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Risk Management Approach in Solar Power Plant Projects Using the SLR Method

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ABSTRACT

Utilizing solar energy is among the renewable energy sources that are both abundant and kind to the environment. Therefore, the development of Solar Power Plants (PLTS) in Indonesia continues to grow as part of the clean energy transition and efforts to meet national renewable energy targets. However, solar power plant (PLTS) projects face various risks ranging from technical risks, resource risks, environmental risks, social and community risks, economic risks, occupational health and safety risks, to regulatory and legal risks that can hinder their success and efficiency in implementation, necessitating risk management. Structured risk management is crucial for ensuring that the solar power plant project can operate efficiently, safely, and sustainably. This research was conducted to identify the most significant risks in a solar power plant construction project using a qualitative method through a systematic literature review approach. Then, the findings from previous studies were synthesized to provide a comprehensive overview by identifying and classifying the main risks documented in the literature. This research aims to enhance the development of policies and risk management strategies for renewable energy initiatives in Indonesia

Keywords: *Solar Power Plant, Risk Management, Renewable Energy*

Introduction

The government's dedication to the promotion of New Renewable Energy (EBT) is being reflected in the accelerated development of Solar Power Plants (PLTS) in Indonesia. According to the Minister of Energy and Mineral Resources Regulation No. 13 of 2019, the objective for New Renewable Energy (EBT) usage is set at 23% by 2025, prompting numerous enterprises and organizations to initiate solar power plant projects across diverse locations [1], The escalating global demand for energy, together rising apprehensions regarding climate change and the exhaustion of fossil fuels, has propelled renewable energy sources to the front of energy policy and technological advancement. Among these sources, solar energy has emerged as a highly promising solution due to its abundant availability, technological advancements, and decreasing costs [2]. Indonesia, with its strategically located equatorial position and abundant sunlight, has great potential for the development of solar power plants [3]. However, the success of implementing solar power generation projects depends on a comprehensive understanding and effective management of the various risks involved. The conversion of solar energy into electricity through photovoltaic technology has experienced exponential growth in recent years and has become a significant contributor to electricity generation worldwide [2].

The studied that power plants have high complexity, require significant capital investment, and relatively long construction times, thus creating considerable uncertainty and risk [4]. Therefore, comprehensive risk identification becomes a crucial step in the risk management of solar power plant projects. One of the main risks in solar power plant projects is technical risk. This risk includes equipment failure, solar panel performance issues, and system integration problems. For instance, partial shadowing brought on by surrounding buildings or trees could lower solar panel performance and even cause permanent damage [5]. The development of large solar power plant projects is nott without various challenges and risks that can hinder the achievement of national targets. These risks include technical, financial, and social aspects, where improper management has the potential to cause significant losses for both the company and the country [1].

To ensure the timely completion of solar power plant projects within the set budget and performance goals, effective risk management practices must be adopted [6]. The first phase of risk management is the risk identification phase, which is designed to identify all potential hazards that could potentially impact the project. This process involves gathering information from various sources including feasibility studies, previous project experiences, and consultations with experts. Accurate and comprehensive risk identification enables the project team to develop appropriate mitigation strategies. The literature review method can be an effective approach to identifying risks in solar power plant projects. A literature review involves a systematic examination of scientific publications, industry reports, and other relevant information sources to identify risks that have been documented in previous PV project [7], [8]. This approach allows the project team to learn from the experiences of other projects and avoid making the same mistakes. Additionally, a literature review can also help identify risks that may be unique to a specific solar power project.

Several studies have identified various risks associated with solar power plant projects. These risks can be categorized into several groups, including technical risks, financial risks, environmental risks, social risks, and regulatory risks [10]. One significant risk in solar power plant projects is related to changes in regulations and government policies [11]. Government incentives for renewable energy can change, affecting the profitability of the project. Licensing and environmental approval processes can be time-consuming and costly, leading to project delays. Therefore, it is important to understand and monitor the applicable regulatory framework and its potential for change. Land and permitting-related risks can also pose significant obstacles in the development of solar power projects. The risk of regulatory and permitting changes is also a significant challenge in the development of solar power plants (PLTS), especially in developing countries like Indonesia. The investigated the significance of participatory planning in tackling the intricacies of sustainable energy challenges at the local government tier [12]. This research concentrates on the identification and evaluation of risks from the initial phases of the collaborative process to strategize the future of sustainable energy. This approach aims to reduce uncertainty and enhance transparency in decision-making related to renewable energy projects.

Additionally, another challenge is the electricity production from solar power plants, which is highly dependent on the intensity of sunlight. Therefore, adverse weather conditions, air pollution, or smoke from forest fires can significantly reduce energy output. In some areas, air pollution from motor vehicles or land fires becomes an external factor that reduces the effectiveness of solar power plants (PLTS), especially on a large scale in fire-prone regions [14]. Therefore, effective risk management is necessary to help improve the reliability and profitability of solar power plant projects [15]. Based on the above description, this research presents a systematic literature review on risk identification in solar power plant construction projects. This literature review aims to identify and classify the main risks documented in the literature, as well as to analyze the factors influencing those risks. This research is expected to yield findings that are beneficial for practitioners in the field and stakeholders in the solar power plant industry to improve project risk management and ensure the success of solar power plant projects.

Research Methods

In associated with solar power plant construction projects. Systematic literature review is a research method that is becoming increasingly relevant in the evolving information era. The use of literature review allows researchers to collect and analyze information from various relevant sources, including scientific journal articles, research reports, industry publications, and case studies, making this method a preferred choice [16]. This approach is effective for gaining a comprehensive understanding of the risks that have been identified in previous solar power plant projects, as well as the factors influencing them [7].

Inclusion and exclusion criteria are defined to guarantee that the chosen literature aligns with the research objectives. The literature comprises papers addressing risk identification, risk analysis, or risk management in the development of solar power plants. Publications irrelevant to the research topic or without adequate information on the dangers associated with solar power plant developments are eliminated from the analysis. The literature selection process is executed meticulously to guarantee the quality and pertinence of the information utilized. This research method enables the synthesis of information from diverse sources, allowing researchers to attain a thorough understanding of the topic under investigation [16], [17].

After the literature is collected, a content analysis is conducted to identify the most frequently occurring risks in solar power plant projects. These risks are then categorized into different groups, such as technical risks, financial risks, environmental risks, social risks, and regulatory risks, and the analysis results are presented in table form to facilitate understanding. The purpose of drawing conclusions and making recommendations based on the analysis and discussion is to make renewable energy projects more successful and to make solar power project risk management more effective [12].

Results and Discussion

Effective risk management is necessary in handling the complexity of power plant project implementation [13]. The results found in this study, after referencing both national and international journals, identified 7 categories of risk: technical risk, resource risk, environmental risk, social and community risk, economic risk, occupational health and safety risk, and regulatory and legal risk. Effective and efficient project management only exists when there is an awareness of risk exposure [14]. Therefore, risk identification is crucial to achieving project objectives [6]. The detailed risks present in the PV project can be seen in Table 1.

Table 1. Types of risks in solar power plants

Technical Risk	Equipment or component failure [20]
	System performance issues [21], [22]
	Risks related to design and technology selection that are not [24], [23]
Resource Risk	Delayed arrival of materials and equipment [25]
	The availability of solar energy sources [20]
	The unskilled workforce [27]
Environmental Risk	Electronic waste from solar panels [28], [29]
	Water and soil pollution during construction and operation [46], [30]
	Extreme weather occurrences and climate change [31], [32], [47]
Social and Community Risks	Rejection or opposition from the local community [11], [33]
	Disruption to traditional livelihoods [34]
Economic and Financial Risk	Increase in project costs [50], [51]
	High initial investment costs [35], [12]
	Changes in interest rates and currency exchange rates [36], [37]
	Regulatory uncertainty and government policy [38]
Occupational Health and Safety	Work accidents during construction [40]
	Electrical and fire hazards during operations [41]
Regulatory and Legal Risk	Changes in regulations and permits [12]
	Non-compliance with standards and codes [42], [43]
	Contract disputes and litigation [44]

The table shows seven different risk categories. Technical hazards in solar power plants are the potential problems or damages that affect the lifespan, reliability, and performance of the PV (Photovoltaic) system. Design, components, installation, operation, and the surrounding environment all play a role in this risk [20]. Solar power systems heavily rely on the proper operation of components. Damage to the inverter or solar panels over time can lead to a decrease in performance, thereby reducing energy efficiency. The performance of the solar power system can be affected by various factors, resulting in a decrease in power and efficiency. The degradation of PV modules over time is one of the primary causes. This degradation can be induced by a variety of factors, including corrosion, delamination, and cell injury as a result of environmental exposure. Furthermore, the efficacy of PV modules can be diminished by high temperatures. Consequently, the lifespan of the solar power system can be extended through the implementation of degradation mitigation strategies and the selection of high-quality components [5]. Furthermore, dust, dirt, pollution, and snow that builds up on the surface of solar panels can block some sunshine from reaching the solar cells, lowering the power output [22]. Design and technology decisions are critical to the success of solar power ventures [24], [23]. As a result, the reduction of these risks largely depends on the selection of the right technology and conducting regular maintenance. The use of AI technology to detect damage and assess system performance can also help optimize the efficiency and reliability of solar power plants.

The delay in the delivery of materials and equipment is one of the risks that can affect the performance of the power plant construction project [25]. The delay can be anticipated by adopting an integrated information system that monitors order progress and tracks deliveries. Additionally, clear contracts with suppliers, including provisions for late penalties, can help mitigate risks [45]. Solar power initiatives heavily depend on adequate resources. The potential resource risk is the accessibility of solar energy. The variability and uncertainty of solar irradiation can affect energy output and project profitability [25]. Solar energy exhibits seasonal fluctuations and is affected by unpredictable weather variations. Proper modeling and risk mitigation measures are crucial to overcoming these difficulties. Additionally, the shortage of skilled and experienced workers can lead to construction errors, substandard installation quality, and prolonged operational issues. The competence of the workforce is crucial to ensure the effective design, installation, and maintenance of solar power systems. In addition, appropriate training and certification programs are necessary. Therefore, resource-related risks are very important to identify and manage effectively to achieve optimal project performance [27].

Solar manufacturing enterprises fall short of national guidelines for energy use and environmental preservation [29]. Byproducts of producing polysilicon and silicon wafers create hazardous waste. Furthermore, since discarded solar panel equipment contains lead, cadmium, antimony, and sulfuric acid, improper disposal of it might contaminate the surroundings. Although solar power plants (PLTS) are an environmentally friendly renewable energy solution, their ecological impact needs to be considered. Thorough planning, biodiversity surveys, and the implementation of effective mitigation strategies can help minimize the negative impact on biodiversity and ecosystems. The potential leakage of chemicals from solar panels can result in soil and groundwater contamination, which could endanger human health and ecosystem balance [46]. Solar panels contain hazardous materials such as cadmium and lead that can contaminate the soil if the panels are damaged or not properly recycled. Additionally, the risk of water and soil pollution can arise from solar power plants. The presence of solar panels can cause changes in soil moisture distribution, potentially affecting plant growth and soil microorganism activity. Large-scale solar power plants can also raise local temperatures—a phenomena sometimes referred to as the Photovoltaic Heat Island Effect [47]. Although solar power plants help reduce global emissions, the increase in local temperatures can have negative impacts on the surrounding ecosystems and environment. The examined that the construction of solar power plants can alter vegetation structure and disrupt species migration paths, potentially reducing local biodiversity [11]. Extreme weather events such as storms, floods, and strong winds can cause damage to solar power plant infrastructure. Solar panels, inverters, and supporting structures can be damaged or destroyed by extreme weather, resulting in disruptions to energy production and significant repair costs. Elevated temperatures can diminish the efficacy of solar panels. Solar panels function most efficiently within a specific temperature range, and elevated temperatures can diminish their power output [32].

The installation of solar power systems as large-scale development projects is often opposed by local residents due to concerns about environmental or social order consequences [33]. It is important to build good communication with the community and all stakeholders in order to minimize potential conflicts. In addition, projects that provide economic benefits to residents, such as through job creation, can help reduce opposition and increase support for the project [11]. The potential leakage of chemicals from solar panels can result in soil and groundwater contamination, which could pose a threat to human health and ecosystem balance [46]. Solar panels contain hazardous materials such as cadmium and lead, which can contaminate the soil if the panels are damaged or not recycled properly. Indicates that the redistribution of soil moisture around solar power plant areas can affect hydrological processes and soil quality [49]. Additionally, the examined that the coverage of land by solar panels can reduce the soil's ability to retain water and increase soil temperature, which ultimately affects soil quality and agricultural productivity, thereby disrupting traditional livelihoods.

The increase in project costs is a significant risk in electrical infrastructure projects, including solar power plants [50]. Local governments need to ensure that residents are protected from potential future increases in electricity prices [12]. Financial risks, especially those faced by independent power producers, also play a significant role in increasing project costs [51]. Effective risk management is crucial for attracting private investment. Factors such as an unfavorable investment climate or misallocation of risk can lead to financial difficulties. The high initial investment cost (capex) often serves as the main barrier to the widespread adoption of solar power plants. This is due to the main components of solar power plants such as solar panels, inverters, batteries, as well as installation and permitting costs [12]. The large initial investment often becomes a hurdle, especially for small-scale projects or individuals with limited budgets. Nevertheless, despite the relatively high initial investment costs of solar power plants, economic feasibility analysis shows potential long-term benefits [52]. The highlights that exchange rate stability can serve as an appealing element for foreign direct investment in the renewable energy sector, so assisting in mitigating the initial investment hurdle [36]. High exchange rate fluctuations increase risks for foreign investors, which can reduce the flow of investments into solar power projects. Conversely, a stable or strengthening exchange rate can reduce currency risk and increase investor confidence in renewable energy projects. The high interest rates can lead to increased borrowing costs, which in turn can reduce the financial viability of Solar Power Plant (PLTS) projects [37]. On the other hand, lower interest rates can reduce borrowing costs and make solar power plant projects more attractive to investors.

Therefore, government policies that support macroeconomic stability, including exchange rates and interest rates, are crucial for attracting investment to the renewable energy sector. Regulatory uncertainty and government policies are significant challenges in the implementation of Solar Power Plant (PLTS) projects. The state that uncertainty in energy policies can affect investment decisions and the development of renewable energy technologies. Sudden changes in policy, such as subsidy reductions or changes in electricity tariffs, can cause investors to delay or cancel solar power projects due to uncertainty regarding long-term financial viability. Overall, regulatory uncertainty and government policies have a significant impact on the development of solar power projects. Therefore, stable, transparent, and innovation-supporting policies are needed to ensure a successful energy transition. Thus, the renewable energy sector can develop optimally, contributing to the achievement of clean energy goals and carbon emission reduction [38].

Work accidents during the construction of solar power plant projects are an important aspect that needs to be considered to ensure worker safety and project sustainability. During the construction phase, solar power plant workers are exposed to various risks, including falls from heights, being struck by materials, electrical shocks, and injuries from heavy machinery use [40]. Construction sites tend to have a high risk of accidents and fatalities due to various hazards and critical work procedures. Therefore, the implementation of strict safety measures is crucial to protect workers and prevent unwanted incidents [53]. The controls that can be implemented to reduce construction accidents through training, the use of personal protective equipment (PPE), work arrangements, and the provision of supporting facilities at the project site. The risks associated with solar power plants (PLTS) during operation include electrical hazards and potential fires. System failures, such as overheating of electrical components or short circuits, can cause fires that potentially damage infrastructure and endanger human safety. Therefore, regular inspections of each component of the solar power plant are essential to ensure optimal operation [41]. Regulatory changes may include the introduction of new standards for energy efficiency, emission regulations, or incentive policies that can affect the investment appeal in solar power projects. Additionally, the complex and prolonged licensing process can cause delays in project implementation, which in turn can result in financial losses for developers [12]. The risk of non-compliance with standards and codes in solar power plants (PLTS) can lead to various serious issues in operational practices. Although Indonesia has great solar energy potential, its implementation must adhere to applicable standards and codes [42], [43]. One example of a case study on a solar power plant fire in Bakersfield highlights the need to update electrical codes to address the higher DC system voltages common in PV systems. Therefore, standards and codes in power plants must be continuously updated in line with technological advancements. Identify the ambiguity of the scope of work clause as the main trigger for EPC contract disputes, particularly regarding the interpretation of "force majeure" and post-construction maintenance responsibilities [44]. Dispute resolution related to work contracts for the procurement and construction of Solar Power Plants (PLTS) is conducted through court mediation, in accordance with the provisions of PERMA No. 1 of 2016. This mediation process is designed to reach an agreement between the disputing parties and avoid litigation, which can be time-consuming and costly. However, if mediation is unsuccessful, the dispute can be taken to court.

Conclusion

Understanding the various risks associated with renewable energy projects, particularly Solar Power Plants (PLTS), is crucial to ensure the success of planning, implementation, and operation of the project. Risks related to technical aspects, resource risks, environmental risks, social and community risks, economic risks, occupational health and safety risks, and regulatory and legal risks must be thoroughly analyzed to reduce potential losses. Each risk category requires specific mitigation strategies, such as detailed planning, appropriate technology selection, workforce training, good communication with the surrounding community, and the use of AI technology to detect damage and assess system performance. This research needs to be further developed using qualitative risk methods and expert validation so that the highest, medium, and low risks are known. Where the highest risk in each risk category can be analysed for causes, impacts, preventive actions, and corrective actions using expert validation delphi analysis, and support from literature. Further research will focus on the highest risk mitigation that can reduce or prevent delays or cost overruns of the project. In addition, the highest risk using qualitative analysis in each risk category can be analysed for causes, impacts, preventive actions, and corrective actions, which are mitigations of the risk. We expect further research to concentrate on the highest risk that affects time and cost performance.

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