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Exploring The Challenges of Battery Energy Storage System Integration in Solar-Powered Manufacturing: A Case Study

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ABSTRACT

The integration of Battery Energy Storage Systems (BESS) in solar-powered manufacturing is gaining attention as a means to enhance energy reliability and sustainability. However, BESS adoption remains limited despite its potential, particularly in industrial settings. This study explores the key barriers hindering BESS integration in solar manufacturing companies in Malaysia. Employing a qualitative case study approach, semi-structured interviews were conducted with six managerial-level informants with experience in solar-powered manufacturing and energy storage initiatives. Thematic analysis revealed five main challenges, namely Theme 1: Financial Barriers (high initial costs, long payback periods, and maintenance expenses), Theme 2: Technical Difficulties (battery lifespan, limited surplus energy, storage capacity, integration compatibility, and safety risks), Theme 3: Regulatory and Policy Limitations (ambiguity in government policies and lack of incentives), Theme 4: Operational Issues (lack of awareness, lack of technical expertise, internal resistance, and limited access to benchmarking data), and Theme 5: Environmental and Sustainability Concerns (battery recycling, battery disposal, and resource extraction). These findings underscore the need for clearer regulatory frameworks, financial incentives, capacity-building, and sustainable lifecycle management of battery systems. This study offers theoretical and practical insights to support policymakers, energy stakeholders, and manufacturers in facilitating the successful integration of BESS to achieve a resilient, cost-effective, and sustainable energy future.

1. Introduction

The importance of shifting to renewable energy sources is primarily related to the global fight against climate change and a move toward less reliance on fossil fuels [1]. In the field of renewable energy, solar photovoltaic (PV) systems have attracted a lot of attention due to their scalability, sustainability, and cost reduction over time [2]. According Hayat, *et al*., [3], solar energy production is forecasted to be the largest electricity source in the world by 2050. However, one challenges with PV systems is intermittency as they depend on weather conditions and daylight for energy, hence

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several challenges in providing stable and reliable energy is poses. Without proper energy storage systems, surplus power during peak sun hours goes wasted as there is inadequacy during low solar production times [4]. In light of this, the intermittency problem provides a pathway for the integration of Battery Energy Storage Systems (BESS) that store surplus energy and discharge it when needed, in order to maintain constant and reliable energy [5].

Innovation in battery energy storage technology proves its evolution such as increased in lithium ion, solid state and flow battery systems have made great advances to achieve efficiency, durability and better energy density [4]. BESS consists of numerous developments that make it an ideal solution for stabilizing power grids, increasing the self-consumption, and minimizing dependence on fossil-fuel. In the solar manufacturing sector, where energy usage varies with manufacturing cycles and machinery operation, BESS is important in enhancing energy efficiency, minimizing production costs, and increasing sustainability. Moreover, BESS deployment is aligned with sustainability strategies as businesses integrate BESS to meet ESG standards to promote clean energy transitions [6]. However, many solar-powered manufacturing companies face significant challenges in deploying battery storage due to several factors.

Although BESS has been extensively studied from the renewable energy integration perspective, there are some theoretical gaps in the literature regarding the implementation of such solutions in the solar manufacturing context. Research on the subject has largely focused on the batteries' technical performance. Abu, *et al*., [7] studied hybrid energy systems, including PV systems, hydrogen fuel cells, batteries, and supercapacitors, to optimize energy management and enhance the stability of systems. They observed improved performance in hydrogen consumption, fuel flow rate, and fuel cell efficiency. Similarly, Zequera, et al. [8] examined the setting of charge diagnostics and algorithm optimization of BESS through artificial intelligence. Supervised learning techniques and feature selection methods were employed to test various lithium-ion battery cell diagnosis methodologies in the study, and transformer models outperformed traditional deep learning algorithms by attaining over 94% accuracy in battery diagnostics. While these findings highlight the potential of systems in reducing grid dependence and improving sustainability, they do not address the management challenges that solar-powered companies face in integrating BESS. Hence this research fills that gap by identifying key barriers that hinder BESS integration in the solar manufacturing sector.

Past research mainly looked at safety, risks of thermal runaway, and fire protection strategies of lithium-ion BESS. Although previous studies have provided strategy in terms of finding better techniques for enhanced battery safety and reliability, they overlook the practical challenges that solar-powered companies face in integrating BESS. Research from Jia, *et al*., [9] have done research on battery management systems and optimization strategies to make performance and safety better. Their study shows the demand for safer lithium iron phosphate batteries with better fire resistance, large-scale fire and explosion tests, optimized multi-dimensional warning systems, and advanced fire suppression technologies. However critical they are in terms of safety, these recommendations do not address the wider challenges that companies face in the integration of BESS. In addressing these challenges this study will contribute to a fuller understanding of the factors affecting BESS integration as well as providing insights into how to facilitate a smoother transition to sustainable solutions.

Ahmad, *et al*., [10] conducted a review of previous research in BESS and based on that identified major challenges concerning the technical, economic, environmental, safety, control, and system integration aspects. This has also lent their work an overview of the advancements in BESS to remain as another literature-based analysis and not address real-world challenges faced by solar-powered manufacturing companies in utilizing such systems. Even though interest in integrating BESS is growing, there still lacks enough empirical investigation on practical barriers from industries regarding this integration. This research gap is what this study attempts to fill by conducting an empirical investigation into factors hindering BESS adoption in the solar manufacturing environment with a view to offering a perspective that goes beyond technical optimization and an understanding that better contributes to strategies for its effective integration.

The major aim of the study is to discover the challenges to integrate BESS in solar-powered manufacturing companies by applying a qualitative approach. This study tries to uncover factors that have hindered BESS integration, a clear understanding of both technical and non-technical barriers. It will be helpful in understanding how energy storage integration is perceived and approached by manufacturers. In-depth qualitative analysis this research proposes will contribute to offering practically deployable strategies by solar manufacturing company to overcome barriers for BESS integration. The findings will also inform policymakers, energy experts, and technology providers about the necessary regulatory and financial support mechanisms needed to drive rapid deployment of battery storage. Finally, this work seeks to contribute to the shift to more sustainable and cost-effective energy use, consistent with broader global energy transition targets.

The structure of this research is organized in the following manner. The first part introduces the research problems and research objectives. The following part discusses the methodology employed in the research. Then, the discussion part presents the results of the research. Finally, the last section of the study elaborates on the study limitations, future research recommendations and the conclusion of the research.

2. Methodology

Qualitative investigation is a method to explore the phenomenon in depth, from the participants' point of view. It has an emphasis on descriptive deeper and gains detailed insight into the underlying structures, meanings and processes around behaviours, events or organisational practices. This method uses primary and formative data collection techniques, such as focus groups, in-depth interviews, and observations, to provide a deeper understanding of participants' opinions and experiences [11]. The primary goal is to identify patterns, concepts, and themes emerging from qualitative data, offering a holistic understanding of the studied phenomenon [12].

To achieve the research objective, this study employs a case study design to examine the challenges to integrating BESS in solar manufacturing organizations. Case study research is an empirical exploration that investigates real-world phenomena and is conducted to answer particular research questions by using multiple sources of evidence [13]. This research method is appropriate as it allows the researcher to explore contemporary phenomena, which is BESS integration within their real-life industrial context. The case study approach offers a systematic protocol to investigate thd challenges of the phenomenon by providing the opportunity of collecting direct primary data from the relevant industry experts. Moreover, it also provides flexibility of the contextual factors affecting the BESS adoption decision within the organization.

2.1 Data Collection Approach

This research adopted semi-structured interviews to collect primary data. As pointed out by Creswell [11], semi-structured interviews fit in qualitatively oriented case studies since they allow an unguided yet somewhat guided flexibility in collecting rich data. In the semi-structured format, the interviewees are required to respond to specified topics with some latitude for open-ended discussion, which can lead to much greater insights; this is also a format that allows for two-way communication, wherein the researcher can follow up on critical issues to obtain more in-depth understanding regarding challenges and decision-making processes related to the adoption of BESS [14].

The study adopted a purposive sampling technique whereby the researcher ensures that only those participants with direct experience and knowledge of BESS integration and solar manufacturing operations are included. Purposive sampling refers to the procedure in which the researcher consciously selects those elements of the population that believes would be most informative regarding the research problem [15]. Organizations and individuals were identified based on their capacity to share the insight into the challenges of BESS, decision-making processes, and experiences in its operations.

For this purpose, two solar-powered manufacturing companies were selected as case organizations based on the following criteria:

i. They have experience in integrating or attempting to integrate battery energy storage systems into their operations.
ii. They have been operating using solar energy for more than two years, indicating a level of maturity in managing solar energy production.
iii. They have made strategic investments in energy management technologies, showing commitment to sustainability and operational efficiency.

Yin [12] suggests that analyzing at least two cases makes the findings more robust and generalizable. With more than one case, therefore, researchers may be able to identify common patterns, contrast different organizational approaches, and have wider views of the systemic challenges to BESS adoption. Cross-case analysis can also uncover underlying mechanisms and external influences on implementation decisions, thus delivering a more complete understanding of the topic [16].

2.2 Participant Selection and Interview Process

At the participant level, a convenience sampling strategy was employed to select interviewees from key managerial and technical roles within the organizations. The criteria for participant selection included:

i. Holding at least a middle-management position.
ii. Having at least five years of experience in the company, ensuring familiarity with the organization’s energy strategies.
iii. Being actively involved in energy management or renewable energy.

Data saturation led to six total interviews. According to Kuzel [17], in the investigation of a homogeneous sample, a smaller number of interviews may suffice as the likelihood of new information emerging decreases after a certain threshold. Saturation was observed to have been achieved as by the sixth interview no new insights were coming forth. These respondents articulated diverse views on the obstacles to BESS adoption. Table 1 provides an overview of the participants’ roles together with their contributions to the research.

Table 1
Overview of the participants' roles and contributions to the research

Informant	Position	Years of Experience	Contribution to Solar Implementation
A	Chief Operation Officer	15 years	Monitors the consumption of energy in the manufacturing processes to ensure energy efficiency and sustainability of the production operations.
B	Maintenance General Manager	11 years	Creates a proposal for BESS integration within the manufacturing company to improve energy reliability plus optimize solar energy utilization.
C	Procurement Manager	8 years	Participates in proposal development related to BESS and takes charge of all matters concerning costs ensuring feasibility within budget and financial efficiency.
D	Facilities Manager	14 years	In charge of scheduling routine inspections and preventive maintenance for solar infrastructure to keep it operationally efficient.
E	Project Manager	13 years	Coordinates solar project implementation, overseeing timelines, budgets, and stakeholder collaboration.
F	Production Engineering Manager	7 years	Coordinates the implementation of the solar project by keeping in view timelines, budgets, and work with stakeholders. Installs solar systems and monitors energy usage after installation to ensure that performance and efficiency are maximized.

2.3 Ethical Considerations and Data Analysis

To ensure the conduct of ethical research, an interview consent was obtained from all participants prior to the interview sessions. A consent form detailing the objectives of the study, assurances of confidentiality, and the procedures of the interview was emailed and signed by each informant prior to their participation. This made sure there would be transparency and adherence to ethical research guidelines alongside protection for participants' privacy.

The data was analyzed using ATLAS.ti software to systematically organize, code, and interpret the interview data. Qualitative data analysis is carried out with the help of an application, ATLAS.ti, allowing researchers to identify keywords, patterns, and thematic relationships within interview transcripts. One major benefit that comes with using ATLAS.ti is that it allows one to do auto-coding which makes the process of discerning repeated motifs much more efficient especially related to challenges in implementing BESS [18]. This approach ensured that qualitative insights were accurately captured and structured in a way that contributes to the study's findings.

The draft findings were shared with key informants to improve the validity and reliability of the study and to confirm that the findings were properly represented. Donnelly, *et al.*, [19] further asserts that such an approach is useful in ensuring that evidence drawn from case studies is accurate and not misused. Participant feedback helped establish credibility of findings and enhanced overall reliability of the study.

3. Result
3.1 Financial Barriers

Based on findings from informants, three key sub-themes were identified under the financial barriers theme: (1) High Investment Costs, (2) Long Payback Period, and (3) Maintenance Costs. These sub-themes reflect the major financial challenges organizations face when considering BESS adoption. Table 2 presents the related quotations from informants regarding financial barriers.

Table 2
Sub-themes and related quotations for financial barriers in BESS integration

Theme	Sub-Themes	Quotation
Financial Barriers	High Initial Costs	*"BESS systems like lithium-ion batteries are very expensive to buy and install. The main issue for the company is the significant cost impact, which makes it difficult to justify the investment."* *"To install the battery, additional investment is needed for infrastructure, not just for the battery but also for preparing a proper area that meets safety requirements, which adds to the overall cost and makes the implementation more challenging."*
	Long Payback Period	*"Our management avoids investing in energy storage systems because the payback period is more than 10 years, unless there's a leasing option or strong financial support."* *"Many companies hesitate to invest in ESS because the cost savings take too long to recover the initial investment."* *"We are cautious about investing in ESS since the returns take too long to justify the high upfront cost."*
	Maintenance Costs	*"The ongoing cost of maintaining and replacing battery components puts extra financial pressure on businesses."* *"Unlike solar panels that need little maintenance, BESS requires regular monitoring, making long-term financial planning more challenging."* *"Our management is concerned about the high maintenance and replacement costs of BESS, which add to the overall financial burden."*

According to informants, one of the most significant financial challenges in adopting BESS is the high initial cost. Informants emphasized that capital expenditure remains a major challenge, as the upfront cost of purchasing and installing BESS is significantly higher than traditional energy solutions. While solar PV panel prices have decreased over the years, they highlighted that battery storage remains expensive due to the high cost of battery cells, power conversion systems, and installation infrastructure. Additionally, informants pointed out that additional expenses such as inverters, cooling systems, and safety mechanisms further strain company budgets. Several informants shared that manufacturers often fail to anticipate these extra costs during project planning, leading to budget overruns or, in some cases, project cancellations. Without financial assistance or flexible financing options, they expressed concerns that the high upfront cost of BESS discourages companies from integrating storage solutions into their energy strategies.

Another major financial challenge raised by the respondents was the length of the payback period and the uncertainty of return on investment. The respondents indicated that, based on their investigation, manufacturers require 10 or more years for BESS to start generating financial returns. Hence, manufacturing plants that prioritize short-term cost savings have found this option less attractive. They further explained that the economic feasibility of BESS depends a lot on electricity tariff structures, which have made manufacturers struggle to see clear financial benefits from it. Thus, investment decisions are even harder to accept by the stakeholders. The respondents also informed that, unlike solar PV, which installation directly offsets electricity costs, BESS offers indirect savings through peak demand management and grid stabilization. They indicated that in the absence of clear and direct financial incentives or an enabling policy framework, organizations would remain hesitant to invest in BESS given the uncertainty regarding long-term cost savings and revenue generation.

In the end, informants highlighted the concern about the costs of continuing maintenance and replacement. Photovoltaic panels have minimal maintenance needs and long lifespans, up to 25 years. The informants informed that the components of BESS, like batteries, need frequent monitoring and optimization for performance, as well as replacement. The interviewees highlight a concern about degradation of battery capacity since the loss in capacity leads to a loss in efficiency, as the replacement of the battery is costly. In addition to that, software updating, upgrading, and preventive maintenance further add to operational costs. Long-term financial planning becomes more complex because of the uncertainty about future expenses on maintenance, making an investment less attractive.

3.2 Technical Challenges

Based on findings from informants, five key sub-themes were identified under the technical challenges theme: (1) Battery Lifespan, (2) Limited Surplus Energy, (3) Storage Capacity, (4) Integration Compatibility, and (5) Safety Risks. These sub-themes highlight the major technical difficulties organizations face when adopting BESS in solar manufacturing operations. Table 3 presents the related quotations from informants regarding technical challenges.

Table 3
Sub-themes and related quotations for technical challenges in BESS integration

Theme	Sub-Themes	Quotation
Technical Challenges	Battery Lifespan	*"Over time, battery efficiency drops, which reduces storage capacity and affects long-term reliability."* *"Frequent charging and discharging wear out the battery faster, meaning it needs replacement and increases overall costs."* *"Once the battery performance starts to decline, we have no choice but to replace it, adding to the overall investment cost."*
	Limited Surplus Energy	*"Our current solar systems were designed for direct consumption, not for surplus storage, making it difficult to integrate BESS effectively."* *"Since the original solar setup was not meant to generate excess energy, adding a battery storage system doesn't make sense because there's nothing to store."*
	Storage Capacity	*"BESS has energy storage limits, so it might not be enough for us since our production require high power demand."* *"We have to clearly calculate the best storage capacity to match our energy needs and avoid overspending on unnecessary units."*
	Integration Compatibility	*"Integrating BESS with an existing solar system is not simple and it needs careful planning, customized solutions, and big investments in system upgrades."*

		"We also have to depend on the same solar panel supplier to ensure compatibility, which limits our choices and flexibility in upgrading or expanding the system."
	Safety Risks	*"Lithium-ion batteries have fire risks, so extra monitoring, proper ventilation, and temperature control systems are needed."* *"If the battery overheats, it can cause a system failure or, in the worst case, even a fire hazard, which is a major safety concern."*

On the technical aspect, several challenges were highlighted by the informants as challenges to the adoption of BESS in manufacturing plants. A primary concern is battery lifespan since the informants noted that battery efficiency degrades overtime which reduces the capacity to store energy. Charge-discharge cycles frequently accelerate the process of deterioration which eventually leads to costly replacements. The informants also expressed a concern that manufacturing often underestimates the impact of battery wear which adds unexpected expenses to the total cost. Hence, in the absence of proper long-term planning, manufacturing companies may struggle with a financial burden on maintaining and replacing batteries.

The informants also pointed out that their solar systems were designed for direct consumption and not for surplus storage. This means that many manufactured solar systems do not have surplus energy to store and therefore the integration of BESS would be impractical. Without sufficient energy surplus, the addition of a storage system will be of no benefit, therefore manufacturing has to consider the necessity of BESS investments. Integration compatibility was also seen as a significant barrier by the informants. They mentioned that adding BESS into current solar PV setups needs customized solutions. In addition, the informants mentioned that manufacturing often has to rely on the same solar panel supplier to ensure the system could properly integrated. This dependency restricts their ability to optimize energy storage solutions.

Another problem highlighted by respondents is storage capacity limitations. They stated that BESS has energy density limitations and therefore, it cannot be used for manufacturing where high energy needs are high. The respondents mentioned that the storage capacity requirement needs to be calculated very carefully to avoid inefficiency and unnecessary expenditure. Without precise energy planning, manufacturing may overspend on storage that exceeds their needs or invest in an insufficient capacity that fails to support their operations effectively. Lastly, the respondents mentioned safety risks as another technical challenge of BESS integration. According to them, inadequate thermal management by the batteries leads to overheating leading to system failure and, in the worst case, may cause fire hazard.

3.3 Regulatory and Policy Barriers

Based on findings from informants, three key sub-themes were identified under the regulatory and policy barrier's theme: (1) Ambiguity in Government Policies and (2) Insufficient Government Incentives. These sub-themes highlight the major regulatory challenges that hinder BESS adoption in solar manufacturing organizations. Table 4 presents the related quotations from informants regarding regulatory and policy barriers.

Table 4
Sub-themes and related quotations for regulatory and policy barriers

Theme	Sub-Themes	Quotation
Regulatory and Policy Barriers	Ambiguity in Government Policies	*"Until now, there is no proper national policy that clearly outlines how energy storage should be implemented. Everything still quite uncertain."* *"We're interested to move forward with BESS, but the lack of clear policy makes us hesitant. We don't want to take unnecessary risks."* *"They have direction for solar energy, but when it comes to storage, it's like the policy is still not fully developed."*
	Insufficient Government Incentives	*"At the moment, there are no real incentives for companies to adopt BESS. The government only informed us that if solar generation goes beyond a certain level, we'll need to install batteries".* *"If there were tax incentives or subsidies for BESS, more companies would consider it seriously. But now, everything has to come from our own budget."* *"Government keeps promoting green energy, but for BESS, we don't see much support."*

The informants expressed their opinion about the ambiguity of the national direction and regulatory framework on energy storage systems. Existing energy policies have started to support solar PV installation, however respondents indicated that the same clarity and structure have not been extended to BESS. In the absence of specific guidelines on the deployment and operation of battery systems, manufacturing company find it difficult to plan for the long term. This ambiguity in policy hesitates the manufacturing companies from embracing these technologies. There is concern that new requirements or restrictions in future regulatory changes. This lack of coherence in policy direction limits the industry's confidence in making strategic investments in storage technologies.

Another major concern highlighted was the lack of financial incentives tailored for BESS adoption. Unlike solar power which gets many government mechanisms including the Net Energy Metering (NEM) plan and no tax charges, energy storage is not currently support by similar incentives. This lack of subsidies, rebates or tax breaks makes BESS economically not possible, especially for small to medium-sized manufacturing company. The respondents thus perceived a perceived imbalance within the clean energy agenda of the government. While initiatives on renewable energy are actively promoted, emphasis seems to be placed more on power generation compared to energy storage. In addition, the participants mentioned that they were informed that BESS would be necessary if their solar generation exceeded some threshold, however, this requirement was not accompanied by any form of support. Thus, companies felt that the rollout of energy storage is being imposed as a self-initiated responsibility of the manufacturing sector rather than being encouraged through constructive policy instruments.

3.4 Operational Challenges

Based on findings from informants, three key sub-themes were identified under the operational and organizational challenge's theme: (1) Lack of Organizational Awareness, (2) Lack of Technical Expertise, (3) Internal Resistance to Adoption, and (4) Limited Access to Benchmarking Data. These sub-themes highlight the internal barriers within organizations that hinder BESS adoption in solar manufacturing. Table 5 presents the related quotations from informants regarding operational and organizational challenges.

Table 5
Sub-themes and related quotations for operational challenges in BESS integration

Theme	Sub-Themes	Quotation
Operational Challenges	Lack of Awareness	*"Within our organization, there is still a considerable gap regarding how BESS can contribute to operational efficiency and long-term cost savings."* *"Many people in our company are not fully aware of the potential value of BESS, so the topic is rarely prioritised in strategic discussions."* *"There is limited understanding internally about how energy storage works, especially when it comes to integrating it with our existing solar systems."*
	Lack of Expertise	*"We currently do not have the internal expertise to assess or design a proper BESS setup, so we rely on third-party consultants."* *"The lack of internal technical know-how slows down decision, as we have to outsource even the basic feasibility analysis."* *"Training our staff on energy storage technologies is not our focus yet, mainly because we're still not familiar with the requirements."*
	Internal Resistance	*"Some of our senior management remain sceptical about investing in BESS due to concerns over high capital costs and delayed return on investment."* *"At the moment, energy storage is not seen as a priority. Most of the company's focus is still on production efficiency."* *"There is limited internal support for BESS because many stakeholders still view it as new technology."*
	Limited Access to Benchmarking Data	*"There are not enough proven examples or case studies of successful BESS use in the local manufacturing sector."* *"We're unable to benchmark properly because there's very no available data showing how BESS performs over time in similar industrial settings."*

An operational challenge that could be addressed was a lack of awareness in the organizations of the practical values attributed to BESS. The informants indicated that the majority of decision-makers did not know how energy storage could enhance operational efficiency and save costs in the long-term making topics related to BESS treated as low priorities compared to other ongoing initiatives. Another challenge was having limited in-house expertise to manage and maintain BESS systems. Several informants indicated that their manufacturing plant did not have qualified personnel to evaluate the feasibility or manage the integration of BESS, therefore there is a high dependence on external experts which increases operational costs and slows down decision-making.

In addition, resistance to BESS adoption from within the organization was also another evident due to its high initial capital cost and uncertain return on investment. Management regarded energy storage as a secondary or non-essential investment in addition to production, efficiency, or other core concerns in operation. Most importantly, as mentioned by most information, the absence of benchmarking data and local case studies became major challenge towards the integration of ESS because there were not enough practical successful examples of BESS deployment within the Malaysian manufacturing sector. Decision-makers found it very difficult to portray long-term performance, financial impact, and overall reliability of BESS solutions without such reference points. Without access to concrete data or peer comparisons, manufacturing companies struggled to justify the expenditure and operational outcome.

3.5 Environmental and Sustainability Concerns

Based on findings from informants, three key sub-themes were identified under the theme under operational and organizational challenge: (1) Lack of Organizational Awareness, (2) Lack of Technical Expertise, (3) Internal Resistance to Adoption, and (4) Limited Access to Benchmarking Data. These sub-themes highlight the internal barriers within organizations that hinder BESS adoption in solar manufacturing. Table 6 presents the related quotations from informants regarding operational and organizational challenges.

Table 6
Sub-themes and related quotations for environmental and sustainability concerns in BESS integration

Theme	Sub-Themes	Quotation
Environmental and Sustainability Concerns	Battery Recycling	*“Right now, there’s no standard procedure for battery recycling. Each company seems to handle it differently, and that can be risky in the long run.”* *“Honestly, we don’t have a proper system to recycle used batteries. Most of the time, they’re just stored or sent to third parties without knowing if it's done the right way.”*
	Battery Disposal	*“Disposing old batteries is quite unclear. It’s not only costly, but we also worry whether it’s done in an environmentally safe manner or not.”* *“There’s a lot of concern on how to dispose batteries properly. If it’s not handled well, it can cause harm to the environment.”*
	Resource Extraction	*“To make these batteries, materials like lithium and cobalt are used. But getting these materials can harm the environment.”* *“Mining activities for the battery material damage the environment, and sometimes, we don’t even know if the source is ethically managed.”*

Environmental and sustainability issues were found as key barriers to the successful integration of BESS in solar-powered manufacturing plants. Where BESS is perceived as a clean energy solution, respondents indicated that it creates new environmental risks and issues of ethics. A big concern that has been reiterated relates to battery recycling. The respondents indicate that though they understand the importance of proper recycling, there is no standardized procedure adopted by the industry. This situation leaves companies to manage recycling leading to inconsistent practices that may pose environmental risks. In most cases, used batteries are either stored or handed over to third-party recyclers with little visibility on how they are handled. Such lack of control and transparency are considered major weaknesses in any current sustainability effort.

Battery disposal was another concern as the informants mentioned that they do not know how to dispose of old or damaged batteries safely and economically. Without clear guidelines on disposal, the delays in disposal or improper handling increase the risk of contamination of the environment. In addition, some respondents mentioned that the disposal services are limited and costly thereby discouraging proper waste management practices within organizations. Another challenge noted by the respondents was the resource extraction, especially the critical battery material sourcing like lithium and cobalt. Informants were aware that the demand for these materials keeps on rising but they expressed the concern about the environmental damage due to mining activities and a lack of assurance whether the sources are ethically managed.

4. Discussion

The findings from this case study highlight several critical barriers to implementing BESS in solar manufacturing organizations. These include financial barriers, technical challenges, regulatory and policy barriers, operational challenges, and environmental and sustainable concerns.

One of the most significant challenges is financial barriers, particularly the high initial investment costs, long payback periods, and financing constraints. Even though in the long run BESS would help reduce peak demand, grid independence, and improved energy resilience, manufacturing companies refrain from investing in it because the returns are not clearly stated and there is no immediate cost saving. The informants emphasized that without government incentives or favorable financing models or tax benefits, it will remain financially unfeasible for most solar-powered manufacturers to adopt BESS. This also creates an additional burden as to how long-term financial planning has to be made more complex due to the increased maintenance and replacement costs.

Technical challenges, such as battery lifespan, degradation, energy density, system integration, thermal management, and round-trip efficiency losses, also present significant obstacles. The informants noted that the energy storage systems lose efficiency over time, so capacity diminishes and replacement cost increases. Thermal management and fire safety risks remain concerns, as lithium-ion batteries require advanced cooling and fire suppression systems to prevent overheating and hazardous incidents. Besides that, BESS must be integrated within existing solar infrastructure and grid networks, posing many technical challenges since most systems have to be upgraded at high costs to make them compatible and optimize performance. Without advanced battery management systems, predictive maintenance solutions, and smart-grid integration businesses have big challenges in making BESS very efficient and reliable.

The regulations and policies thus set a great influence on the adoption of BESS. It was noted that the lack of clear policies and complicated regulations on grid interconnection and rigid Power Purchase Agreements (PPAs) make it a big challenge for any business to deploy and monetize energy storage solutions. Most of the businesses are experiencing huge delays in regulatory approvals, facing an unfriendly tariff structure plus restrictions on selling stored energy back to the grid. On top of all this, future policy and market regulation uncertainty increases investment risk, so companies shy away from investing in BESS projects. Without strong policy backing, easier regulations, and market incentives for energy storage, companies would not be enthusiastic about integrating BESS into their solar manufacturing operations. Beyond financial, technical, and regulatory barriers, market and infrastructure challenges also limit the scalability of BESS adoption. The lack of standardization in battery technology, supply chain constraints, and grid infrastructure limitations create additional obstacles. Informants pointed out that BESS manufacturers use proprietary technologies, making interoperability between different battery systems difficult. Additionally, fluctuations in raw material availability (such as lithium, cobalt, and nickel) lead to price volatility and supply chain disruptions, increasing the cost of battery procurement. Furthermore, many existing power grids are not designed to accommodate large-scale energy storage, requiring additional infrastructure investments and grid modernization efforts.

Environmental and sustainability issues add challenges towards the integration of Battery Energy Storage Systems. Though BESS is known as a green technology, its manufacturing process, material extraction, and disposal raises glaring environmental issues. The informants noted that the production of lithium-ion batteries has a high carbon footprint because the mining and processing are energy-intensive. Moreover, battery recycling and disposal are still underdeveloped making a strong concern about e-waste accumulation and contamination by a toxic material. Without robust recycling infrastructure and circular economy initiatives, BESS adoption could contribute to new sustainability challenges, counteracting the environmental benefits of solar energy.

Besides the external challenges, several operational and organizational barriers within companies hinder the integration of BESS. Informants emphasized that many organizations lack awareness, expertise, and internal support for energy storage projects. The uncertainty about the financial viability of BESS leads to resistance to investment approval. Moreover, manufacturers do not have an internal technical team and place third-party consultants who increase costs and dependencies. In addition, benchmarking data and case studies on successful BESS integration in the solar manufacturing industry are very limited, making investment justification complicated. Without a strong knowledge base, adequate employee training programs, and support from the top management team, manufacturers would find significant challenges integrating BESS in their long-term energy strategies.

One more challenge is the intermittency and variability of solar generation which makes it even harder for BESS adoption. In most cases, peak solar generation happens during the day, however, manufacturing facilities have a very fluctuating demand which creates an unbalanced supply and demand situation. Apart from this, seasonal variations play a big role in the production from solar sources and hence manufacturers have to rely on grid power for long periods when there is little sunlight. While BESS may be able to smoothen small short-term fluctuations, it will not be sufficient for long-term energy stability without grid backup or hybrid energy solutions. This calls for new advanced models in energy forecasting, better battery management systems, and strategies in energy storage that would maximize the use of solar energy.

4.1 Limitations and Suggestions for Future Research

While this study provides valuable insights into the barriers to BESS in solar manufacturing companies, some limitations must be acknowledged. A key limitation is the exclusive use of interviews for data collection, which restricted the depth of the findings. Logistical constraints led to the exclusion of observational methods, such as site visits and operational assessments, which limited the opportunity to cross-validate the data and gain a deeper understanding of the challenges associated with real-world BESS integration. Observational techniques could have provided firsthand insights into technical and operational issues, decision-making processes, and practical experiences in integrating energy storage. Future research should adopt a mixed-methods approach that incorporates direct observations, surveys, and focus groups alongside interviews. This would enable triangulation of data sources, resulting in a more comprehensive and validated analysis of BESS integration barriers. Furthermore, increasing the sample size and including a diverse range of solar manufacturing company with varying operational scales and energy requirements would enhance the generalizability of the findings.

This research was conducted within a particular place and rules, which means the results might not fit areas with different energy plans, grid setups, and money situations. The rules for renewable energy rewards, grid joining standards, and energy storage policies change a lot between countries and places; this affects how easy and good BESS investments are. Future work should include cross-country comparisons to see how policy landscapes, financial assistance, and technological advancement affect BESS adoption worldwide. By widening the scope of research to more regulatory and market settings, researchers can develop more universally applicable strategies for overcoming BESS integration barriers in solar manufacturing organizations.

5. Conclusion

The integration of BESS in solar manufacturing organizations plays a critical role in advancing sustainable energy management and reducing reliance on fossil fuels. However, despite the growing interest in energy storage solutions, manufacturers face significant challenges in adopting and scaling BESS, limiting its widespread integration. This research aimed to investigate the barriers preventing successful BESS adoption and provide insights into overcoming these challenges to support a more resilient and efficient renewable energy transition.

This study identified several key challenges: financial barriers, technical challenges, regulatory and policy barriers, operational challenges, and environmental and sustainability concern. High upfront cost and a long payback period with an uncertain return on investment are major financial challenges that keep manufacturing company from prioritizing BESS integration. Other technical challenges are system integration issues; battery degradation and fire safety risks present further challenges. There are no explicit regulations, grid interconnection is highly complex, and restrictive PPAs make it harder for a manufacturer to navigate the policy landscape. Further market limitations on supply chain volatility, environmental concerns on battery production and disposal, as well as resource extraction complicate the integration of BESS.

Overcoming these challenges requires an integrated approach that combines financial incentives, regulatory guidelines, technological innovation, and organizational readiness. In addressing these challenges, companies make the integration of BESS, thereby improving energy efficiency, cost savings, and environmental sustainability in the solar-powered manufacturing industry. Such installations are the main enablers for energy independence and carbon emission reduction as well as stable power supplies for industrial loads. In the long term, more capacity plus enabling policies for broader industry collaboration shall be needed to accelerate the integration of energy storage solutions with a greener and resilient renewable energy sector.

5.1 Theoretical Contributions

Theoretically, this study advances the knowledge of current barriers to the integration of BESS by identifying and analyzing the major challenges to the successful integration of BESS in the solar-powered manufacturing industry. Thus, it can be noted that financial, technical, regulatory, market, environmental, and operational challenges create a strong motivation for this study to develop a comprehensive framework in explaining complexities in energy storage integration within solar-powered manufacturing company. Unlike earlier studies whose attention is centered mainly on technical aspects of BESS, this investigation embraces dimensions delivering a holistic view of management challenges faced by the manufacturers.

This study therefore enriches the literature on energy storage policy and investment decision-making, with more emphasis on the need for government incentives, financing mechanisms, and regulatory support for BESS adoption. More importantly, it redirects the attention from general energy storage benefits to specific challenges that have a direct impact on the solar-powered manufacturing company. This research will act as a foundation for further studies in energy storage solutions across industries while providing a basis for scholars and practitioners to discover more strategies within this proposed framework aimed at scaling up BESS integration.

5.2 Practical Contributions

From a practical point of view, this study is important for solar-powered manufacturing companies, policymakers, and energy investors seeking to navigate the challenges related to the integration of BESS. By recognizing major obstacles, manufacturing companies can create strategic plans to reduce the challenges and make energy storage investments more practical and viable. This study presents an elaborate roadmap for players in the industry, highlighting the need for a strategic approach that embraces financial planning, technological readiness, adherence to regulations, and sustainability aspect.

For decision-makers in manufacturing companies, the findings underline the need of integrating BESS into long run energy plans by taking advantage of governmental incentives, system design optimization, and energy management skilled personnel investment. This study further explains the importance of collaborative partnerships with battery manufacturers providers and regulators to facilitate adoption. In addition, improving workforce training, enhancing supply chain resilience, and investing into green battery technology will be crucial in overcoming economic and environmental barriers associated with BESS.

The results of this research offer guidance to manufacturing companies that plan to integrate BESS in their solar system but are facing challenges with the financial, operational, and regulatory aspects. If companies take a holistic approach toward the integration of energy storage, they can maximize the benefits of BESS and minimize the risks in operations as well encourage sustainability in the efficient solar energy ecosystem.

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