ensured that participants had sufficient engagement to reflect on both pre-installation decision-making and post-installation performance experiences.

Data collection was conducted via semi-structured interviews, a method well-suited for uncovering nuanced meanings and behavioral context (Creswell & Poth, 2018). Interviews lasted between 40 to 90 minutes and followed an open-ended guide designed around key SES adoption themes. All sessions were audio-recorded, transcribed verbatim, and anonymized to preserve data integrity and respondent confidentiality. These methodological steps reflect best practices in qualitative inquiry and were particularly useful in maintaining trust and enabling participants to speak freely (Braun & Clarke, 2006).

Thematic analysis was used to process the data, following the six-phase framework developed by Braun and Clarke (2021): (1) data familiarization, (2) code generation, (3) theme searching, (4) theme reviewing, (5) theme defining and naming, and (6) report writing. This iterative and inductive process was supported by ATLAS.ti 9 software, which facilitated the systematic organization of codes, excerpts, and emerging themes (Friese, 2019). A total of 601 meaning-laden excerpts were coded, generating 68 initial codes, which were then organized into 24 sub-themes and subsequently grouped into six main themes: Financial Viability, Service Capability, Technology Flexibility, Company Credibility, Regulatory Feasibility, and External Influences.

To ensure coding consistency and thematic reliability, the study conducted Inter-Rater Reliability (IRR) testing using Cohen's Kappa, a robust statistical measure for agreement between independent raters. A κ value of 0.9205 was obtained, which, based on the benchmarks established by Landis and Koch (1977), represents "almost perfect agreement". This high IRR value confirms the credibility and trustworthiness of the thematic structure and suggests minimal bias in the interpretation of participants' responses (McDonald et al., 2019).

The outputs of this phase provided the conceptual foundation for the second phase of the study, where these themes were converted into criteria and sub-criteria for quantitative prioritization using the AHP. The integration of this qualitative rigor ensured that the final decision-making framework is both data-grounded and reflective of actual user experiences, contributing to its practical validity and scalability.

Phase 2: Quantitative Design – AHP Prioritization

Building upon the qualitative findings, the second phase of the study employed the AHP to quantitatively prioritize the six main themes identified in Phase 1. AHP was selected for its ability to transform complex, multi-criteria decision problems into a structured hierarchy, allowing for systematic pairwise comparisons of factors based on participant judgment (Saaty, 2008; Ahmad & Tahar, 2014). This method aligns well with the study's aim of developing a pragmatic and data-driven SES decision-making framework that balances both subjective perception and objective weighting.

To maintain alignment and strengthen the internal validity of the triangulation process, the same cohort of nine SES adopters from the qualitative phase was retained. This consistency ensured that the criteria evaluated in AHP were based on the participants previously expressed lived experiences and that judgments were made with contextual continuity in mind (Creswell & Poth, 2018).

The AHP process involved (1) constructing hierarchical decision models, (2) developing pairwise comparison matrices, (3) normalizing values, (4) calculating priority vectors, and (5) validating consistency through the Consistent Ratio (CR). A CR value below 0.10 was used as the threshold for logical consistency in judgments (Saaty, 2008). All matrices in this study met this benchmark, ensuring reliable quantitative outputs.

Lastly, the use of AHP in this context provided two strategic advantages: first, it quantified the relative importance of criteria that were previously explored only qualitatively, and second, it allowed for transparent traceability in how stakeholder preferences are reflected in the final framework. This strengthens both the methodological rigor and the applied relevance of the research for decision-makers and practitioners in the Malaysian renewable energy sector.

Triangulation and Integration

The findings from both the qualitative and quantitative phases were systematically triangulated to construct a consumer-oriented decision-making framework for Solar Energy System (SES) adoption. This integration not only enhanced the depth and reliability of the results but also ensured that the framework reflects both behavioral realities and prioritization logic. The thematic insights provided rich, grounded narratives about the motivations and constraints faced by household SES adopters, while the AHP added structural weight to those themes by ranking them based on relative importance.

The triangulation process also addressed key methodological concerns commonly seen in SES research such as the over-reliance on either purely qualitative or quantitative approaches by adopting a mixed-methods strategy rooted in pragmatism (Creswell & Creswell, 2018). This design ensured that qualitative depth informed quantitative precision, resulting in a model that is empirically validated, contextually appropriate, and directly applicable for use by both policy institutions and solar service providers.

The overall methodological process, including the transition from thematic analysis to quantitative prioritization and the construction of the decision support framework, is summarized in Figure 2. This figure visually maps out the sequential logic and analytical integration that underpin the research design, reinforcing the transparency, rigor, and applicability of the proposed model.

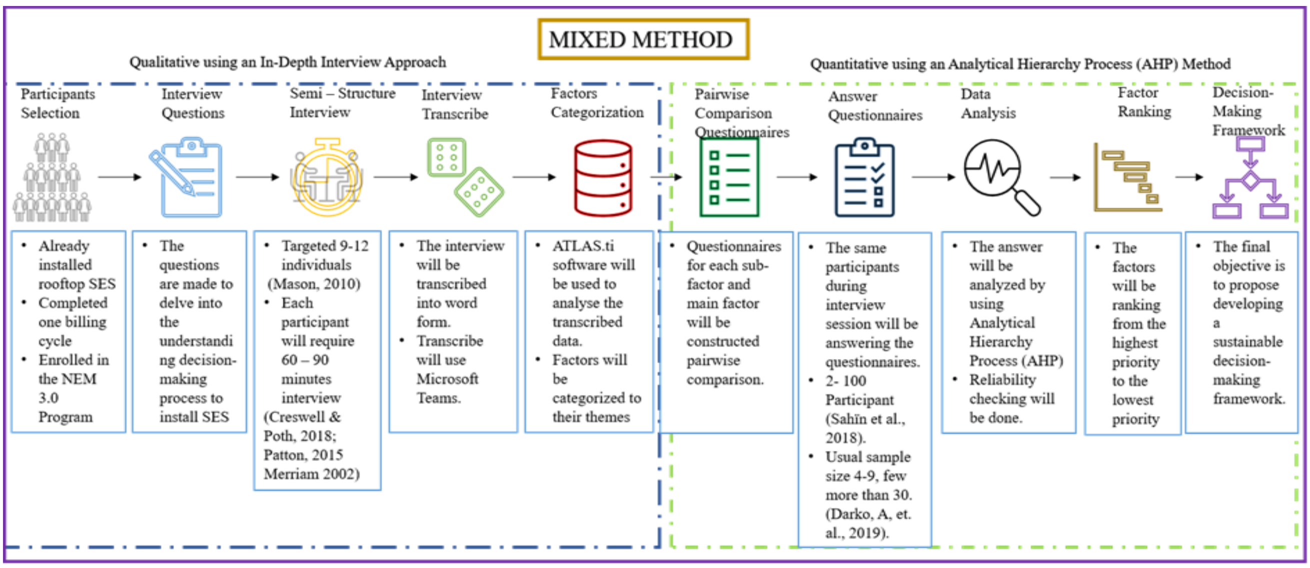

Figure 2: Summary of Research Design

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FINDINGS AND DISCUSSION

This section presents the results from the two-phased sequential mixed-method approach, followed by an integrated discussion of the triangulated findings. The findings respond to the study's objective of developing a consumer-centric, evidence-based decision-making framework to enhance household adoption of SES in Malaysia under the NEM 3.0 program.

Phase 1: Qualitative Approach – Thematic Analysis

Thematic analysis of 601 coded excerpts (Figure 3) drawn from in-depth interviews with nine residential SES adopters revealed six major themes that significantly influence household decisions regarding SES adoption under NEM 3.0 program from 68 initial codes and further refine into 24 axial codes (Table 3).

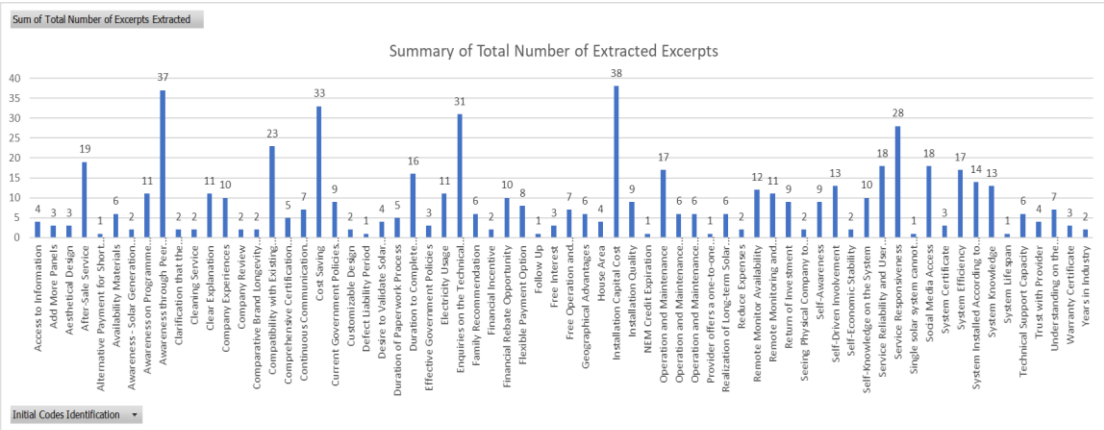

Figure 3: Summary of Total Number of Extracted Excerpts

Table 3: Axial Coding Identification

No	Initial Code	Axial Coding
1	Continuous Communication with Provider	Access To Information
2	Social Media Access	
3	Access To Information	
4	Family Recommendation	Community Engagement
5	Awareness Through Peer Connection	
6	House Area	Geographical Advantages
7	Geographical Advantages	
8	System Lifespan	Long-Term Usage
9	Electricity Usage	
10	Reduce Expenses	
11	Realization Of Long-Term Solar Benefits	
12	Comparative Brand Longevity Perception	
13	Self-Knowledge On the System	Self-Awareness

14	Self-Driven Involvement	
15	Awareness – Solar Generation and Consumption Concept	
16	Self-Awareness	
17	Follow Up	After-Sale Service
18	Service Reliability and User Confidence	
19	Service Responsiveness	
20	After-Sale Service	
21	Trust With Provider	Company Experiences
22	Company Review	
23	Seeing Physical Company to Gain Trust	
24	Company Experiences	
25	System Knowledge	System Knowledge
26	Years In Industry	Years In Industry
27	Financial Rebate Opportunity	Financial Incentive
28	Financial Incentive	
29	Free Interest	Financial Support
30	Alternative Payment for Short Term	
31	Flexible Payment Option	
32	Self-Economic Stability	Installation Capital Cost
33	Installation Capital Cost	
34	Free Operation and Maintenance	Operation And Maintenance Cost
35	Operation And Maintenance Cost	
36	Cost Saving	Payback Period
37	Return Of Investment	
38	System Certificate	Comprehensive Certification System
39	Warranty Certificate	
40	Comprehensive Certification System	
41	Duration Of Paperwork Process	Ease Of Administrative Process
42	Understanding On the Paperwork Required	
43	Current Government Policies Structure	Effective Government Policies

44	Single Solar System Cannot Install in Two Different Houses	
45	Awareness On Programme Under SEDA	
46	NEM Credit Expiration	
47	Effective Government Policies	
48	Installation Quality	Implementation Ability
49	Duration To Complete Installation	
50	Availability Materials	
51	Operation And Maintenance Duration	Operation And Maintenance
52	Cleaning Service	
53	Clarification That the Company Offer a Warranty Instead of and O&M Package	
54	Provider Offers a One-To-One Replacement Warranty	
55	Defect Liability Period	
56	Operation And Maintenance	
57	Clear Explanation	Technical Support Capacity
58	Enquiries On the Technical Explanation	
59	Technical Support Capacity	
60	Compatibility With Existing Infrastructure	Compatibility With Existing Infrastructure
61	Aesthetical Design	Customizable Design
62	Add More Panels	
63	Customizable Design	
64	System Installed According to Usage	
65	Desire To Validate Solar System Performance	Energy Performance and Efficiency
66	System Efficiency	
67	Remote Monitor Availability	Remote Monitoring and Control
68	Remote Monitoring and Control	

Finally, the final six themes are identified: Financial Viability, Service Capability, Technology Flexibility, Company Credibility, Regulatory Feasibility, and External Influences. Each theme synthesizes a set of interrelated perceptions, motivations, and constraints experienced by real-world adopters, offering a grounded understanding of decision-making beyond abstract models.

Service Capability emerged as the most dominant and frequently emphasized theme across all participants. Respondents underscored the importance of after-sales service, system reliability, and technical support availability, often stating that the post-installation experience shaped their satisfaction more than the installation

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process itself. The ability to contact service personnel, receive fast responses, and resolve technical issues especially in the first few months after installation was cited as essential to maintaining confidence in the investment. This finding suggests that SES providers must offer not just technical products but also dependable support systems to sustain consumer trust and word-of-mouth advocacy.

Financial Viability was the next most prevalent theme, encapsulating concerns about initial installation costs, payback period duration, and monthly energy bill reductions. Participants revealed that their decision hinged on a clear understanding of cost-benefit ratios, with financial incentives like SolaRIS rebates and tax exemptions playing a supporting—but not sole—role. This implies that affordability, while crucial, must be framed within broader household economic planning.

Technology Flexibility included subthemes such as panel layout compatibility, system efficiency, and the availability of remote monitoring applications. Participants valued systems that could be easily integrated with their home structure and offered real-time feedback on energy generation. These perceptions indicate an increasing consumer expectation for user-friendly, smart-enabled solar solutions, particularly among tech-savvy households.

Company Credibility emerged as a trust-based filter for decision-making. Attributes such as transparent quotations, online presence, peer recommendations, and previous project portfolios were important indicators of provider legitimacy. Participants were cautious about fly-by-night installers and emphasized the need for transparent and verifiable provider information. This theme reinforces the view that SES adoption is not solely a technological transaction, but a trust-based service agreement.

Regulatory Feasibility and External Influences, while frequently mentioned, were treated more as contextual enablers than core decision-making factors. Regulatory aspects such as NEM application procedures and approval timelines were important for procedural ease but did not independently determine adoption. Similarly, external influences like media exposure, environmental awareness, and peer endorsement played a role in creating awareness, but required stronger financial or service-related justification to translate into actual uptake. This divergence between frequency and impact suggests that awareness alone is insufficient—effective adoption hinges on enabling mechanisms that align with practical household priorities. the summary of the themes is tabulated in Table 4.

Table 4: Summary of Themes Identification

Themes	Axial Code
Financial Viability	Financial Support
	Financial Incentive
	Payback Period
	Installation Capital Cost
	Operational and Maintenance Cost
Company Credibility	Years in Industry
	Company Experiences
	System Knowledge
	After-Sale Service
External Influences	Community Engagement

	Geographical Advantages
	Self-Awareness
	Long-term Usage
	Access to Information
Technology Flexibility	Compatibility with Existing Infrastructure
	Customizable Design
	Energy Performance and Efficiency
	Remote Monitoring and Control
Service Capability	Implementation Ability
	Technical Support Capacity
	Operation and Maintenance
Regulatory Feasibility	Effective Government Policies
	Ease of Administrative Process
	Comprehensive Certification System

The validity and consistency of the coding process were verified through inter-rater reliability analysis, using Cohen's Kappa, which yielded a coefficient of $\kappa = 0.9205$. According to Landis and Koch (1977), a kappa value above 0.61 signifies "almost perfect agreement." This result demonstrates that the thematic categories were interpreted consistently between independent raters, thus reinforcing the credibility and methodological rigor of the qualitative findings (McDonald et al., 2019).

Together, these six themes not only reflect the lived realities of SES adopters under NEM 3.0 but also provide a nuanced understanding of the trade-offs and trust considerations that shape household energy transitions. These findings later formed the foundational criteria in the AHP-based prioritization process, ensuring a coherent linkage between qualitative depth and quantitative structure in the proposed decision-making framework.

Phase 2: Quantitative Approach – AHP

The second phase of the study employed the AHP to systematically prioritize the six main themes and their 24 associated sub-criteria identified in the qualitative phase. This step aimed to quantify the relative importance of decision-making criteria influencing household adoption of SES under the NEM 3.0 program.

The AHP analysis revealed Service Capability as the most influential main criterion with a Global Weight (GW) of 26.07%, followed by Financial Viability (24.79%), Technology Flexibility (16.22%), Company Credibility (14.12%), Regulatory Feasibility (11.14%), and External Influences (7.65%). This ordering validates a strong preference among consumers for post-installation support, cost-effectiveness, and system performance, over broader contextual factors such as external awareness or regulatory processes.

At the sub-criteria level, the ranking patterns reinforced this prioritization. The top three globally weighted (GW) sub-criteria were all drawn from the Service Capability category: Operation and Maintenance (GW = 11.49%), Technical Support Capacity (GW = 7.87%), and Implementation Ability (GW = 6.71%).

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These results reflect consumers' clear expectations for long-term system dependability, professional service delivery, and technical support assurance. The highest-ranked technology-related sub-criterion was Energy Performance and Efficiency (GW = 8.05%) under Technology Flexibility, reflecting the importance of output reliability and functional performance. Meanwhile, Installation Capital Cost (GW = 6.39%) and Payback Period (GW = 5.73%) ranked highest within Financial Viability, underscoring economic sensitivity in adoption decisions.

To ensure the robustness and reliability of the prioritization outputs, all CR values were assessed across the matrices. According to Saaty (2008), a CR of ≤ 0.10 indicates that the judgments are logically coherent. In this study, all main and sub-criteria matrices achieved CR values well below this threshold, ranging from 0.01 to 0.07, with the highest inconsistency observed in the External Influences matrix (CR = 0.07). This still falls within the acceptable range and confirms that the pairwise judgments provided by participants were logically consistent.

A summary of CR values across all matrices is presented in Table 5, which illustrates the overall internal consistency of the quantitative process. This step is crucial in validating the AHP results and strengthening the methodological reliability of the framework.

Table 5: Summary of Consistent Ratio

No	Criterion	CI	n	RI	CR	Result
1	Main Criterions	0.0152	6	1.24	1%	**Passed**
2	Financial Viability	0.0388	5	1.12	3%	**Passed**
3	Company Credibility	0.0350	4	0.9	4%	**Passed**
4	External Influences	0.0769	5	1.12	7%	**Passed**
5	Technology Flexibility	0.0140	4	0.9	2%	**Passed**
6	Service Capability	0.0049	3	0.58	1%	**Passed**
7	Regulatory Feasibility	0.0060	3	0.58	1%	**Passed**

A summary of the Relative Weight (RW)—which reflects each sub-criterion's importance within its own group—and the Global Weight (GW)—which reflects each sub-criterion's importance across all groups—is provided in Table 6. This distinction provides both micro-level insight into within-group priorities and macro-level clarity across all adoption factors.

Table 6: Global Ranking of Decision-Making Criteria in Adopting Solar Energy System among Household Consumers

Criteria	**RW**	**Sub-Criteria**	**RW**	**RR**	**GW**	**GR**
Financial Viability	0.2479	Financial Support	0.1709	4	4.24%	11
		Financial Incentive	0.1289	5	3.20%	16
		Payback Period	0.2311	2	5.73%	6
		Installation Capital Cost	0.2578	1	6.39%	5
		Operational and Maintenance Cost	0.2112	3	5.24%	8
Company Credibility	0.1412	Years in Industry	0.0826	4	1.17%	23
		Company Experiences	0.1508	3	2.13%	18

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		System Knowledge	0.3681	2	5.20%	9
		After-Sale Service	0.3985	1	5.63%	7
External Influences	0.0765	Community Engagement	0.1636	3	1.25%	21
		Geographical Advantages	0.0694	5	0.53%	24
		Self-Awareness	0.1539	4	1.18%	22
		Long-term Usage	0.4369	1	3.34%	14
		Access to Information	0.1762	2	1.35%	19
Technology Flexibility	0.1622	Compatibility with Existing Infrastructure	0.1981	3	3.21%	15
		Customizable Design	0.0815	4	1.32%	20
		Energy Performance and Efficiency	0.4966	1	8.05%	2
		Remote Monitoring and Control	0.2237	2	3.63%	13
Service Capability	0.2607	Implementation Ability	0.2573	3	6.71%	4
		Technical Support Capacity	0.3018	2	7.87%	3
		Operation and Maintenance	0.4408	1	11.49%	1
Regulatory Feasibility	0.1114	Effective Government Policies	0.3665	2	4.08%	12
		Ease of Administrative Process	0.3946	1	4.40%	10
		Comprehensive Certification System	0.2389	3	2.66%	17

The prioritization patterns derived from AHP mirrored the thematic prominence identified in Phase 1, affirming the effectiveness of the study's triangulated methodology. This strong convergence confirms that household SES adoption decisions are driven by practical, performance-based, and financially oriented concerns, rather than abstract or externally imposed influences.

This coherence between qualitative and quantitative findings strengthens the empirical foundation for the final SES decision-making framework, ensuring that it is not only contextually grounded for the Malaysian residential landscape but also actionable for stakeholders across industry, government, and civil society.

Decision Making Framework

Integration of Phase 1 and Phase 2 Findings

The triangulated analysis revealed strong convergence between the thematic insights (Phase 1) and the AHP prioritization (Phase 2) for most criteria. Service Capability emerged as the most dominant factor in both phases, ranking first in AHP (26.07%) and receiving 108 coded excerpts from the qualitative data. Sub-criteria such as Operation and Maintenance, Technical Support Capacity, and Implementation Ability consistently appeared in participant narratives and were also top ranked in global AHP weightings, reinforcing the centrality of post-installation reliability and provider responsiveness.

Financial Viability also showed strong alignment, ranking second in both the qualitative (121 codes) and AHP results (24.79%). Participants frequently discussed upfront capital costs, long-term savings, and incentive mechanisms, emphasizing cost-benefit logic in their decisions.

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Technology Flexibility demonstrated similar coherence, placed third in AHP (16.22%) and fourth in qualitative analysis (90 codes). Sub-criteria like Energy Performance and Efficiency and Monitoring App Functionality highlighted the desire for technical performance, modular compatibility, and digital control.

Company Credibility presented partial convergence, ranked fourth in AHP (14.12%) and fifth in qualitative rank (98 codes). While trust, transparency, and provider experience were discussed, participants often saw these as secondary to technical or financial factors when making final decisions.

Regulatory Feasibility and External Influences revealed divergence. Although External Influences ranked first in qualitative coding (136 codes)—with participants frequently referencing peers, media, and environmental awareness—it ranked last in AHP (7.65%), indicating that while such factors influence initial interest, they carry less weight during final decision-making. Similarly, Regulatory Feasibility, while ranked fifth in AHP (11.14%), received only 48 qualitative mentions, showing moderate relevance in practice.

This triangulation process confirmed that while all six themes are relevant, the most decisive factors are service, financial feasibility, and system functionality. All of which are actionable by service providers and policymakers. Summary of triangulated result is shown in Table 7.

Table 7: Summary of Triangulation Result

Theme	Qualitative Rank	AHP RW (%)	AHP Rank	Most Influential Sub-Criterion	Triangulation Result
Service Capability	3rd (108 codes)	26.07	1st	Operation & Maintenance (GR: 1)	Strong Convergence
Financial Viability	2nd (121 codes)	24.79	2nd	Installation Cost (GR: 5)	Strong Convergence
Technology Flexibility	4th (90 codes)	16.22	3rd	Energy Performance and Efficiency (GR: 2)	Strong Convergence
Company Credibility	5th (98 codes)	14.12	4th	After-Sale Service (GR: 7)	Partial Convergence
Regulatory Feasibility	6th (48 codes)	11.14	5th	Ease Administrative Process (GR: 10)	Partial Convergence
External Influences	1st (136 codes)	7.65	6th	Community Engagement (GR: 21)	Divergence

Proposed Decision-Making Framework

Building on the triangulated findings, a structured decision-making framework was developed to guide household SES adoption in a realistic, evidence-based, and policy-relevant manner. The framework synthesizes the qualitative insights from lived experiences with the quantitative weights generated via AHP, offering a comprehensive structure that addresses the complexity of SES decision-making in the Malaysian residential context. The framework is organized around six primary criteria as shown in Table 6.

Each of these core dimensions is operationalized through 24 sub-criteria, which were prioritized using global and local weightings derived from the AHP process. This multi-criteria model reflects real-world decision considerations such as system efficiency, technical support, payback period, company reputation, and environmental motivation.

As shown in Figure 4, the framework illustrates how these six themes interact dynamically across different stages of the consumer decision journey.

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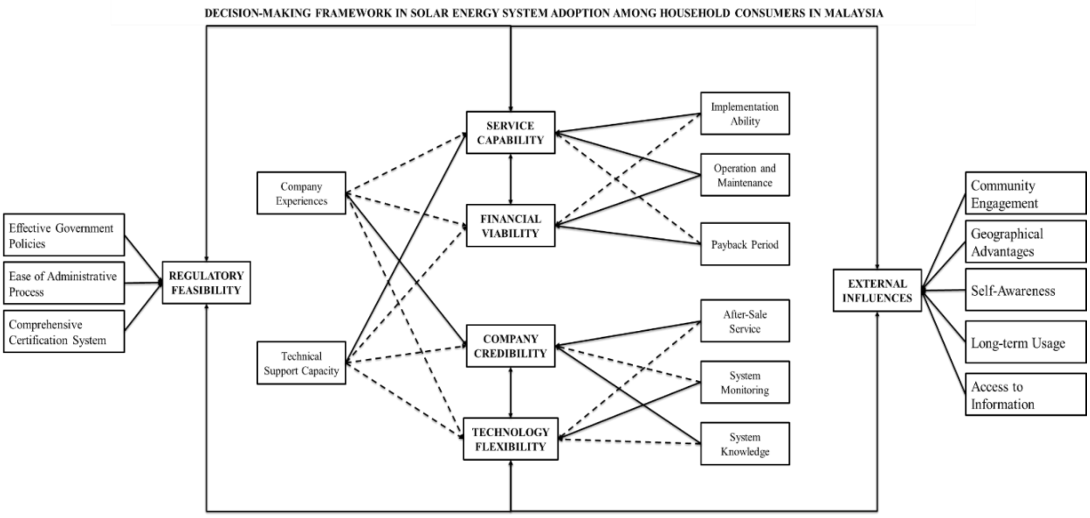

Figure 4: Decision-Making Framework in Solar Energy System Adoption Among Household Consumers In Malaysia

Based on Figure 4, early phases are shaped by External Influences, such as community visibility, peer engagement, and public narratives. These stimuli prompt consumer awareness and initial research, leading into evaluation stages, where Financial Viability and Technology Flexibility become key filters. In later stages, Service Capability and Company Credibility influence provider selection, system validation, and installation confidence.

Moreover, surrounding all stages are Regulatory Feasibility components, which act as boundary conditions and enablers through licensing ease, program comprehension, and policy support. The central positioning of Company Experiences and Technical Support Capacity (as shown in the figure's core) reflects the strong overlap between Service Capability and Company Credibility, emphasizing that household trust and post-installation reliability are at the heart of sustained adoption.

Lastly, the framework also incorporates feedback loops, recognizing that SES adoption is not always linear. Consumers may revisit earlier stages such as provider selection or financial feasibility when encountering technical challenges, policy updates, or new offers in the marketplace.

Step-by-Step Process Flow on the Decision-Making Framework

Building upon the decision-making structure outlined in Section 5.2, this section presents a behaviourally realistic, step-by-step process flow, designed to simulate the actual progression of household consumers in adopting SES. The model is presented in Figure 5 and reflects both the empirical insights from thematic analysis and the quantitative priorities derived via AHP.

The structure is inspired by classical process flow models first proposed by Frank and Lillian Gilbreth (1921), later adapted for behavioural applications, and reviewed by Sharma (2019). This ensures that the framework remains operationally relevant and theoretically robust, particularly for energy decision research in residential contexts.

The decision-making framework for household SES adoption comprises the following seven sequential and behaviorally informed steps, each mapped to key themes and prioritized sub-criteria from the triangulated findings:

Awareness & Motivation

Consumers are first exposed to solar energy through external sources such as media, peers, and environmental concerns. This stage corresponds to the External Influences theme, which initiates interest and exploratory behavior.

Research & Evaluation

Motivated consumers begin to collect detailed information on SES options, including system types, provider offerings, and potential financial benefits. If information remains unclear, the framework includes a feedback loop to reinforce informed decision-making.

Financial Feasibility

This step involves assessing whether SES adoption is financially viable based on capital costs, payback period, operational savings, and available incentives. It aligns with the Financial Viability theme and reflects the second-highest ranked factor in AHP (24.79%).

Engage with Provider

Consumers initiate contact with providers to obtain quotations, validate system design claims, and clarify technical and service-related questions. This step reflects both Service Capability (26.07%) and Company Credibility (14.12%), highlighting the importance of trust and support.

Technology Flexibility

The compatibility of the proposed SES with household infrastructure is assessed—covering rooftop space, system design, wiring, and expected performance. This step emphasizes Technology Flexibility (16.22%), ensuring consumers understand installation feasibility and output.

Provider Comparison

Consumers evaluate SES providers on factors such as after-sales service, warranties, technical reliability, and reputation. If concerns remain, the consumer is prompted to revisit prior steps. This iterative logic mirrors real-world purchase behavior and reinforces Service Capability.

Adoption Decision & Commitment

Upon satisfaction of financial, technical, and trust-based considerations, the consumer proceeds with the final decision to adopt SES. However, built-in feedback loops allow for ongoing reconsideration if doubts emerge or circumstances change.

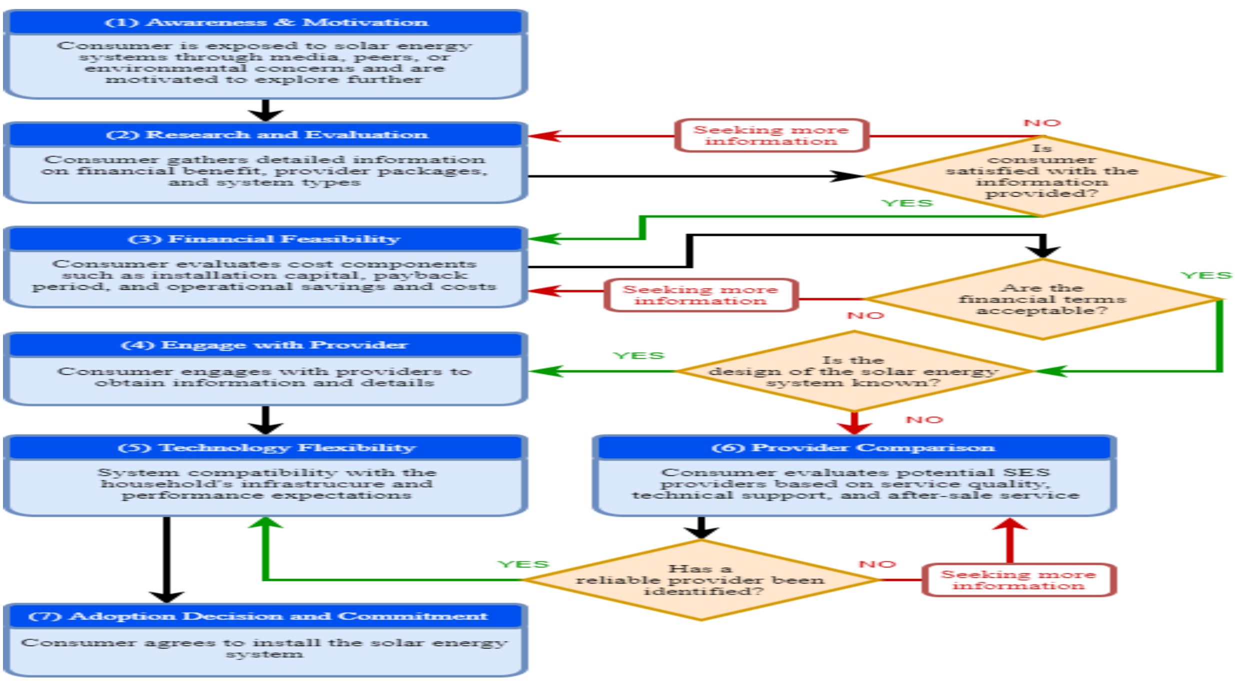

Figure 5: Step-by-Step Flow on the Decision-Making Process

CONCLUSION AND FUTURE DIRECTIONS

This study set out to explore and prioritize the key factors influencing household adoption of SES under Malaysia's NEM 3.0 program, ultimately proposing a decision-making framework rooted in actual user experience and analytical rigor. By adopting a sequential mixed-method approach merging thematic insights from qualitative interviews with quantitative prioritization through the AHP. The study successfully triangulated the perceptions, motivations, and preferences of residential SES adopters.

The findings revealed that Service Capability and Financial Viability are the most influential decision-making criteria. Households emphasized the importance of post-installation technical support, reliability, and affordability as foundational to their confidence in adopting SES. While themes such as External Influences and Regulatory Feasibility were frequently mentioned in interviews, their lower ranking in AHP highlighted a distinction between initial motivation and final decision-making weight. This differentiation strengthens the contribution of this study by not only identifying what factors matter—but also how much they matter at different decision stages.

The resulting decision-making framework offers a practical tool for guiding stakeholders across multiple domains. For households, it simplifies complex choices by structuring the decision journey into clear, actionable phases. For solar service providers, it reveals critical performance areas to strengthen, such as after-sales support and cost transparency. For policymakers, it highlights where strategic interventions—such as streamlined approvals and incentive alignment—can generate the highest adoption impact.

This research supports Malaysia's efforts to enhance residential solar participation in line with SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action),and contributes empirically to the growing body of literature on sustainable energy adoption behavior in the Global South.

Future Research Directions

Building on the empirical and conceptual contributions of this study, several future research avenues are recommended to extend the applicability and impact of the proposed SES decision-making framework:

Cross-Regional Replication: Applying this framework in other Malaysian states or across ASEAN countries would allow researchers to test its generalizability and uncover regional or cultural variations in SES adoption behavior. Such comparative studies could highlight differences in policy effectiveness, infrastructure readiness, or consumer awareness levels.

Non-Adopter Comparative Analysis: Including households that have not adopted SES, but express strong interest could illuminate critical gaps between intention and action. This would provide insight into persistent barriers—financial, informational, or psychological—that prevent potential adopters from transitioning to actual users.

Policy Scenario Modelling: Integrating dynamic simulation techniques, such as system dynamics or agent-based modelling, could allow researchers and policymakers to explore the impact of changes in subsidies, approval processes, or provider regulations on consumer decision weights and adoption rates.

Technology Integration and Innovation: As the SES landscape evolves, future frameworks could be enhanced by incorporating next-generation technologies such as AI-powered energy management systems, blockchain-based incentive tracking, or smart-home compatibility assessments. These integrations would improve predictive capabilities and user confidence.

Collectively, these directions would contribute to the evolution and refinement of the decision-making model, ensuring its relevance in a rapidly changing renewable energy ecosystem and aligning with Malaysia's commitment to long-term sustainability under SDG 7 and SDG 13.

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