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# Examine Risk Management Processes in Power Generation: A Case Study of the 2mVA Solar Power Plant in Shangombo

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**Abstract**

In the ever-evolving global energy landscape, the adoption of renewable energy technologies has emerged as a critical strategy for addressing a range of pressing issues, including climate change, depletion of fossil fuel resources, and the need for cleaner, more sustainable energy solutions. Among the various renewable energy technologies, solar power has gained significant prominence due to its wide availability, low environmental impact, and rapid advancements in technology that have made it increasingly cost-effective and scalable. Solar energy harnesses the power of the sun to generate electricity through photovoltaic (PV) systems or concentrated solar power (CSP) technologies. Despite these advantages, solar power generation is not without its share of operational challenges and risks. These may include fluctuations in solar irradiance due to weather variability, technical failures in equipment such as inverters or panels, issues related to grid integration, regulatory compliance, and financial uncertainties related to initial investment and long-term maintenance. Given these complexities, effective risk management is essential to ensure the reliability, safety, and financial viability of solar power plants. Risk management in this context involves systematically identifying, analyzing, and mitigating potential threats that could adversely affect the performance or sustainability of the power plant. Implementing robust risk management strategies not only safeguards assets and operational integrity but also builds investor confidence, enhances project efficiency, and ensures compliance with environmental and safety standards. As solar energy continues to play a central role in the global energy transition, understanding and improving risk management practices within this sector becomes increasingly vital. The study will embrace a cross-sectional exploratory case study design, employing a quantitative methodology for gathering primary data. STATA will be used for data entry and data analysis. Descriptive statistics, including frequencies, percentages, and means, was used to summarize data. The study found that the 2mVA Solar Power Plant faces multiple high-priority risks, with environmental, supply chain, grid, technical, cybersecurity, financial, and health and safety risks reported as frequent or significant concerns, alongside human-related and regulatory disruptions. Existing risk management strategies were generally effective, supported by strong technical and environmental risk mitigation, rapid response times, early detection systems, proactive prevention measures, and sufficient staff training. Stakeholder involvement was substantial, with both internal and external actors contributing meaningfully through engagement, communication, and decision-making, supported by transparent reporting and clear role definitions. However, challenges such as funding shortages, unreliable data, workforce limitations, regulatory constraints, stakeholder engagement difficulties, and training gaps hindered optimal implementation. The study recommends enhancing financial support, strengthening human resource capacity, and investing in continuous training to address workforce and knowledge gaps in risk management. Improving data reliability through digital monitoring tools, fostering stronger stakeholder engagement, and aligning regulatory frameworks with operational needs are also essential. Additionally, the plant should invest in advanced risk management technologies, particularly in cybersecurity, and promote a proactive risk management culture embedded across all organizational levels. These measures will collectively strengthen resilience, improve decision-making, and ensure sustainable risk management.

**Keywords:** Power Generation, Solar Power Plant, Zambia Development Agency (ZDA)

## 1. Introduction

### 1.1 Background

The increasing global demand for energy, coupled with the adverse environmental impacts of fossil fuel-based power generation, has spurred a global transition towards renewable energy sources (Al-shetwi, 2022) [6].

Among these, solar energy has emerged as a leading solution due to its sustainability, environmental friendliness, and technological scalability. As countries strive to meet energy demands while simultaneously addressing climate change concerns, solar power has become a central focus of energy policy, investment, and infrastructure development (Adewumi, 2024).

Risk management in power generation particularly in renewable energy projects like solar power plants is a vital process that ensures project success, operational stability, safety, and financial viability (Akhigbe, 2024).

It involves the identification, assessment, and mitigation of risks that may arise during the planning, construction, and operational phases of a power generation facility (Sanchez, 2022). These risks can range from technical failures, design flaws, and equipment malfunctions to policy changes, environmental disruptions, and financial uncertainty. As the energy sector evolves, the complexity and variety of risks have also increased, requiring more advanced and integrated approaches to risk management (Egbumokei, 2024).

Globally, the energy sector has seen a marked shift in policy and regulatory frameworks aimed at promoting clean energy technologies. International conventions such as the Paris Agreement on Climate Change (2015) have galvanized efforts to reduce carbon emissions, driving investments in renewable energy projects, including solar power plants (Hughes, 2022) [27]. The International Renewable Energy Agency (IRENA) and other global institutions have also emphasized the need for robust risk assessment frameworks to enhance the sustainability and bankability of renewable energy projects (Koutoudjian, 2021).

In many developing countries, including those in Sub-Saharan Africa, the integration of solar power into the national energy mix has become a priority due to its potential to address energy access challenges, especially in rural and off-grid areas (Bishoge, 2020).

In Zambia, for example, the government has committed to expanding renewable energy sources as part of its national development plans and energy policy frameworks. The Zambian Renewable Energy Feed-in Tariff (REFiT) strategy and various public-private partnerships have encouraged the development of solar power plants of varying capacities (Mhango, 2024) [37].

Despite the progress, the sector faces significant policy, financial, and technical risks. Inadequate risk management practices can result in project delays, financial losses, system inefficiencies, and even complete project failure (Shaktawat, 2021).

Additionally, inconsistent policy enforcement, limited technical expertise, and climatic variability continue to challenge the resilience of solar power infrastructure (Famoti, 2025). The effects of poor risk management in power generation can be severe, leading to operational downtimes, reduced energy output, increased maintenance costs, stakeholder dissatisfaction, and loss of investor confidence.

Conversely, effective risk management contributes to optimized performance, improved cost efficiency, long-term sustainability, and greater stakeholder engagement (Gandhi, 2022).

This study, therefore, aims to critically examine the risk management processes implemented in the 2mVA Solar Power Plant, identifying gaps, challenges, and best practices. By understanding how risks are managed within this context, the study will contribute to the broader discourse on enhancing the resilience and effectiveness of solar power generation projects, especially within emerging economies like Zambia.

### 1.2 Statement of the Problem

Despite the growing adoption of solar energy as a sustainable alternative to conventional power sources, many solar power generation projects continue to face significant operational, financial, and technical risks that threaten their long-term viability (Ukoba, 2024).

In Zambia, the expansion of renewable energy particularly solar has been embraced as part of the government's strategy to address energy shortages and meet rising electricity demands (Moyo, 2024).

However, the implementation of effective risk management processes in power generation remains limited and inconsistent, particularly in small to medium-sized solar power plants (Chama, 2020) [15].

Current data from the Zambia Development Agency (ZDA) and the Energy Regulation Board (ERB) indicates that most of solar projects in Zambia experience operational inefficiencies due to poor risk assessment and mitigation planning (Malala, 2022).

Additionally, a 2023 report by the Ministry of Energy revealed that many solar installations suffer from delayed maintenance, equipment failure, and underperformance due to inadequate planning for environmental and technical risks (Moyo, 2024).

In the context of the 2mVA Solar Power Plant, preliminary reports from internal technical audits show repeated interruptions in power output and increased maintenance costs, which are primarily attributed to gaps in structured risk management frameworks.

Although risk management is a critical component of project planning and sustainability in energy systems, most small-scale and medium-scale solar power plants in Zambia operate without comprehensive, formalized risk management systems. This gap not only limits operational efficiency but also affects investor confidence, project scalability, and the broader national agenda for renewable energy development.

### 1.3 Objectives of the Study

To examine the risk management processes employed in power generation, with a specific focus on identifying, assessing, and mitigating risks at the 2mVA Solar Power Plant.

### 1.4 Specific Objectives of the Study

1. To establish the types of risks associated with the 2mVA Solar Power Plant.
2. To assess the effectiveness of the existing risk management strategies implemented at the 2mVA Solar Power Plant.
3. To assess the role of stakeholder involvement in the risk management process at the 2mVA Solar Power Plant.
4. To ascertain limitaions in implementing effective risk management practices at the 2mVA Solar Power Plant.

### 1.5 Research Questions

1. What types of risks are associated with the operation of the 2mVA Solar Power Plant?
2. How effective are the existing risk management strategies implemented at the 2mVA Solar Power Plant?
3. What role do stakeholders play in the risk management process at the 2mVA Solar Power Plant?

4. What challenges are faced in implementing effective risk management practices at the 2mVA Solar Power Plant?

### 1.6 Theoretical Framework

Enterprise Risk Management (ERM) Theory is a strategic and structured approach to identifying, assessing, managing, and monitoring risks across all aspects of an organization (Mayaba, 2023) [36].

Unlike traditional risk management, which often addresses risks in isolated departments, ERM offers a holistic framework that integrates risk management into the core functions and decision-making processes of an organization (Mua, 2024). It acknowledges that risks are interrelated and should be addressed collectively to ensure that organizational goals are met effectively.

The theory is underpinned by principles such as comprehensive risk identification, stakeholder involvement, governance structures, and continuous improvement. Key international models like the COSO ERM Framework and ISO 31000 standard offer guidance on how organizations can implement these principles effectively, focusing on accountability, transparency, and adaptability to dynamic risk environments (Maimbolwa, 2020).

In the context of this study, ERM Theory provides a suitable lens to examine the risk management processes at the 2mVA Solar Power Plant. One of the core applications of ERM in this research is in the identification of various categories of risks affecting the plant's operations.

These risks may include technical failures such as solar panel degradation and inverter malfunctions, environmental challenges like extreme weather conditions, financial constraints, and regulatory compliance issues. ERM encourages a proactive approach to recognizing and classifying these risks in order to mitigate their potential impact on the plant's performance and sustainability (Amuah, 2023) [7].

Additionally, ERM theory emphasizes the need to evaluate the effectiveness of existing risk management strategies. This study will assess how well the 2mVA Solar Power Plant is implementing risk controls and mitigation measures. It will also investigate whether these strategies are merely reactive or part of a proactive, forward-thinking plan aligned with the plant's objectives. ERM supports continuous improvement through regular reviews and adjustments to the risk management approach, which will be a key focus of the research (Monazzam, 2024).

Stakeholder engagement is another central theme of ERM Theory (Kareem, 2024). Effective risk management requires the active involvement of all key stakeholders, including plant operators, technical staff, management, regulatory bodies, and even financial sponsors.

This study will explore the roles and contributions of these stakeholders in the risk management process at the 2mVA Solar Power Plant, as well as the level of communication and coordination among them. According to ERM, strong stakeholder collaboration leads to more informed decisions and improved risk mitigation outcomes.

Furthermore, ERM highlights the importance of integrating risk management into strategic and operational decision-making (Hristov, 2024). This study will examine the extent to which risk considerations are embedded in the plant's planning, operations, and long-term sustainability strategies.

For instance, it will assess whether risk assessments influence maintenance schedules, procurement decisions, and energy output forecasting. Such integration ensures that risks are not only managed but also factored into performance evaluation and business continuity planning.

## 2. Literature Review

### 2.1 The types of risks associated with the Solar Power Plant

Operational risks in solar power plants refer to the challenges and potential hazards that arise during the day-to-day functioning of the plant (Almoud, 2023). These risks encompass a wide range of factors that can impact the efficiency, safety, and financial performance of the plant. Effectively managing these risks is crucial for ensuring the plant operates at optimal capacity and generates reliable, cost-effective power (Suresh, 2022).

Financial risks are a major concern for solar power plants, as they directly affect the plant's economic viability and long-term sustainability (Ao, 2022). These risks can arise from various sources, such as fluctuating revenues, capital constraints, cost overruns, and price volatility of equipment.

Since solar power generation involves significant upfront investments and ongoing operational costs, the financial stability of the plant depends heavily on managing these risks (Shahnazi, 2025).

Technological risks are an inherent part of the operation and management of solar power plants, particularly as these plants rely heavily on advanced technologies for efficiency, performance, and integration with national grids (Malama, 2022) [35]. As technology evolves rapidly, these plants must keep pace with innovations to remain competitive and efficient. However, technological risks arise when existing systems and equipment face limitations, become outdated, or encounter issues related to integration. These risks, including obsolescence of technology, integration with grid systems, and cybersecurity threats, can significantly affect the performance and operational stability of solar power plants (Krause, 2020).

The rapid advancement of solar technology poses a significant risk to the long-term viability of solar power plants. New innovations in solar panels, inverters, storage solutions, and power management systems are frequently introduced, promising higher efficiency, longer lifespan, and reduced costs (Kalogirou, 2023) [31]. However, existing technology used in the plant may quickly become outdated or less effective in comparison to these new advancements.

Supply chain risks play a critical role in the construction and ongoing operation of solar power plants. The procurement and delivery of materials, components, and services are essential to ensure that a plant is built to specifications and maintained efficiently over time (Akhigbe, 2024). These risks can significantly impact the project timeline, costs, and overall success of the solar power plant. The key supply chain risks associated with solar power plants include material shortages and supplier reliability issues, both of which have the potential to delay projects, increase operational costs, and compromise performance (Bowa, 2022).

### 2.2 The effectiveness of the existing risk management strategies implemented at Solar Power Plants

The effectiveness of the risk management strategies employed can significantly impact the performance and long-term sustainability of solar plants. This section discusses the existing risk management strategies, their implementation, and the degree of their effectiveness in mitigating the risks faced by solar power plants (Shaktawat, 2021).

One of the most widely implemented risk management strategies in solar power plants is the focus on preventative maintenance and the use of predictive analytics to identify potential issues before they escalate (Cortes, 2022).

Solar panels, inverters, and other components of the solar power plant are subject to wear and tear over time, which can lead to system inefficiencies or even failures. A robust maintenance strategy ensures that the plant is regularly serviced to keep it operating at peak performance (Qureshi, 2024).

Effective risk management strategies in this area involve comprehensive environmental monitoring and adaptation (Kalfin, 2022). Many solar power plants implement weather forecasting systems that provide real-time information on weather patterns, allowing operators to make informed decisions about plant operations.

Furthermore, solar power plants are increasingly adopting climate adaptation strategies (Lyster, 2022). These include designing plants with enhanced resistance to extreme weather, such as reinforcing panel mounts to withstand high winds or installing stormwater management systems to prevent flooding. In regions prone to high temperatures, operators may invest in cooling systems to prevent overheating of panels or inverters (Ashayeri, 2024) [9].

Risk management strategies for solar power plants are most effective when all relevant stakeholders are engaged in the process (Ashayeri, 2024) [9]. This includes plant operators, government authorities, equipment suppliers, local communities, and investors. Effective communication and collaboration among these stakeholders are critical for managing risks and ensuring that the plant operates smoothly (Ledmaoui, 2025).

Regular communication with local communities can help address concerns and gain support for the plant's operations, especially in areas where solar farms may face opposition. Moreover, involving local stakeholders in the decision-making process can help identify potential environmental or operational risks that might otherwise go unnoticed (Lyster, 2022).

**2.3 To assess the role of stakeholder involvement in the risk management process at Solar Power Plants**

Stakeholder involvement plays a critical role in the effective risk management of solar power plants (Mukhtar, 2023). A solar power plant is a complex system that involves multiple actors, each with distinct roles, responsibilities, and interests. These actors, or stakeholders, can have a significant impact on the identification, assessment, mitigation, and management of risks associated with the plant. Effective collaboration between these stakeholders ensures that the plant operates efficiently, complies with regulatory standards, and adapts to potential challenges (Bekrisky, 2022).

This section explores the importance of stakeholder involvement in risk management at solar power plants, discussing key stakeholders, their roles, and the benefits of their active participation in the risk management process (Jayaraj, 2025).

The primary stakeholders involved in the risk management process at solar power plants include plant operators, investors, regulatory bodies, equipment suppliers, contractors, local communities, and government authorities (Mukhtar, 2025).

Each stakeholder plays a pivotal role in identifying, managing, and mitigating the various risks associated with the operation of solar power plants. Their contributions ensure the plant's efficiency, compliance with regulations, financial stability, and overall success in the long term (Beskirsky, 2022).

Plant Operators: Plant operators are crucial in managing the day-to-day functioning of the solar power plant. They are the first line of defense when it comes to operational risks such as equipment failure, maintenance challenges, and underperformance. These operators monitor the performance of solar panels, inverters, and other critical components of the plant (Mukhtar, 2025). They are responsible for implementing regular maintenance programs that ensure the plant operates efficiently and that potential issues are identified and resolved early. By closely monitoring system performance, they can quickly address any problems such as malfunctioning equipment or system inefficiencies, minimizing downtime and maximizing energy production. Their active involvement in risk management ensures that operational risks are effectively mitigated, and the plant's productivity is maintained (Van, 2020).

Investors, which include financial institutions, private equity firms, and banks, provide the capital required for the development and operation of solar power plants. They have a direct interest in ensuring the financial sustainability of the project (Gandhi, 2025). Their role in risk management primarily focuses on mitigating financial risks such as revenue fluctuations, capital and funding challenges, and cost overruns.

Solar power plants depend on consistent revenue generation, which is influenced by factors like sunlight availability and market conditions (Jayari, 2025). Investors closely monitor these financial aspects to assess profitability and ensure that the plant can generate sufficient returns.

They also manage risks related to securing adequate funding, as the high capital expenditure required to build and maintain solar plants can make financing a key challenge. Investors assess the long-term financial viability of the project, requiring risk assessments and financial forecasting to safeguard their investments (George, 2022).

Suppliers and contractors are integral to managing technological and supply chain risks in solar power plants (Onukwulu, 2023). The plant's functionality relies heavily on high-quality components, such as solar panels, inverters, batteries, and transformers, all of which are sourced from specialized suppliers. These suppliers must meet stringent quality standards, and timely delivery of materials is crucial for avoiding delays in construction and operations (Gawusu, 2022). Contractors are responsible for the installation and integration of these components into the plant's systems. Any failure in quality control, installation errors, or delays in material delivery could significantly impact the plant's operational efficiency, leading to performance issues or increased operational costs. Thus, suppliers and contractors must be carefully selected and managed to mitigate these technological risks (Yahyazadeha, 2022) [48].

The communities surrounding a solar power plant are directly affected by its construction and operation (Roddis, 2020). These stakeholders can include residents, local businesses, community organizations, and environmental advocacy groups. Their role in risk management is crucial for addressing social and environmental risks. Solar power plants can alter local landscapes, impact wildlife habitats, and change land use patterns, which can lead to public opposition or local protests if not managed properly (Dhar, 2020).

Engaging with these communities early on and addressing concerns related to land use, environmental impacts, and local development benefits can help mitigate social risks and garner community support. Open communication and community engagement help prevent misunderstandings and opposition, making the plant's integration into the local area smoother and more harmonious (Roddis, 2020).

**2.4 Limitations in implementing effective risk management practices at the Solar Power Plant**

One of the most significant challenges in implementing effective risk management at solar power plants is the inherent technical complexity and uncertainty associated with their operation (Abb, 2022). Solar power systems consist of numerous interconnected components such as photovoltaic (PV) panels, inverters, battery storage units, control systems, and advanced monitoring technologies (Karamoozian, 2022).

In addition to hardware and software challenges, solar power generation is inherently variable and dependent on external environmental conditions, especially solar irradiance. While weather forecasting technologies have improved, predicting cloud cover, rainfall, and temperature shifts with absolute accuracy remains impossible. Sudden changes in weather can lead to drastic fluctuations in energy production, affecting the plant's ability to meet its energy delivery targets and maintain consistent revenue streams (Roddis, 2020).

These unpredictable patterns make it difficult for operators to accurately forecast production levels and financial returns, complicating both operational planning and contractual obligations with off-takers or utility companies (Yahyazadeha, 2022) [48].

Furthermore, the integration of solar energy into existing electrical grids introduces technical uncertainties. Solar power is non-dispatchable and intermittent, which can strain grid stability, especially in systems not designed to accommodate renewable energy. Grid operators and solar plant managers must collaborate closely to manage load balancing, frequency control, and voltage regulation, often requiring investments in smart grid infrastructure and advanced forecasting tools (Roddis, 2020).

Financial constraints pose a significant barrier to the successful implementation of effective risk management practices at solar power plants. Risk management, while essential for ensuring the long-term viability and safety of solar projects, often involves high upfront and ongoing costs (Jayaraj, 2025).

These expenses include investments in advanced monitoring and control systems, recruitment and training of skilled technical personnel, regular system audits and assessments, and securing appropriate insurance coverage. For many solar power developers particularly those operating in developing countries or with limited access to capital, these costs can be prohibitive, undermining efforts to implement comprehensive and proactive risk mitigation strategies (Roddis, 2020).

**3. Methods and Procedures**

**3.1 Research Design**

Study design refers to a collection of instruments and techniques intended for specific application, detailing the rationale and methods behind their usage (Rassel, 2020). Meanwhile, a research design serves as a roadmap that directs researchers in their data collection, analysis, and interpretation endeavors, aiming to address research inquiries.

Considering this, the study will embrace a cross-sectional study design, employing a quantitative methodology for gathering primary data (Taherdoost, 2021). This approach will allow for the collection of data at a single point in time, offering a snapshot of the variables under investigation. Through the quantitative methodology, the study will gather numerical data and employ statistical analysis techniques to draw conclusions and establish relationships among variables).

**3.2 Target Population**

By definition, a population is defined as a collection of objects, events, or individuals sharing common characteristics that the researcher is interested in studying (Muratovji, 2021). The target population for this study are project managers, contractors and engineers under 2mVA Solar Power Plant in Shangombo.

**3.3 Sample Size**

A sample is a subset of a population that is used to represent the entire group. The study consists of 40 project managers, contractors and engineers under 2mVA Solar Power Plant in Shangombo.

**3.4 Sampling**

The took a convenience sampling approach. This choice is based on its practicality and feasibility in accessing study participants. Given the limitations of resources and time, convenience sampling enabled the efficient collection of data from individuals who are readily available and accessible.

**3.5 Data Collection Methods**

The primary research tool for this study is a structured questionnaire comprising closed-ended questions. Data will be collected through structured surveys and interviews, utilizing standardized questionnaires.

**3.6 Data Analysis**

Data entry and statistical analysis will was done using the Statistical Package for the Social Sciences (SPSS) version 26 and STATA. For inferential statistics Chi-square analysis will be employed to establish associations between variables.

## 4. Presentation of Findings

### 4.1 Presentation of results on background characteristics of the respondents

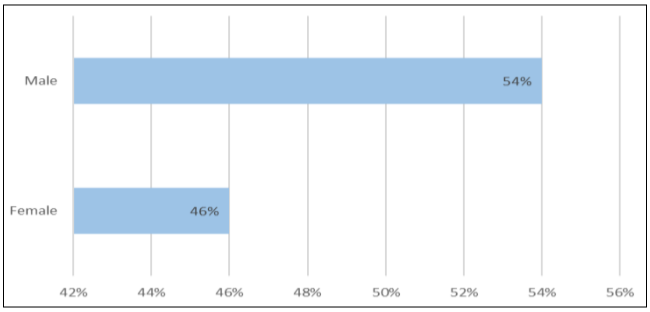


**Fig 4.1.1:** Participants' Gender

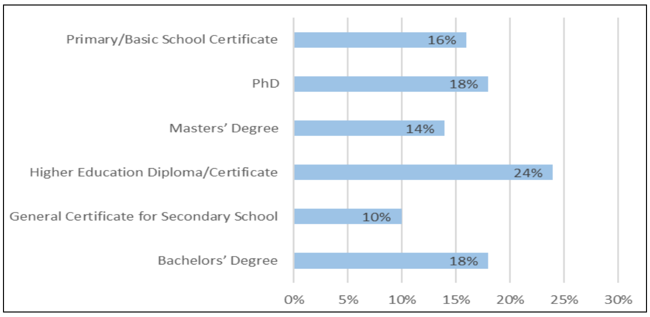


**Fig 4.1.3:** Highest Level of Education

Respondents have varied educational backgrounds, with the majority holding higher education diplomas (24%). Degrees and PhDs each account for 18%, showing a highly educated sample. This diversity may enrich the perspectives collected in the study.

### 4.2 Types of Risks Associated with the 2mVA Solar Power Plant

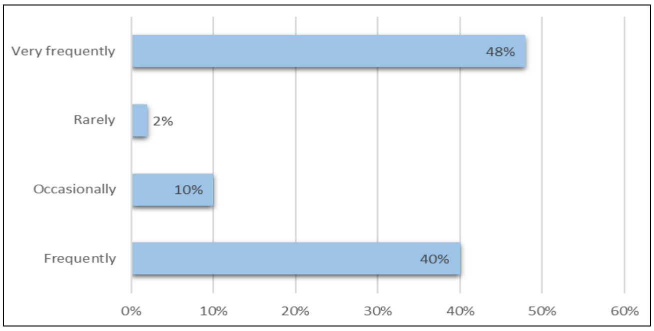


**Fig 4.2.1:** Environmental Risksd

Environmental risks are mostly very frequent (48%) or frequent (40%). Rare occurrences are minimal. This highlights the need for continuous environmental monitoring.

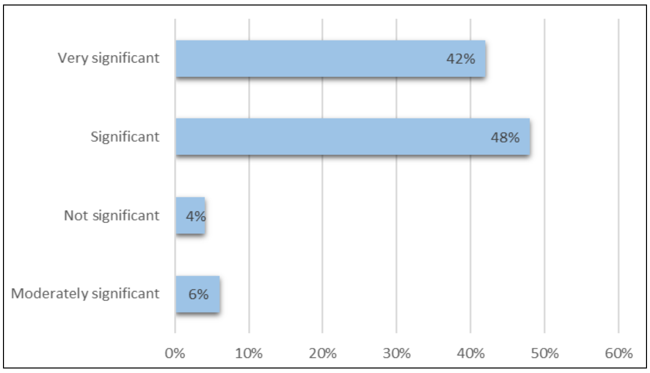


**Fig 4.2.2:** Supply Chain Risks

Most respondents consider supply chain risks significant (48%) or very significant (42%). Minor or moderate risks are rare. This indicates supply chain stability is a key concern for the organization.

**Table 4.2.1:** Association Between Environmental Risks and Technical Failures in Plant Operations

Chi-Square Tests

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 96.667[a] | 6 | .000 |
| Likelihood Ratio | 112.288 | 6 | .000 |
| Linear-by-Linear Association | 1.820 | 1 | .001 |
| N of Valid Cases | 100 | | |

The chi-square test examined the association between the frequency of environmental risks and the likelihood of technical failures at the plant. Results from the Pearson Chi-Square test ($\chi^2 = 96.667$, df = 6, $p < 0.001$) indicate a statistically significant relationship between the two variables. This suggests that the occurrence of environmental risks is strongly associated with the likelihood of technical failures.

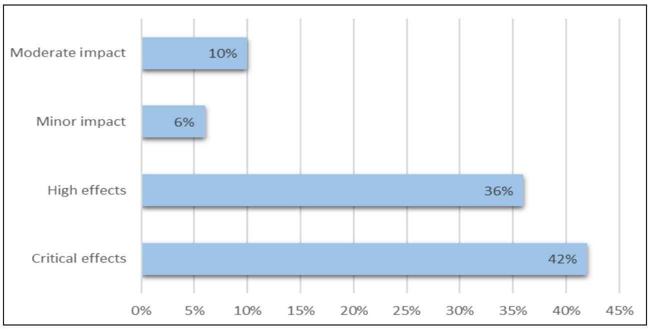


**Fig 4.2.3:** Grid Issues

Grid issues are predominantly seen as critical (42%) or high effect (36%). Moderate or minor issues are less common. This shows power reliability is a major operational concern.

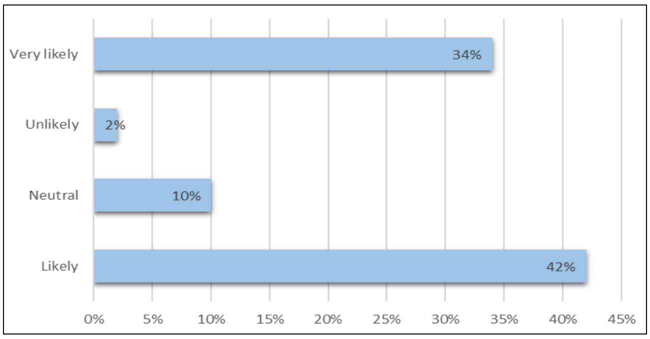


**Fig 4.2.4:** Technical Failures

Technical failures are mostly likely (42%) or very likely (34%). Unlikely events are rare. This indicates that technical risks are a regular concern requiring preventive measures.

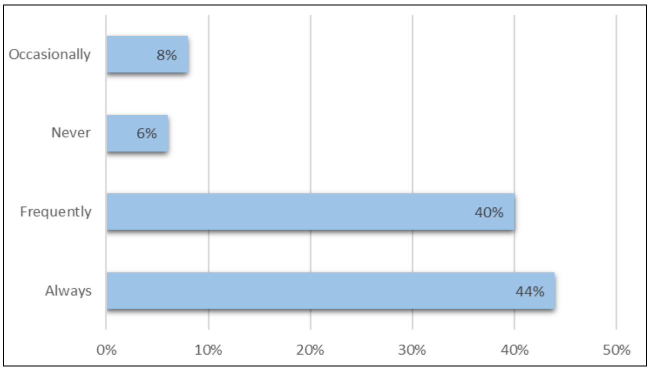


**Fig 4.2.5:** Financial Risks

Financial risks are experienced always (44%) or frequently (40%). Rarely or never occurring risks are minimal. This emphasizes the constant vigilance needed for financial management.

**Table 4.2.2:** Relationship Between Financial Risks and Technical Failures in Plant Operations

Chi-Square Tests

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 96.667[a] | 6 | .009 |
| Likelihood Ratio | 112.288 | 6 | .000 |
| Linear-by-Linear Association | 1.820 | 1 | .000 |
| N of Valid Cases | 100 | | |

The chi-square test examined the relationship between the frequency of financial risks and the likelihood of technical failures at the plant. The Pearson Chi-Square test ($\chi^2$ = 96.667, df = 6, p = 0.009) indicates a statistically significant association between financial risk occurrence and technical failures. The likelihood ratio test ($\chi^2$ = 112.288, df = 6, p < 0.001) further confirms this significant relationship. Additionally, the linear-by-linear association ($\chi^2$ = 1.820, p < 0.001) suggests a significant linear trend, indicating that as the frequency of financial risks increases, the likelihood of technical failures also tends to increase.

### 4.3 Effectiveness of Existing Risk Management Strategies at the 2mVA Solar Power Plant

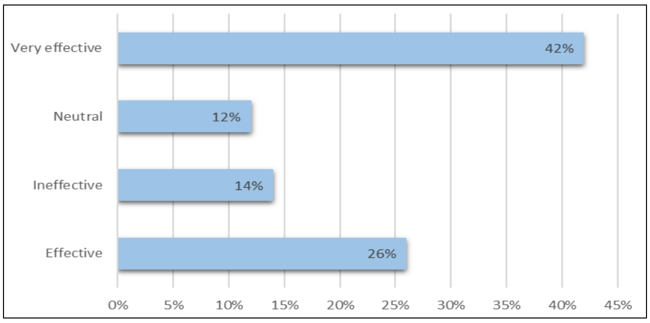


**Fig 4.3.1:** Perceptions of the Effectiveness of Risk Management

Most respondents consider risk management very effective (42%) or effective (26%). A smaller portion views it as ineffective (14%) or very ineffective (6%). This indicates a generally positive perception of organizational risk management.

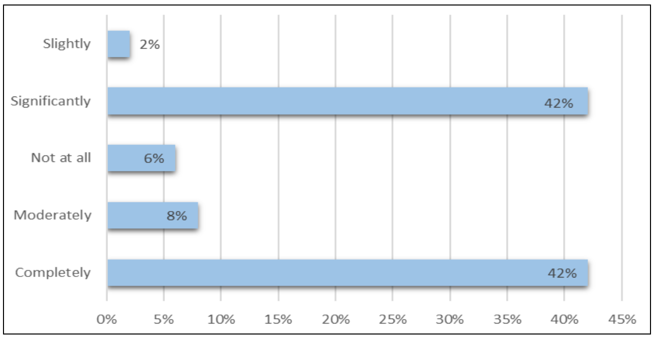


**Fig 4.3.2:** Technical Risk Mitigation

Technical risk mitigation is viewed as completely or significantly effective by 84% of respondents. Minimal responses indicate low or no mitigation. This suggests strong technical risk strategies are in place.

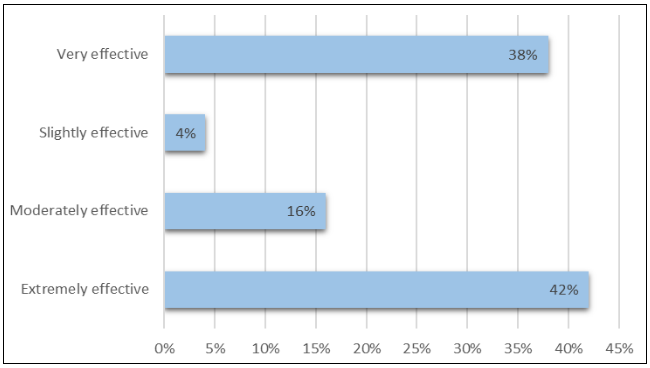


**Fig 4.3.3:** Environmental Risk Mitigation

Environmental risk mitigation is generally rated highly, with 42% extremely effective and 38% very effective. Moderate and slight effectiveness are reported by fewer respondents. This indicates proactive measures for environmental risk management.

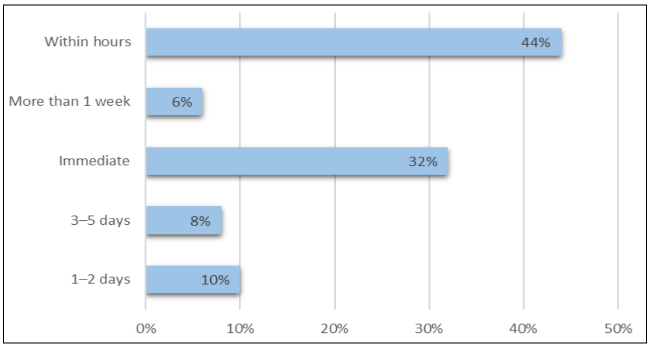


**Fig 4.3.4:** Response Time

Most risks are responded to within hours (44%) or immediately (32%). Longer response times over several days are less common. This shows that rapid risk response is a key operational strength.

**Table 4.3.1:** Association Between Operational Response Time and Effectiveness of Technical Risk Mitigation

| Chi-Square Tests | | | |
|---|---|---|---|
| | Value | df | Asymp. Sig. (2-sided) |
| Pearson Chi-Square | 96.667a | 6 | .004 |
| Likelihood Ratio | 112.288 | 6 | .000 |
| Linear-by-Linear Association | 1.820 | 1 | .004 |
| N of Valid Cases | 100 | | |

The chi-square test examined the association between the response time to identified operational risks and the effectiveness of current strategies in mitigating technical risks. The Pearson Chi-Square test ($\chi^2 = 96.667$, df = 6, p = 0.004) indicates a statistically significant relationship between these variables. The likelihood ratio ($\chi^2 = 112.288$, df = 6, $p < 0.001$) further confirms the significance of this association. Additionally, the linear-by-linear association ($\chi^2 = 1.820$, p = 0.004) suggests a significant linear trend, indicating that faster operational response times are associated with more effective technical risk mitigation strategies.

## 4.4 Role of Stakeholder Involvement in the Risk Management Process

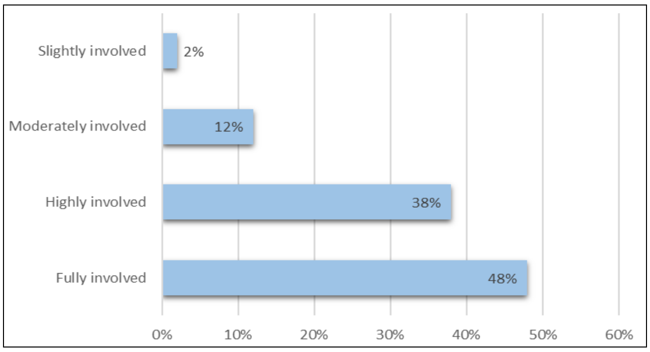


**Fig 4.4.1:** Internal Stakeholder Involvement

Most respondents report that internal stakeholders are fully (48%) or highly (38%) involved in risk management processes. Only a small fraction indicate moderate (12%) or slight involvement (2%). This suggests strong internal engagement in organizational risk activities.

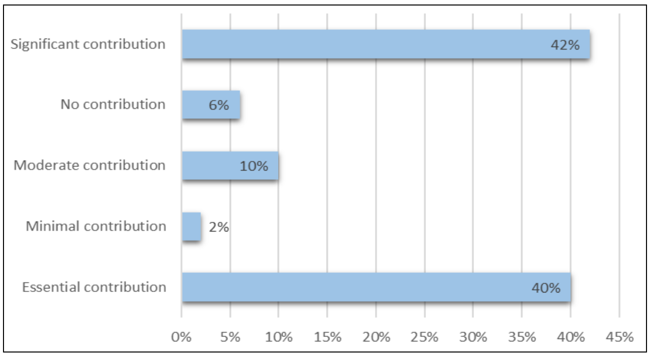


**Fig 4.4.2:** External Stakeholder Contribution

External stakeholders are viewed as making essential (40%) or significant (42%) contributions. Minimal or no contribution is rare, reported by only 8% of respondents. This shows that external stakeholders play a meaningful role in organizational risk management.

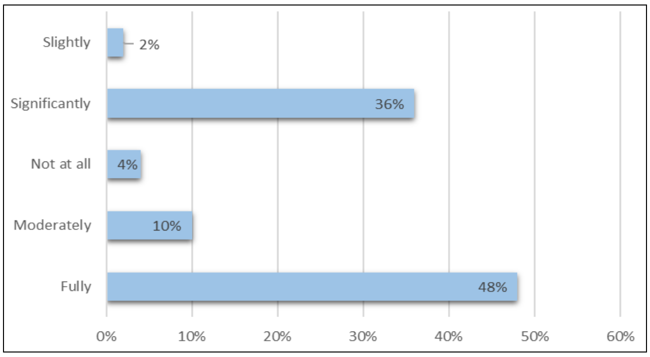


**Fig 4.4.4:** Input Incorporation

Input from stakeholders is fully (48%) or significantly (36%) incorporated into decision-making. Very little input is moderately incorporated (10%) or not incorporated at all (4%). This reflects a strong culture of including stakeholder perspectives in organizational risk management.

## 4.5 Challenges in Implementing Effective Risk Management Practices at the 2mVA Solar Power Plant

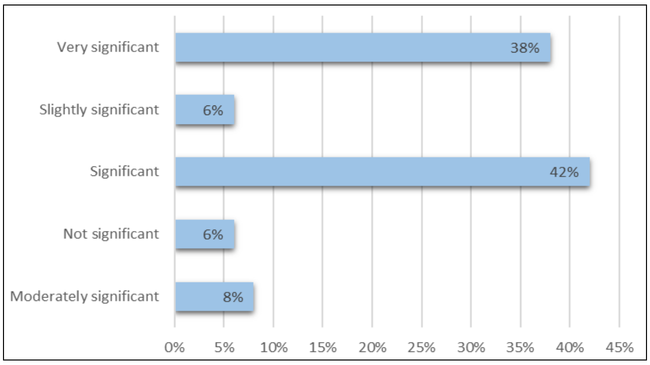


**Fig 4.5.1:** Lack of Funding

Funding shortages are seen as significant (42%) or very significant (38%) by most respondents. Only 14% consider funding issues moderately or not significant. This shows that lack of financial resources is a major challenge for risk management activities.

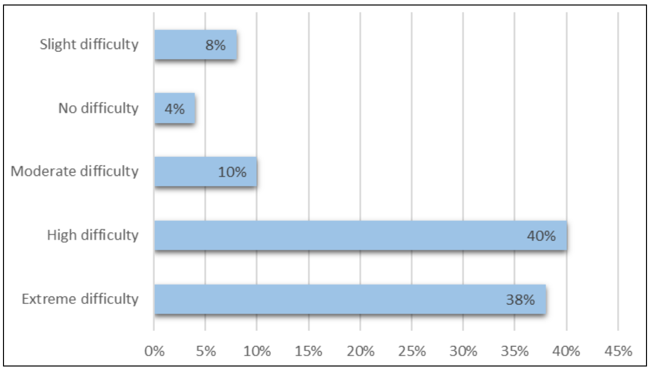


**Fig 4.5.2:** Difficulty in Reliable Data

Obtaining reliable data is challenging for respondents, with extreme (38%) and high difficulty (40%) dominating. Moderate or slight difficulties are less common (22%). This highlights data reliability as a significant barrier to effective risk management.

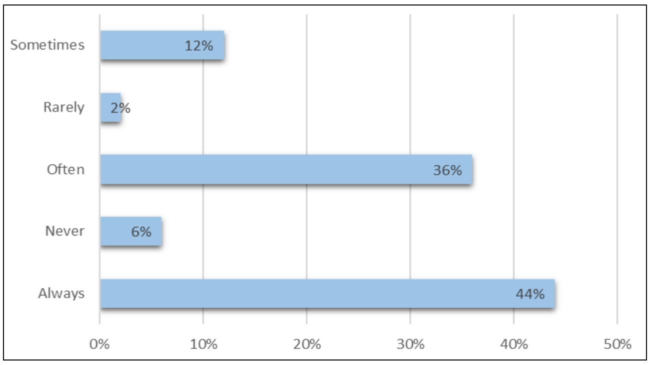


**Fig 4.5.3:** Human Resource Limitations

Human resource limitations are frequently reported as affecting risk management, with 44% indicating "always" and 36% "often." Rare or no limitation is reported by only 8%. This indicates workforce constraints are a key operational challenge.

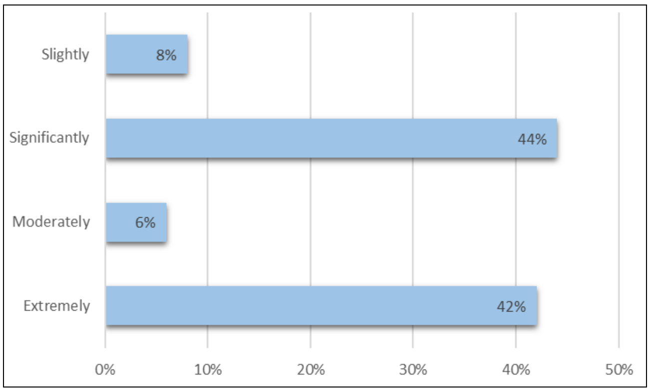


**Fig 4.5.4:** Regulatory Constraints

Regulatory constraints are perceived as extremely (42%) or significantly (44%) limiting by most respondents. Minimal or moderate impact is reported by only 14%. This reflects the strong influence of regulatory frameworks on organizational risk management.

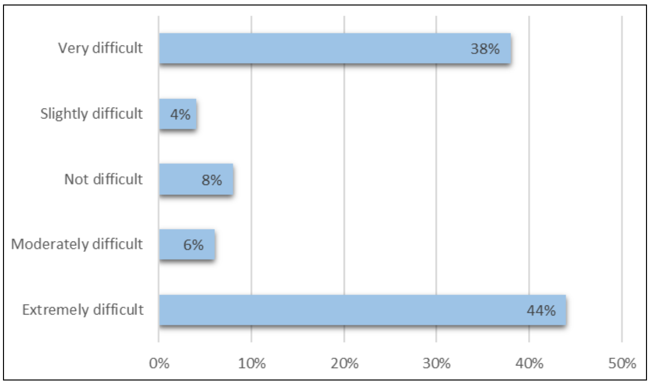


**Fig 4.5.6:** Stakeholder Engagement Difficulty

Engaging stakeholders is challenging, with 44% reporting extreme difficulty and 38% very difficult. Only 18% perceive minimal difficulty. This shows that effective stakeholder engagement requires focused attention and strategy.

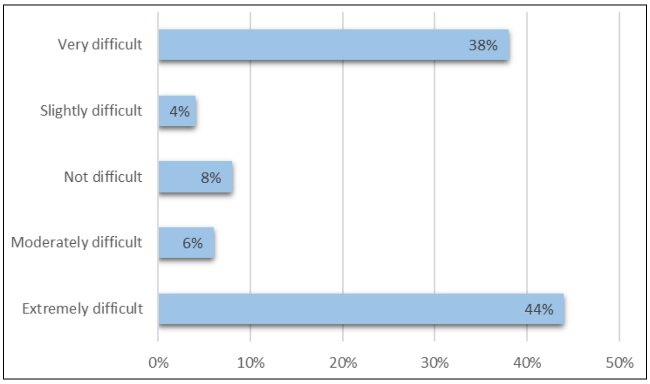


**Fig 4.5.7:** Lack of Training Frequency

Training deficiencies occur frequently (56%) or very frequently (24%). Minimal gaps are reported by 8%. This highlights a need for continuous capacity-building initiatives to support risk management.

## 5. Discussions

This discussion examines the various types of risks identified at the 2mVA Solar Power Plant. The findings reveal a complex risk profile where regulatory, security, and human-related risks are perceived as more prevalent and disruptive than the technical and environmental risks often emphasized in broader literature. This suggests that the operational context of a smaller plant in Zambia shapes a unique risk landscape that requires tailored management strategies.

The most frequently reported risk category was regulatory, with 46% of respondents identifying it as the most common. This was closely followed by security risks at 36%, which encompassed both physical security and cybersecurity threats. Financial risks were cited by 16% of participants, while environmental risks were a distant minority at just 2%.

When asked to identify the most disruptive type of risk to day-to-day operations, human-related risks were the foremost concern for 44% of respondents, with regulatory risks again being significant at 40%. Technical and operational risks were considered minimally disruptive by only 4% of respondents each. Delving into specific risk types, supply chain issues were viewed as significant or very significant by a overwhelming 90% of participants.

The likelihood of technical failures was rated as likely or very likely by 76% of those surveyed. Cybersecurity was perceived as a high or extremely high risk by 80% of respondents. Financial risks were reported to occur frequently or always by 84% of participants. Health and safety risks were a critical or high concern for 84% of the plant's staff.

These findings paint a picture of an operation where external pressures, human factors, and systemic vulnerabilities are of greater immediate concern than the technological performance of the solar infrastructure itself.

The prominence of regulatory risks aligns with recent studies on renewable energy in emerging economies. Mhango (2024) [37] notes that the Zambian renewable energy sector faces significant challenges due to regulatory complexities and evolving policy frameworks.

The high level of concern over regulatory issues at the 2mVA plant likely reflects this broader national context, where policies may be inconsistent or subject to change, creating uncertainty for plant operators. This finding supports the work of Chama (2020) [15], who observed that regulatory uncertainty was a major factor in delays for solar projects in Zambia.

The strong emphasis on security risks, particularly cybersecurity, is consistent with global trends in energy infrastructure. Abdelkader (2024) and Krause (2021) have documented the increasing vulnerability of digitized energy systems to cyber threats. The high rating for cybersecurity risk at the 2mVA plant indicates that these global concerns are equally relevant at the smaller scale of operation, challenging any assumption that smaller plants might be less exposed to such threats.

The low ranking of environmental risks at merely 2% seems to contradict a substantial body of literature that emphasizes the susceptibility of solar power generation to environmental factors. Al-Shetwi (2022) [6] and Sharma (2023) extensively discuss how variables like solar irradiance, temperature fluctuations, and dust accumulation can significantly impact energy output.

This discrepancy might be explained by the plant's specific geographical location, which could experience relatively stable weather patterns, or it might indicate that existing environmental mitigation strategies, such as regular panel cleaning, are perceived as effective by the staff. Alternatively, it could suggest that other risks are simply more immediate and salient in the minds of the operators.

The high level of concern over human-related risks as the most disruptive category is a crucial finding. While technical literature often focuses on equipment and systems, this result underscores the fundamental role of human factors in operational reliability. This aligns with the perspective of Bafandegan Emroozi and Modares (2024) [10], who argue that human error and personnel issues are critical but often underestimated risks in power plant operations.

The finding suggests that at the 2mVA plant, challenges related to staffing, training, decision-making, or organizational culture pose a greater threat to daily operations than any equipment failure.

The overwhelming concern about supply chain risks (90% finding them significant or very significant) is strongly supported by contemporary research. Ukoba (2024) and Bowa (2022) highlight how renewable energy projects, particularly in developing nations, are highly vulnerable to disruptions in the global supply chain. Delays in receiving critical components like inverters or specialized solar panels can bring construction and maintenance to a halt. This finding confirms that the 2mVA plant, despite its smaller size, is not insulated from these global logistical challenges.

The fact that 76% of respondents see technical failures as likely or very likely corresponds with the technical literature on photovoltaic systems. Almoud (2023) and Gunda (2020) detail the common points of failure in solar plants, such as inverter malfunctions and panel degradation. However, the fact that these technical risks were not ranked as the frequent or disruptive category is an important nuance. It implies that while the plant faces technical challenges, they are within the range of expected operational issues and are perhaps managed through robust maintenance protocols, making them less salient than other risk categories.

The high frequency of financial risks reported by respondents aligns with the analyses of Adewumi (2024) and Shahnazi (2025), who identify financial uncertainty as a major hurdle for renewable energy projects. These risks can stem from fluctuating revenue due to variable energy output, currency exchange rates affecting the cost of imported equipment, or challenges in securing financing for upgrades and expansions.

The perception of health and safety as a critical or high concern for 84% of staff is a positive indicator of a strong safety culture within the plant. This concern, while highlighting a risk area, suggests that staff are vigilant and aware of potential hazards, which is the first step toward effective risk mitigation. It echoes the importance placed on safety protocols in the work of Rukijkanpanich and Mingmongkol (2020).

The specific risk profile of the 2mVA plant with regulatory, human, and supply chain risks at the forefront deviates from the standard risk models often developed for large-scale utility plants in Europe or North America. This deviation is not an anomaly but rather a reflection of its operational context.

Smaller plants in developing economies operate under different constraints; they may have less bargaining power with regulators, face greater challenges in attracting and retaining skilled personnel, and have less buffer against supply chain disruptions due to smaller inventory holdings. Therefore, the findings suggest that risk management frameworks cannot be one-size-fits-all but must be adapted to the specific scale, location, and operational context of the power plant.

These findings have direct practical implications for the management of the 2mVA Solar Power Plant and similar facilities. The dominance of regulatory risk suggests that management should prioritize building strong, ongoing relationships with regulatory bodies like the Energy Regulation Board (ERB). Proactive engagement, rather than reactive compliance, could help navigate the complex policy environment.

Assigning a specific team or individual to monitor regulatory developments and assess their impact could be beneficial. The high perception of security and cybersecurity risks necessitates investment in both physical and digital security infrastructure. This could include surveillance systems, access controls, and cybersecurity measures like firewalls, intrusion detection systems, and regular security audits. Training staff to recognize and respond to security threats is equally important.

The positive findings regarding staff training are particularly significant given the plant's previous identification of human-related risks as highly disruptive. This suggests that while human factors remain a concern, the plant has made substantial investments in addressing these risks through training and development. This alignment between identified risks and mitigation strategies represents a mature approach to risk management. The emergency response capabilities are especially important given the plant's location and operational context. Famoti (2025) emphasizes that renewable energy facilities in relatively remote locations must have strong self-sufficient emergency response capabilities, as external support may not be immediately available. The high ratings in this area suggest the plant has developed appropriate standalone response capacities.

The generally positive assessment of risk management effectiveness at the 2mVA plant provides valuable insights for similar facilities. The strong performance in technical risk mitigation suggests that the plant's maintenance and monitoring protocols could serve as a model for other small to medium-scale solar operations. The rapid response capabilities indicate that the incident management system is well-designed and effectively implemented. However, the fact that 20% of respondents rated the overall framework negatively suggests there are still areas needing improvement. This mixed feedback aligns with the concept of continuous improvement in risk management advocated by Monazzam (2024), who argues that even effective systems require regular refinement and updating.

The plant should maintain its strong technical risk mitigation practices while addressing any gaps in other risk domains. Regular independent audits could help identify areas where perceived effectiveness might not align with actual performance. The continued investment in staff training appears to be yielding positive results and should be sustained. The emergency response capabilities represent a significant strength that should be maintained through regular drills and plan updates. For other similar plants, the 2mVA case suggests that focusing on core operational risks first technical mitigation, response capabilities, and staff training can create a solid foundation for risk management that can later be expanded to address more strategic risks.

The positive assessment of risk management effectiveness at the 2mVA plant, while somewhat contrasting with broader literature about risk management challenges in similar facilities, provides a valuable case study of successful implementation. It suggests that with appropriate focus and investment, smaller solar plants can develop effective risk management frameworks. The areas of strongest performance—technical mitigation, rapid response, and staff training—align well with the plant's previously identified risk profile, indicating a strategic approach to addressing the most significant threats. This alignment between identified risks and mitigation effectiveness represents a mature risk management culture that other similar facilities might emulate.

This discussion examines the critical role of stakeholder involvement in the risk management framework of the 2mVA Solar Power Plant. The findings reveal a generally robust and effective system of stakeholder engagement, characterized by high levels of internal involvement, significant external contribution, transparent communication, and well-defined roles. This active participation appears to be a cornerstone of the plant's risk management efficacy, though the data also points to persistent challenges in maintaining consistent engagement across all groups.

These findings also have theoretical implications for risk management frameworks in renewable energy. They suggest that existing risk management models, often developed in contexts with abundant resources and stable regulatory environments, may need adaptation to address the specific constraints faced by smaller plants in developing economies. The challenges identified at the 2mVA plant highlight the importance of contextual factors in risk management implementation and the need for more flexible, resource-sensitive approaches that can function effectively under significant constraints.

The plant's experience demonstrates that effective risk management is possible despite substantial challenges, but requires strategic prioritization, creative resource management, and continuous effort to overcome implementation barriers. For similar facilities facing comparable constraints, the 2mVA case suggests that focusing on core risk management capabilities while systematically addressing underlying implementation challenges offers the most promising path toward improved risk resilience. The findings ultimately underscore that risk management implementation is not merely a technical challenge but a complex organizational endeavor that requires addressing multiple interconnected constraints simultaneously.

## 6. Conclusions and Recommendations

### 6.1 Conclusions

The study concluded that the 2mVA Solar Power Plant faces significant risks, particularly environmental, technical, cybersecurity, financial, and health and safety concerns, alongside supply chain and grid reliability issues. Existing risk management strategies were found to be largely effective, supported by strong technical and environmental measures, rapid response systems, and proactive staff training, which foster a positive perception of organizational risk management. Stakeholder involvement was identified as substantial, with high levels of engagement, transparency, and information access enhancing decision-making processes. However, challenges such as funding shortages, unreliable data, human resource limitations, regulatory constraints, and training gaps continue to hinder optimal effectiveness. Addressing these challenges through improved capacity building, resource allocation, and stakeholder collaboration will be essential for strengthening resilience and ensuring sustainable risk management at the plant.

### 6.2 Recommendations

Enhance Financial Support for Risk Management: Adequate funding should be allocated to risk management activities to ensure that preventive and corrective measures, including cybersecurity defenses, technical upgrades, and emergency preparedness, are consistently implemented.

Strengthen Human Resource Capacity: The organization should invest in expanding and retaining skilled personnel to address workforce shortages that limit the effectiveness of risk management processes. This includes recruitment, specialized training, and retention strategies.

Improve Training and Capacity Building: Continuous training programs should be introduced to address knowledge gaps and ensure that employees remain competent in managing technical, environmental, and operational risks. Training should also focus on new and emerging risks such as cybersecurity.

Enhance Data Collection and Reliability: Systems for collecting, analyzing, and verifying risk-related data should be strengthened to improve decision-making and early detection of risks. Adoption of digital risk monitoring and reporting tools can help achieve this.

Strengthen Stakeholder Engagement: Strategies should be developed to improve collaboration with both internal and external stakeholders. This includes regular consultative meetings, transparent communication frameworks, and mechanisms to ensure stakeholder input is effectively integrated into decision-making.

Review and Align Regulatory Frameworks: The plant should work closely with regulators to ensure compliance requirements are clear, practical, and supportive of operational risk management needs. Advocacy for flexible and adaptive policies can help reduce regulatory constraints.

Invest in Technology and Tools: Upgrading and diversifying risk management tools will support real-time monitoring, faster response, and better risk mitigation. Cybersecurity systems in particular should be prioritized given the high risks identified.

Promote a Strong Risk Management Culture: The organization should reinforce a culture of proactive risk management through leadership commitment, continuous communication, and embedding risk awareness into all operational levels.

**7. Acknowledgements**

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