International Journal of Hydrological and Environmental for Sustainability
Volume 4, Issue 1, 32-41.
e_ISSN: 2828-5050
https://www.journal.foundae.com/index.php/ijhes

Development of Comprehensive Risk Management Framework for Sustainable Solar Mini-Grid Project Implementation in Zambia

Sabita Thapa*
Department of Civil Engineering,
University of Zambia,
ZAMBIA

Balimu Mwiya
Department of Civil Engineering,
University of Zambia,
ZAMBIA

Mabvuto Mwanza
Department of Civil Engineering,
University of Zambia,
ZAMBIA

***Correspondence: E-mail:** sabitathapa442@gmail.com

Article Info

Article history:

Received: December 15, 2024
Revised: February 15, 2025
Accepted: February 20, 2025

Abstract

Solar mini-grids present a viable solution for electrifying off-grid rural and remote areas. However, their implementation and long-term sustainability encounter several challenges in most developing countries, including Zambia. This study aims to identify the risks associated with solar mini-grids in Zambia and to explore effective mitigation strategies. By adopting ISO 31000 for risk management, the research develops a comprehensive Risk Management Framework tailored to the needs of solar mini-grid projects. An inductive approach is used to investigate the key risks affecting the faster adoption and deployment of solar mini-grids in Zambia, allowing for an in-depth exploration and understanding of complex phenomena. Expert interviews serve as the primary data collection method, providing detailed insights from individuals experienced in solar mini-grid projects in Zambia. The data gathered through these interviews is analyzed using MAXDQA software, a tool for qualitative data analysis. The findings reveal a lack of a standardized and comprehensive risk management framework, with organizations relying on isolated tools such as risk registers and assessment matrices, leading to inefficiencies and sustainability challenges. Key risks identified include funding difficulties, licensing issues, technology acceptability issues, energy affordability, and system design failures leading to technical issues. The study proposes several mitigation strategies, including diversifying funding sources, streamlining regulatory processes, implementing training programs, engaging local communities, and ensuring high-quality procurement. It is recommended that a comprehensive, integrated risk management framework be established, incorporating continuous risk monitoring throughout the project lifecycle. Additionally, the research highlights the importance of capacity-building initiatives, stakeholder engagement, sustainable business models, and post-project monitoring to ensure the long-term success and resilience of solar mini-grids in Zambia.

Keywords: solar mini-grid; risk management; renewable energy; off-grid electrification; iso 31000

To cite this article: Thapa, S., Mwiya, B. and Mwanza, M. (2025). Development of Comprehensive Risk Management Framework for Sustainable Solar Mini-Grid Project Implementation in Zambia. *International Journal of Hydrological and Environmental for Sustainability, 4*(1), 32-41. https://doi.org/10.58524/ijhes.v4i1.572

INTRODUCTION

Construction projects, including renewable energy initiatives like solar mini-grids, are inherently risky due to internal and external factors that affect key project objectives such as cost, time, safety, and quality . Identifying risks is crucial for successful project outcomes, but methods like literature reviews, surveys, and expert interviews often rely on expert knowledge, which can be challenging for novel projects with limited historical data, such as renewable energy projects in Zambia. The feasibility of renewable energy projects must be assessed based on available resources, and risk management should be a continuous process throughout the project lifecycle.

Despite global advancements in renewable energy (RE) projects, such as wind, solar, and biomass, many continue to face significant financial, technological, organizational, legal, and regional risks. Countries like Azerbaijan, Canada, China, and India have developed risk management frameworks to address these challenges, improving project viability and sustainability. In Zambia, solar mini-grids, though promising for rural energy access, face technical, financial, regulatory, and socio-environmental risks (Kasayanond et al., 2019). However, the focus in Zambia has been on larger-scale infrastructure projects, creating a gap in tailored risk management frameworks for solar mini-grids. This lack of structure hampers stakeholders' ability to effectively manage risks, leading to delays and cost overruns. This research aims to develop a comprehensive risk management framework for solar mini-grid projects in Zambia to ensure successful implementation and sustainable growth in renewable energy.

Risk management plays a critical role in understanding and addressing risks across various sectors like finance, healthcare, transportation, and energy. It involves both assessing risks tied to specific activities and conducting broader research on risk concepts, frameworks, and models (Aven, 2015). ISO 31000 (2009) defines risk as the effect of uncertainties on objectives, and risk management as a coordinated effort to manage these uncertainties. The process is proactive and aims to minimize negative outcomes while enhancing the potential for positive events, involving stages such as planning, identification, analysis, response, and monitoring (Flanagan & Norman, 1993; Tembo & Khatleli, 2016).

Key principles outlined in ISO 31000 emphasize a structured and transparent approach to risk management, tailored to specific contexts, and incorporating uncertainty management. The stages-identification, analysis, evaluation, and treatment—form the backbone of a comprehensive risk management process. Communication and consultation are integral, ensuring a dynamic and iterative process that adapts to changes (ISO 31000, 2009).

Risk management standards have evolved to help organizations effectively manage risks across various sectors. The first risk-related standard, Norsk Standard NS5814:1991, focused solely on risk analysis, and over time, standards have expanded to address the full risk management process. Key risk management standards offer comprehensive guidelines for addressing various types of risks across different sectors. ISO 31000 provides a global framework for identifying, evaluating, and treating risks. COSO ERM integrates risk management into business strategy, while NIST SP 800-30 focuses on information security risk assessment and mitigation. PMI-RMP certifies project managers in risk planning, identification, and response, and OSHA 1910.119 offers process safety management guidelines for industries handling hazardous chemicals. Together, these standards cover a broad range of risk management practices, ensuring effective risk handling in diverse environments.

These standards help organizations tailor their risk management processes according to their specific needs, ensuring risks are managed consistently and effectively. Overall, these standards provide a framework for managing risks and ensuring sustainability in various industries, including Zambia's energy sector. Zambia faces significant energy challenges, particularly due to droughts affecting hydropower generation and limited access to electricity in rural areas. The Zambian government has identified solar energy as a promising solution to diversify the energy mix and reduce reliance on hydropower. This move is crucial for ensuring sustainable development, addressing energy deficits, and promoting energy security across Zambia and the broader Sub-Saharan Africa region (Bowa et al., 2017).

Zambia's energy resources include hydropower, petroleum, coal, biomass, and renewable energy. Hydropower is the dominant source, contributing 83% of the total installed capacity of 3,356.6 MW, with coal (9%), heavy fuel oil (5%), and solar (3%) as additional sources. The mining sector is the largest energy consumer, followed by domestic use (Ministry of Energy, 2022). Despite these resources, only 45% of urban areas and 3% of rural areas have access to electricity, with ambitious targets to reach 90% in urban areas and 51% in rural areas by 2030 (Ndhlukula et al., 2015).

Renewable energy (solar, wind, biomass, and geothermal) presents opportunities for sustainable development, with Zambia benefiting from significant solar potential. The country receives 1,600–1,800 kWh/kWp annually with average peak sunshine hours between 5hrs to 8hrs per day (Mwanza & Ulgen, 2021) , with favorable solar production, especially in the southwest and around Lake Bangweulu. Solar energy prices have decreased, spurring Zambia's push to diversify its energy sources, including the World Bank's Scaling Solar program, which has led to the installation of utility-scale solar plants in Lusaka (GIZ, 2024).

However, rural areas, where more than half of the population resides, continue to lack access to electricity. Over 600 million people in Africa face similar challenges. Solar mini-grids (SMGs) are seen as a viable solution to provide electricity to underserved rural communities. For example, a private company called Engie Power Corner Zambia has plans to deploy about 60 mini-grid solar project around Zambia (Mpanga, et al., 2021). Currently, several SMGs have been developed by both private companies such as Engie Power Corner Zambia and Zambia's Rural Electrification Authority (REA), which aims to achieve universal rural electrification by 2030. Despite recent progress, only 5% of rural areas have access to grid power, while 7% rely on solar energy. In 2023, Zambia's solar generation capacity increased by 37.4%, highlighting a growing commitment to renewable energy (ERB, 2023).

Some of the key risks face by renewable energy projects are listed below:

- Financial Risks: Investment, financing, profitability, and credit availability are major concerns, especially in regions like Zambia where limited financial resources and partnerships with local banks hinder project development (Petrova et al., 2019; Shyu, 2022).
- Technical Risks: Challenges in operation, maintenance, product quality, and technical expertise are common across renewable energy sectors, with factors like lack of qualified personnel and ineffective after-sales services impacting long-term success (Goh et al., 2014; Rangnath, 2022).
- Political and Social Barriers: Political instability, regulatory changes, and social perceptions about renewable technologies, including Solar Home Systems, can severely affect project outcomes (Shyu, 2022). Political risks and social acceptance are particularly crucial in developing regions.
- Economic and Environmental Risks: Fluctuations in commodity prices, resource availability, and environmental impacts contribute to project uncertainty (Michelez et al., 2011).

Some of the risks associated with mini-grid operations are: price variability, non-payment of bills, and construction delays (Manetsgruber et al., 2018). In Zambia, solar mini-grids have struggled with financial and technical sustainability challenges (Kapole et al., 2023). For successful implementation of renewable energy projects, especially in developing countries requires a systematic risks management approach, considering political, economic, technical, and social factors to overcome barriers and attract investment, ensuring the sustainability of these solar mini-grid in Zambia and globally. Therefore, this study also aimed to identify the various risks associated with solar mini-grid projects and investments in Zambia so that a comprehensive framework for RM can be developed for attracting future RE and particularly solar mini-grid operation.

METHOD

Qualitative research was conducted using an inductive research approach. This approach is suited for exploring decision-making processes and risk management in solar mini-grid (SMG) projects, where theories are built from the data itself without predefined frameworks. This research is designed to uncover motivations, explore existing frameworks, and identify patterns in SMG risk management.

This methodology is designed to provide comprehensive insights into risk management practices in Zambia's SMG sector, ensuring that the proposed framework addresses real-world challenges based on expert input and empirical data.

Data Collection

Data was collected using primary and secondary data collection methods. For primary data : Expert opinion was gathered. Meanwhile, secondary data was collected through systematic review of the published documents and documents analysis from various project documents and policy documents where available. Experts Opinion was the major primary data collection tool. An interview guide was used to interview experts from the solar mini-grid and risk management sectors. These experts were selected based on their experience and involvement in the development and operation of SMG projects in Zambia.

The interviews focused on understanding the risks associated with SMGs, how they are being managed, and the current frameworks or standards in use. These interviews provided in-depth insights into practical aspects of risk management, challenges faced in the field, and the lessons learned from past projects. Interviews were either in-person or via video conferencing and were recorded (with consent) for later transcription and analysis. These methods allowed the researchers to gather both primary data (from experts) and secondary data (from literature and documents) to comprehensively understand risk management practices in solar mini-grid projects in Zambia.

Data Analysis

Thematic analysis was the primary method used to analyze the data collected from the expert interviews, document analysis, and systematic review. Thematic analysis involves identifying, analyzing, and reporting patterns (or themes) within the data. This method helped to categorize the different types of risks, risk management practices, and frameworks associated with solar mini-grid projects in Zambia. MAXQDA software was utilized to assist in organizing and analyzing the qualitative data.

RESULTS AND DISCUSSION

Solar Mini-Grid Projects Risks

The research identified 18 significant risks associated with solar mini-grids in Zambia, categorized into six major groups: Financial Risks, Regulatory Risks, Technical Risks, Social Risks, Environmental Risks, and Operation and Maintenance Risks. The details of these risks are listed in **Table 1**. These categories align closely with risks identified in previous studies of renewable energy projects, such as those by Mohamed et al. (2019) in India and Michelez et al. (2011). The risks uncovered in this study—such as technology acceptability, long payback periods, waste disposal, theft, and shortage of skilled technician—are consistent with the findings of previous literature on renewable energy projects, further confirming their relevance.

Table 1. The List of Risks Inherent in Solar Mini-Grid Projects

1	**Financial Risks**	**5**	**Environmental Risks**
	a. Challenges in Securing Funds		a. Ecological impact from construction activities
	b. Challenges in reaching Break-Even		b. Solid waste disposal
	c. Energy Affordability	**6**	**Operation and Maintenance Risks**
2	**Regulatory Risks**		a. Security Vulnerability
	a. Licensing Challenges		b. Unauthorized Connection
	b. Delays Due to Compliance		c. Maintenance Delays
	c. Costly process of Compliance		d. Lack of Skilled Technicians
3	**Technical Risks**		e. Lack of Business Model
	a. System Design Failure		
	b. Lack of technical Expertise		
4	**Social Risks**		
	a. Technology Acceptability		
	b. Local Mindset		
	c. Land Issue		

However, this study is unique in focusing specifically on solar mini-grid projects in Zambia, revealing four risks not previously highlighted: system design failure, lack of a sustainable business model, difficulty in securing funding, and unauthorized connections. These risks appear to be particular to the Zambian context, with its unique regulatory and operational environment. For instance, the difficulty in securing funding may be exacerbated by the country's economic challenges and the nascent state of its renewable energy sector.

Risk Ranking

Online Analytical Hierarchy Process (AHP) was used to ranked these risks. Consistency Ratio while comparing the risks were less than 10% (CR < 0.1), to maintain the consistency of the judgment while comparing. Multicriteria comparison was done at 3 levels as shown by the **Figure 1**.

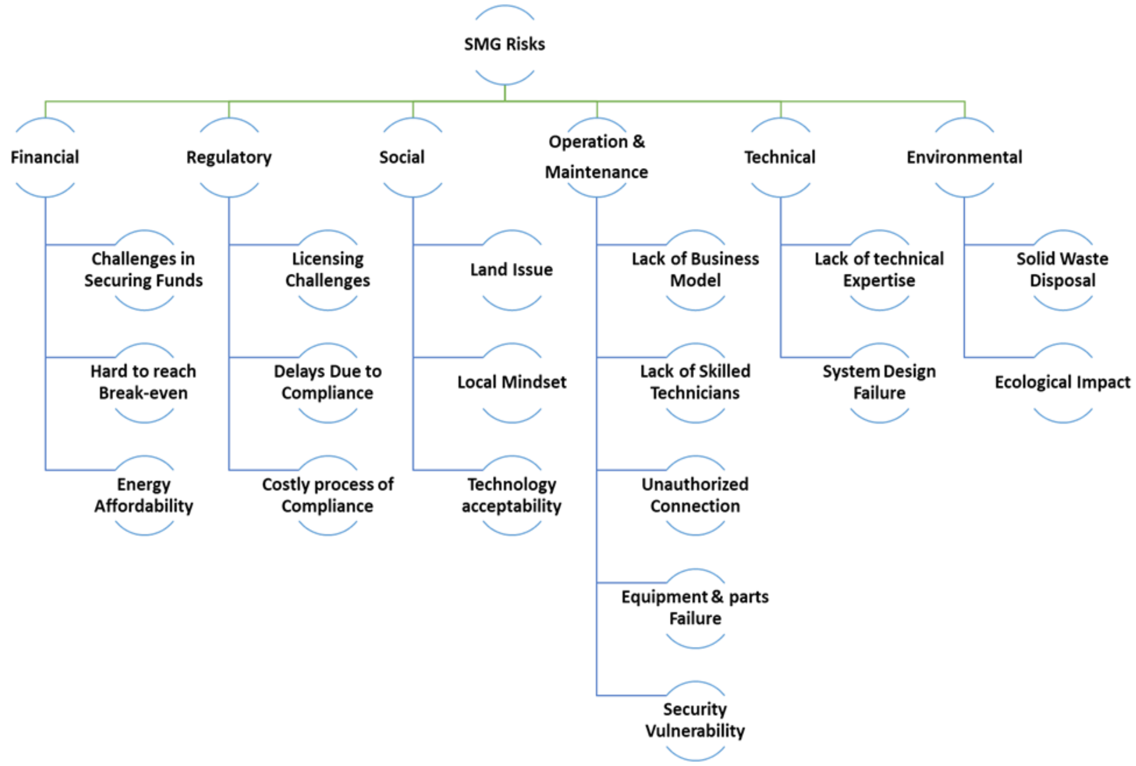

Figure 1. The AHP Risks Ranking Hierarchy

The first level of comparisons was between risks categories: Financial, social, regulatory, environmental, technical and operation and maintenance. Second level of comparisons was done using the 18 risks from each category. Finally, the alternative criteria as also used: the probability and impact of these risks in the project. the final ranking of these risks is presented in the **Table 2**.

Table 2. Ranked Risks Using AHP Decision Tool

Risks	Weightage	Ranking
Challenges in Securing Funds	14.70%	1
Licensing Challenges	12.20%	2
Costly process of Compliance	9.40%	3
Energy Affordability	8.70%	4
Delays Due to Compliance	8.70%	5
Ecological Impact	5.20%	6
Solid Waste Disposal	5.20%	7
System Design Failure	4.90%	8
Lack of technical Expertise	4.90%	9
Lack of Business Model	4.80%	10
Technology acceptability	4.20%	11
Hard to reach Break-Even	4.10%	12

Land Issue	3.60%	13
Local Mindset	3.20%	14
Lack of Skilled Technicians	1.80%	15
Equipment and Parts failure	1.60%	16
Security Vulnerability	1.50%	17
Unauthorized Connection	1.50%	18

Risk Mitigation Strategies

Several mitigation strategies were proposed by experts to address the identified risks. These strategies ranged from proven approaches to novel suggestions tailored to Zambia's context. Some of the key strategies included:

- *Hiring skilled technicians;* to prevent system design failure by ensuring proper design and installation of solar mini-grid systems.
- *Stakeholder engagement;* community meetings to address social acceptability and mindset challenges, which are crucial in rural areas.
- *Use of certified, high-quality equipment* and the establishment of a solid Standard *Maintenance Program (SMP)* to minimize operation and maintenance risks.

These strategies resonate with approaches found in other countries, such as the work by Rangnath (2022) in India. However, the issue of land acquisition, which involves traditional leaders in Zambia, contrasts with suggestions in India to use alternative spaces such as rooftops or canal tops due to a scarcity of land. Despite the similarities in mitigation strategies between Zambia and other countries, the land issue in Zambia underscores the necessity of a tailored approach that takes into account local governance and customary land rights. Engaging traditional leaders early in the project development process appears crucial in overcoming this challenge.

Solar Mini-Grid Project Risk Management Practices

The research revealed that risk management practices in Zambia's solar mini-grid sector are generally underdeveloped. Most institutions lack dedicated resources and expertise for comprehensive risk management planning. Some organizations have attempted to use tools like risk matrices, but these are often applied in isolation or without the necessary depth.

- *Risk Identification:* Institutions in Zambia often rely on ad-hoc methods like brainstorming, expert interviews, and Google searches to identify risks. Due to the novelty of the solar mini-grid projects and the lack of a central database, this informal approach may lead to overlooked or poorly understood risks.
- *Risk Assessment:* Zambia's solar mini-grid sector predominantly uses simple risk assessment techniques, such as a 5x5 risk matrix, which combines qualitative descriptions and numerical rankings. This approach is practical but may not capture the full complexity of the risks involved. More advanced techniques, such as Monte Carlo simulations and HAZOP, are mentioned in the literature but were not widely adopted due to their complexity and the lack of specialist knowledge.
- *Risk Mitigation and Monitoring:* The risk register is an essential tool for continuous risk monitoring in Zambia, helping track and update the risks and their mitigation plans. However, many institutions still overlook the importance of ongoing risk monitoring, often addressing risks only when they manifest. There is a clear need for a more systematic and proactive risk management approach.

Risk Management Framework Needs

A recurring theme throughout the research is the necessity for a comprehensive risk management framework tailored to solar mini-grid projects in Zambia. Experts agree that such a framework would facilitate better identification, allocation, and mitigation of risks throughout the lifecycle of SMG projects. This need for a structured risk management approach aligns with recommendations from Menstruburg et al. (2015) and Abba et al. (2022), who advocate for an integrated and interdisciplinary approach to managing risks in renewable energy investments. The proposed framework should consider the unique characteristics of solar mini-grid projects in Zambia, particularly the socio-political environment and challenges related to land acquisition and stakeholder engagement. A framework based on established guidelines such as ISO 31000 and COSO ERM could help standardize risk management practices and improve the overall risk profile of the sector.

Risks Management Framework Development

The development of a Risk Management (RM) framework for Solar Mini-Grids (SMG) in Zambia was guided by both expert opinions and the ISO 31000 standard for risk management. The framework was designed to be comprehensive yet easy to follow, addressing the specific needs of SMG projects in Zambia while aligning with global best practices.

1. Establishing the Context: This stage involves defining the project's objectives, understanding the project's scope, and identifying stakeholders. The framework emphasizes the need for both internal and external environmental analysis, using tools like PESTEL and SWOT, to identify regulatory, economic, and cultural factors that could influence the project.
2. Development of the Risk Management Process: This phase outlines the processes for risk identification, assessment, treatment, and continuous monitoring:
   - *Risk Identification*: The study suggests holding workshops and using tools like brainstorming, Google searches, and past project data to identify risks, based on 18 risks identified in the study.
   - *Risk Assessment*: The framework promotes using qualitative risk assessment through a 5x5 risk matrix to categorize risks based on their likelihood and impact, allowing for prioritization.
   - *Risk Treatment*: Mitigation strategies were suggested, including diversifying funding, promoting stakeholder engagement, and ensuring high-quality procurement and regular maintenance. Specific strategies were proposed for financial, regulatory, technical, operational, environmental, and social risks.
   - *Monitor & Review*: Monitoring involves using tools like a risk register and conducting regular reviews to track mitigation measures and adjust strategies as needed.
3. Implementation: Successful implementation requires integrating risk management practices into all project phases, defining roles and responsibilities, and ensuring active stakeholder involvement. The framework emphasizes documenting and reporting the risk management process and providing training and capacity building to local staff to enhance the effectiveness and sustainability of SMG projects.
4. Monitoring and Reviewing of the Framework: The framework suggests continuously tracking performance through Key Performance Indicators (KPIs), such as return on investment (ROI), operational efficiency, and payback periods. Periodic reviews should be scheduled to assess the framework's effectiveness, and adjustments should be made to keep the framework relevant.
5. Continuous Improvement: Based on the findings from monitoring and review processes, the framework encourages making necessary improvements to enhance the risk management practices and ensure that the SMG projects achieve sustainable development and operational success over time.

Overall, the framework serves as a step-by-step guide for managing risks in solar mini-grid projects, with a focus on ease of use, stakeholder collaboration, and continuous improvement to ensure project success. The adoption of this framework will help mitigate risks and improve the long-term sustainability of solar mini-grids in Zambia. The framework consists of five main components, which are illustrated in **Figure 2**.

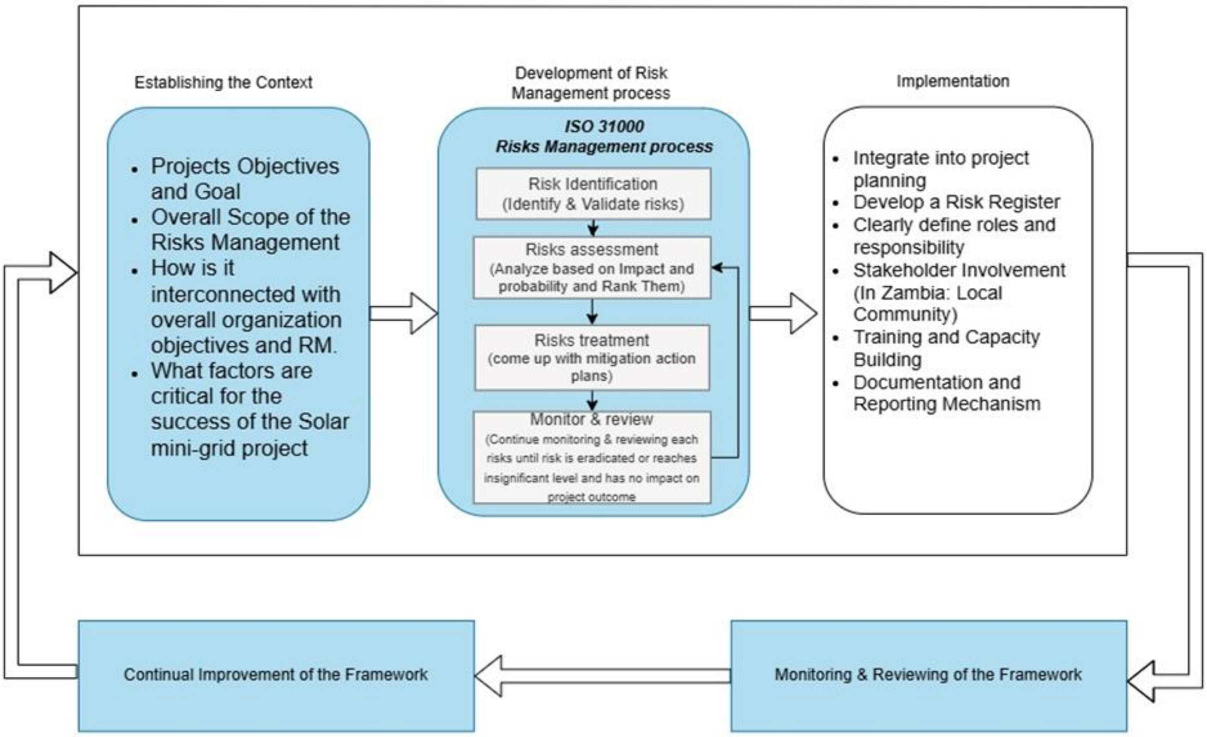

Figure 2. The Risks Management Framework for Solar Mini-Grid in Zambia.

CONCLUSION

This research aimed to explore and address the various risks associated with solar mini-grid projects in Zambia, with a focus on identifying, ranking, and mitigating these risks, as well as developing a comprehensive risk management framework. Through an extensive review of literature, expert interviews, and analysis, the study successfully met its four specific objectives:

- Identification and Categorization of Risks: The research identified 18 key risks inherent to solar mini-grid projects in Zambia, including financial, regulatory, technical, operational, environmental, and social risks. The most critical risks were challenges in securing funding, licensing issues, and high costs of compliance, which represent significant barriers to successful project implementation and long-term sustainability.
- Risk Mitigation Strategies: The study proposed a range of tailored mitigation strategies for each category of risk. These strategies emphasize proactive measures such as diversifying funding sources, improving regulatory engagement, implementing scheduled maintenance, engaging with communities, and ensuring high-quality procurement and training. These strategies are designed to address the specific challenges faced by SMG projects in Zambia and enhance their chances of success.
- Examination of Existing Risk Management Practices: The study found that while some institutions had adopted risk management strategies, there was a general lack of structured risk management practices in Zambia's solar mini-grid sector. Many organizations either overlooked risk management or lacked the necessary expertise to implement it effectively. This highlighted a significant gap in the sector's approach to managing risks.
- Development of a Comprehensive Risk Management Framework: The research culminated in the development of a comprehensive risk management framework, tailored to the unique needs of solar mini-grid projects in Zambia. This framework integrates global best practices, particularly from ISO 31000, and provides a clear, step-by-step guide for identifying, assessing, mitigating, and continuously monitoring risks. The framework is designed to be practical, accessible, and contextually relevant for local stakeholders, from project developers to regulatory bodies and local communities.

In conclusion, the findings underscore the importance of a systematic and structured approach to risk management in solar mini-grid projects. The development of the proposed framework is essential for addressing the risks identified in the study and ensuring the long-term viability and sustainability of SMG projects in Zambia. By adopting this comprehensive risk management framework, stakeholders can better navigate the challenges of implementing solar mini-grid projects, improve project outcomes, and contribute to the broader goal of expanding renewable energy access in off-grid and rural areas of Zambia. This research is essential to contributes significantly in bridging the risk management practices gap in Zambia and providing a foundation for more robust, sustainable solar mini-grid initiatives in the country. With reference to researching finding, the research, therefore recommends several actions to enhance the implementation, sustainability, and risk management of solar mini-grid projects in Zambia, and this includes:

1. Capacity Building: Invest in targeted training programs for local communities, technicians, and project managers to enhance their technical and operational skills, as well as in risk management education to ensure effective project implementation and long-term success.
2. *Integrating Risk Management into Project Planning:* Risk management should be integrated throughout the project lifecycle. Incentives, such as funding access, should encourage developers to adopt comprehensive risk management frameworks from the planning phase onward.
3. *Stakeholder Engagement:* Early and continuous involvement of key stakeholders, including local communities, regulatory bodies, and financial partners, is essential for project acceptance and success. Engaging local leaders can also reduce resistance and prevent vandalism.
4. *Project Monitoring and Evaluation:* A robust post-implementation monitoring and evaluation (M&E) system is crucial to track performance, identify challenges, and make improvements. Regular M&E will ensure the sustainability and continued success of mini-grid projects.
5. *Sustainable Business Models:* Solar mini-grid projects must develop clear, sustainable business models that outline financing, revenue generation, and operational plans. This will help ensure financial viability and long-term operational success.

These recommendations are aimed at strengthening the resilience and sustainability of solar mini-grids in Zambia, ensuring that these projects effectively meet the energy needs of the rural and remote communities while minimizing risks.

ACKNOWLEDGMENT

The author would like to thank the relevant parties who have provided support for this research. I would like to express my sincere gratitude to the following individuals and institutions for their invaluable support throughout this research. First, my heartfelt thanks go to Dr. Balimu for his expert guidance and continuous support, which were instrumental in shaping the direction of this research. I am also deeply appreciative of Dr. Mwanza for his time, encouragement, and contribution to the research process. I extend my sincere thanks to the University of Zambia for providing the necessary resources and approving this research, which made this study possible. Finally, I would like to acknowledge the various institutions and individuals who actively participated in this research. Without their cooperation and contributions, this study would not have been possible.

CONFLICTS OF INTEREST

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

REFERENCES

Abba, Z. Y. I., Balta-Ozkan, N., & Hart, P. (2022). A holistic risk management framework for renewable energy investments. *Renewable and Sustainable Energy Reviews*, 160, 112305. https://doi.org/10.1016/j.rser.2022.112305

Bowa, K.C., Mwanza, M., Sumbwanyambe, M. and Pretorius, JH. (2017). Solar Photovoltaic Energy Progress In Zambia: A Review. Southern African Universities Power Engineering Conference, pp 470-475, [online] Available at: Energy Regulation Board. "ERB 2023 ANNUAL REPORT - Energy Regulation Board." Energy Regulation Board, 2023, www.erb.org.zm/document/erb-2023-annual-report. (Accessed 31 Jan. 2025.)

Diani, R., Yuberti, & Syarlisjiswan, M. R. (2018). Web-enhanced course based on problem-based learning (PBL): Development of interactive learning media for basic physics II. *Jurnal Ilmiah Pendidikan Fisika Al-BiRuNi, 7*(1), 105–116.https://doi.org/10.24042/jipfalbiruni.v7i1.2849

GIZ (2023). Renewable Power Generation and Energy Storage Systems in the Commercial and Industrial Sector.

Goh, H.H., Lee, S.W., Chua, Q.S., Goh, K.C., Kok, B.C. and Teo, K.T.K. (2014). Renewable energy project: Project management, challenges and risk. Renewable and Sustainable Energy Reviews, [online] 38, pp.917–932. doi: https://doi.org/10.1016/j.rser.2014.07.078.

ISO 31000. (2009). Risk management — principles and guidelines n.d. https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-1:v1:en (Accessed 7 June, 2024).https://core.ac.uk/download/pdf/79171462.pdf (Accessed 26 Feb. 2024).

Kapole, F., Mudenda, S. and Jain, P. (2023). Study of major solar energy mini-grid initiatives in Zambia', *Results in Engineering*, 18, p. 101095. doi: 10.1016/j.rineng.2023.101095.

Kasayanond, A., Umam, R., & Jermsittiparsert, K. (2019). Environmental Sustainability and its Growth in Malaysia by Elaborating the Green Economy and Environmental Efficiency. International Journal of Energy Economics and Policy, 9(5), 465–473. https://doi.org/https://doi.org/10.32479/ijeep.8310

Manetsgruber, D.,Wagemann, B., Bozhil, K., Katrin, D. (2015). Risk Management For Mini-Grids A new approach to guide mini-grid deployment, Alliance for Rural Electrification (ARE).[https://www.ruralelec.org/sites/default/files/risk_management_for_mini grids_2015_final_web_0.pdf].

Michelez, J., Rossi, N., Blazquez, R., Martin, J.M., Mera, E., Christensen, D., Peineke, C., Graf, K., Lyon, D. and Stevens, G. (2011). Risk quantification and risk management in renewable energy projects. www.osti.gov. [online] Available at: https://www.osti.gov/etdeweb/biblio/21507913 (Accessed 25 Jul. 2023).

Ministry of Energy. (2022). Zambia Energy sector, Ministry of Energy. Available at: https://www.moe.gov.zm/?page_id=2198 (Accessed 25 Jul. 2023).

Mohamed, S.P.A., Firoz, N., Sadhikh, M. and Dadu, M. (2019). Risk Analysis in Implementation of Solar Energy Projects in Kerala. *Journal of Physics*: Conference Series, 1355, p.012026. doi: https://doi.org/10.1088/1742-6596/1355/1/012026.

Mpanga S., Zulu, A., Mwanza, M., & Holle, RL. (2021). Articulating the Threat of the Lightning Phenomenon in Zambia, 2021 International Conference on Electrical, Computer and Energy Technology, IEEE, pp 1-6.

Mwanza, M., & Ulgen, K. (2020). Sustainable electricity generation fuel mix analysis using an integration of multicriteria decision-making and system dynamic approach. *International Journal of Energy Research*, 44(11), 8809-8823. https://doi.org/10.1002/er.5216

Mwanza, M., & Ulgen, K., (2021), GIS-based Assessment of Solar Energy Harvesting Sites and Electricity Generation Potential in Zambia, Springer International Publishing, African Handbook of Climate Change Adaption, pp 899-946

Petrova, N., Kiteva Rogleva, N. and Fustik, V. (2019). Managing renewable energy projects including Risk Analysis', *MEST Journal*, 7(1), pp. 71–79. doi:10.12709/mest.07.07.01.10.

Rangnath, N. (2022) Project Risk Management Of Solar Power Plants. [Doctoral Dissertation].

Shyu, C.-W. (2023). Lessons from the World Bank's Solar Home System-based Rural Electrification Projects (2000–2020): Policy implications for meeting Sustainable development goal 7 by 2030', *Energy Reports*, 9, pp. 2820–2838. doi: 10.1016/j.egyr.2023.01.128.

Tembo, C.K. and Khatleli, N. (2016). Risk Management Practices on Building Projects in the Zambian Construction Industry (ZCI). In: 10th Built Environment Conference. [online] Port Elizabeth, South Africa, pp.309–320. Available at: https://www.researchgate.net/publication/341112457 (Accessed 20 Feb. 2024).