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Risk Analysis of the Solar Power Plant (SPP) Development Project at PLN *Nusantara* Power Up Gresik

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ABSTRACT

This research aims to identify, analyze, and evaluate risks in the SPP construction project and determine priority mitigation actions from the project owner's perspective. A quantitative case study approach was employed using the House of Risk (HOR) method in two phases. Data were collected through literature reviews, field observations, surveys, and discussions with project stakeholders. Initially, 32 risk variables were identified using Risk Breakdown Structure (RBS), which expanded to 44 variables after preliminary surveys. Phase 1 calculated Aggregate Risk Potential (ARP) values with Pareto analysis to prioritize risk agents. Phase 2 determined mitigation actions based on Effectiveness-to-Difficulty Ratio (ETD) calculations. Risk mapping identified six main risk events (catastrophic, political, *K3L*, materials and equipment, technology and design, and management and construction) with four high-risk and two very high-risk categories. Phase 1 analysis revealed five priority risk agents: location change (ARP 684), scope of work changes (ARP 392), contractor capabilities (ARP 376), licensing (ARP 348), and schedule changes (ARP 320). Phase 2 produced 20 mitigation actions, with 10 prioritized based on ETD values. Five key mitigation recommendations emerged: internal/external checkpoint meetings, work plan and KPI working papers, technical/regulatory standard documents, project manager selection, and technology innovation utilization. The HOR method effectively identifies and prioritizes risks and mitigation actions for SPP construction projects. The five recommended actions provide practical guidance for project management to enhance risk control and project success. This research contributes to risk management literature and offers actionable insights for similar renewable energy projects in Indonesia.

Keywords: *Solar Power Plants, Risk Management, Project Risk, Mitigation, Risk Breakdown Structure, House of Risk.*

INTRODUCTION

Based on the Law of the Republic of Indonesia number 16 of 2016 concerning the ratification of the Paris Agreement to the United Nations Framework Convention on Climate Change, it mandates the increase of bilateral and multilateral cooperation that is more effective and efficient to carry out climate change mitigation and adaptation actions with the support of funding, technology transfer, capacity building supported by transparency mechanisms and sustainable governance. Solar Power Plants or abbreviated as solar power plants are one of the technologies that have a very important role in supporting global policies.

Solar PV is a system or equipment that utilizes energy from sunlight to produce electricity. The working principle of solar power is to convert solar energy into electrical energy through a photovoltaic process by means of devices known as solar panels. Solar power is a renewable energy source that is highly environmentally friendly because it does not produce carbon emissions during operation. This technology is essential to reduce dependence on fossil fuel-based power plants and to contribute to climate change mitigation efforts in the future.

In supporting the fulfillment of the program, PLN Holding assigned PT PLN *Nusantara* Power to develop the Company's Long-Term Plan (*RJPP*) for 2022–2024, namely increasing the capacity of Solar PV (photovoltaic) plants by 225 MW. PT PLN Gresik Generation Unit was appointed as one of the sites for the development of the solar power plant project. The solar power plant project was built on vacant land within the power plant area. The business scheme related to the construction of solar power plants is for self-use substitution, which increases the efficiency of the self-use load of the power plant unit and is not a business development program that generates revenue directly. This efficiency measure is implemented to reduce electricity production costs.

This solar PV project will be implemented in 2024 in the UP Gresik area. UP Gresik is located on *Jalan* Harun Tohir No. 1, Gresik, which is in close proximity to residential and industrial areas, such that it may potentially interfere with the activities of residents and companies in the surrounding vicinity. In the UP Gresik area, there are various companies that have assets and operations at the location, such as PLN Transmission, Pertamina Gas, Pertagas, CNG Plant, UMRO, cooperatives, and other vendors related to the external and internal work of the company. The project is also likely to disrupt plant operations related to employee mobility, overhaul, dock work, and possibly even the power plant process itself. Land readiness considerations such as land status, building permits, EIA permits, and land acquisition are critical factors in implementing the project. In the area, there are also gas and fuel oil pipelines that play a critical role in plant operations.

Based on field conditions, there is potential for various operational and managerial risks that can affect the performance of the solar power plant construction project, particularly in terms of implementation timeline and project costs. In terms of time, if the implementation of the project interferes with plant operations, it may cause delays that impact the project completion schedule, the company's performance, and the achievement of the company's long-term plan targets. In terms of costs, delays may result in increased project costs. However, in the solar power plant construction project at UP Gresik, the cost is already in the form of a fixed budget and is fully included in the contract with the appointed vendor. Delays will nonetheless have an impact on project performance and the company's financial performance, particularly budget absorption, investment realization, and annual performance targets, as they may exceed the specified deadline. The risk management process plays a crucial role by identifying every aspect of project management, enabling potential uncertainties at each project stage to be analyzed and addressed accordingly.

Several previous studies have examined risk management in construction projects. (Adelhardt & Berneiser, 2024) analyzed risks for *agrivoltaic* projects in Sub-Saharan Africa, identifying technical, social, and environmental risks, but focused on rural *agrivoltaic* systems rather than utility-scale solar plants and did not use the House of Risk method. Qudsy, Soetjipto, and Arifin (2021) applied the House of Risk method to analyze project delay risks, successfully identifying risk agents and mitigation actions based on ARP calculations, but their research was limited to delay risks and did not address the full spectrum of risks relevant to power plant construction. Fahlevi, Safaria, and Susetyaningsih (2019) analyzed construction project risks using probability-impact matrix analysis, but did not provide a systematic method for determining mitigation priorities based on effectiveness and ease of implementation.

Several gaps remain unaddressed. First, no previous studies have specifically focused on solar power plant development projects in Indonesian state-owned enterprises, particularly in power generation units with complex operational environments involving gas pipelines and industrial activities. Second, existing research has not comprehensively applied the two-phase

House of Risk method to both identify priority risk agents and determine effective mitigation actions tailored to solar PV projects in power plant settings. Third, previous studies have not integrated the Risk Breakdown Structure framework with the House of Risk method to systematically analyze risks across multiple dimensions (catastrophic, political, *K3L*, material, technological, and managerial). Fourth, there is a lack of research providing actionable mitigation recommendations based on the Effectiveness-to-Difficulty Ratio calculation, which balances effectiveness with ease of implementation.

This study offers unique contributions by applying the two-phase House of Risk method to a solar power plant project at PLN *Nusantara* Power UP Gresik, integrating the Risk Breakdown Structure to categorize 44 risk variables across six risk events, and combining Pareto analysis with ARP calculations to identify the most critical 20% of risk agents. The research produces 10 priority mitigation actions ranked by ETD values and provides five key mitigation recommendations tailored to the Indonesian state-owned enterprise context, filling a critical gap in both academic literature and practical project management in the renewable energy sector.

The risk management process must be implemented and applied at each project stage. During the planning and implementation phases, different risks arise, each requiring distinct treatment activities. The risk management process in the project focuses on communication, consultation, determination of scope and criteria, risk assessment, risk treatment, recording, and monitoring. Risk calculation is based on the likelihood of occurrence and the magnitude of impact produced.

The risk value obtained is measured using a risk matrix. Based on previous research, there are various methods for conducting risk analysis, such as the Probability-Impact Matrix, which is used to determine the risk level of causative factors and their impacts. The FTA (Fault Tree Analysis) and ETA (Event Tree Analysis) methods are also employed in assessing the likelihood and impact within a project. Some of the existing methods have facilitated risk-level assessment but still lack systematic approaches for determining mitigation strategies for identified causes or impacts.

Risk mitigation is essential as it constitutes a responsive treatment to the causes and impacts of identified risks. The HOR (House of Risk) method is one of the most suitable methods for project risk analysis because it has the ability to determine the level of risk and identify appropriate mitigation actions for each cause and impact. This method consists of two phases with a semi-quantitative model to identify which risks and mitigation actions should be prioritized in a project.

This study formulates three main problems in the Solar Power Plant development project at UP Gresik, namely: (1) what risks affect the implementation of the project, (2) the causes, probabilities, and impacts of these risks, and (3) risk handling for control and mitigation with the aim of analyzing all three in depth from the perspective of the project owner (PT PLN *Nusantara* Power) at the preparation and implementation stages, without discussing financial risks due to the nature of the project as an electricity production efficiency program (not revenue development). This research benefits both companies and vendors by providing a risk reference and control-mitigation action guidance, keeping the analysis focused.

METHOD

This study employed a quantitative research design with a case study approach to analyze the risks associated with the Solar Power Plant (SPP) construction project at PLN Nusantara Power UP Gresik. The quantitative approach was chosen to enable systematic measurement and prioritization of risks based on numerical data from expert assessments, while the case study approach allows for an in-depth investigation of the specific context and unique characteristics of the project. The research design is descriptive and evaluative, aiming to identify, analyze, and evaluate project risks as well as determine appropriate mitigation actions.

Data Collection Methods

Based on the general theory of data collection, information is gathered through preliminary studies. Preliminary studies can be conducted by determining who to contact, what to observe, and what topics to research. Data objects can take the form of literature, books, journals, written documents, web-based sources, individuals, or locations. Data collection can be carried out through document review, questionnaire distribution, interviews, and observations (Hikmawati, 2020).

Document review, or documentation-based data collection, is conducted by reading books, laws and regulations, and daily meeting records. Document review can be performed by retrieving data directly from the subject to be analyzed or by compiling a list of required variables.

Questionnaires were administered by providing a set of written questions to obtain information from respondents regarding the subject of analysis. The questionnaire format can be adapted to the needs of the sample, employing multiple-choice items, checklists, or rating scales.

Interviews are conducted through direct dialogue to obtain information. Under current conditions, interviews can be held face-to-face or remotely via platforms such as WhatsApp, Telegram, Zoom, or similar applications. The questions posed can be structured or unstructured. Responses provided by the subjects are used as data for analysis.

Observation plays an important role in data collection, enabling researchers to obtain accurate and comprehensive data and information. Observations are conducted directly in the field to gain a holistic understanding of the data, providing a firsthand view uninfluenced by preconceived notions, capturing information not obtained during interviews, and allowing the identification of variables not previously mapped.

Research Objects and Respondents

The solar PV project at UP Gresik involves both Owners and Contractors. The owner of the solar power plant construction project is responsible for executing the solar PV program assigned by PLN Holding to PLN *Nusantara* Power, encompassing documentation, design planning, procurement of goods and services, and field supervision, while the contractor role is assigned to a third party, namely PLN *Nusantara* Power Construction, which is responsible for physically constructing the solar power project. On the owner's side, the PLN NP Project Management Division serves as the work director, the PLN NP Technology Development Division oversees design supervision, the PLN NP Procurement Division manages the procurement of goods and services, and the PLN NP Project Implementation Unit serves as the field director.

The Project Management Division comprises three sub-divisions: pre-construction, construction control, and the project management office. The pre-construction sub-division is responsible for planning, implementing, developing, and evaluating construction permits, as well as land provision and acquisition. The construction control sub-division oversees the planning, implementation, development, and evaluation of construction control activities, including project QA/QC, contract management, project completion, and the resolution of strategic issues during the construction process. The project management office sub-division handles the planning, implementation, development, and evaluation of construction administration and project documentation, including project management, review of construction execution, and the resolution of all project issues that impede project implementation.

The Procurement Division is responsible for planning all procurement activities related to goods and services for the solar PV project. The Technology Development Division oversees the planning and supervision of solar PV design. The PLN Project Implementation Unit serves as the field supervisor.

Figure 1. Location of the Solar Power Project

Source: PT PLN Nusantara Power UP Gresik Field Documentation (2024)

UP Gresik acts as the asset owner for the solar power plant and as a supervisor in design planning. At UP Gresik, a dedicated support team is assigned to the solar power plant construction project, consisting of *K3*, Security, Environment, Engineering, Operations, and Maintenance personnel. This research conducted a project risk analysis on the construction of solar power plants at UP Gresik from the perspective of the Solar Power Plant Project Owner, not the contractor. The location of the solar power plant construction project that serves as the research object is shown in Figure 1.

Research Stages

This section describes each stage of the research methodology as outlined in the research flowchart. Each stage is elaborated in detail to address the problem formulations established in the previous chapter.

a. Determination of Scope, Context and Criteria
   The first stage of the researcher is to conduct a literature study from books, journals, company documents related to risk management, projects, business processes, risk variables and informal and formal discussions with stakeholders. Then it is continued by looking for the purpose of the project being built, the location of the project, the business process on the project and looking for variables that are in accordance with the conditions of the project being studied. Business processes are defined in detail regarding who has a role and who is responsible for the project.
b. Risk Breakdown Structure
   The determination of risk variables is carried out after the researcher knows the objectives and business processes of the project by looking for references based on books and journals. The researcher must collect data and summarize variables that have been researched from previous researchers. The results of the summary of the variables will be compared by the researcher to the objectives of the project to be studied. The researcher will conduct discussions with related parties to add data related to variables that may appear during the interview and are not present in the previous reference.
c. Risk Measurement
   The next stage is to identify the risk of risk events and risk agents (risk agents). Initial identification was carried out using the risk breakdown structure method. The results of determining variables in the initial stage after the literature study will be carried out with a preliminary survey to validate and obtain what risks will be used as the object of the research. A preliminary survey was conducted to PT PLN *Nusantara* Power which is directly responsible for the solar power plant construction project. The preliminary survey contains relevant or non-risk-related statements from the literature study related to the solar power plant construction project and respondents can also add relevant risks if the researcher has not written them down in the previous risk variables. The results of the literature study and preliminary survey will be processed and used as risk variables to be studied in the main questionnaire.

   After a preliminary survey, a main survey will be conducted which aims to measure risks based on occurrence and impact. The calculation of probability (occurrence) was carried out using a qualitative approach which was converted to a scale of 1-5. The calculation of the impact (severity) is carried out using a qualitative approach and considers the effect on any impact and then converted to a scale of 1-5. After determining the value (occurrence) and (severity), the risk level assessment is carried out and described in the risk matrix. The risk matrix is used to find out the location of the level of risk that has been calculated based on a predetermined scale. The last step of this stage is to evaluate the risks that arise by calculating the value of the Aggregate Risk Potential (ARP) with the formula (1). The selection of risk agents is carried out using the Pareto approach (80% of problems are the result of the cause of 20%). The calculation is adjusted to the formula that has been determined with the Microsoft Excel tool. The results of the calculation are prioritized by sorting from the highest to the lowest value. The stages of this risk measurement are adjusted according to the stages of House of Risk phase 1. The output from phase 1 will be used as data input in the House of Risk phase 2.

d. Risk Treatment
   Risk Treatment is carried out in House of Risk phase 2. The risk treatment in question is to take action against the risk. This stage requires reading the literature and field observation. Field observations were carried out by brainstorming with relevant stakeholders. The results of the list of actions will be included in the House of Risk phase 2 framework. Then calculate the relationship between the risk agent and the list of actions that have been obtained with a value of 0, 1, 3 or 9. The assessment is carried out by involving related parties.
   The results of the relationship calculation (*Ejk*) are then calculated related to the total effectiveness (*TEk*) of each action with formula (2). Then measure the level of ease (*Dk*) on a scale of 1 to 5. The calculation of the level of convenience is carried out by involving related parties. After the discussion was carried out and the value of the ease level was obtained, the total effectiveness of the implementation of the action was calculated, namely Effectiveness to Difficulty of Ratio (ETDk). The result of the second House of Risk phase is to order the largest to the smallest value (ETDk) of handling actions.
e. Mitigation Recommendations and Managerial Implications
   The stage of this research is to propose a form of action that has been processed using HOR phase 1 and HOR phase 2. The recommendations used must be adjusted to the company's conditions. The results of the mitigation recommendations are expected to be as desired so that they can ensure that the project runs as desired. The form of recommendations is in the form of a structured narrative by displaying the risk variables that have been identified and described with the risk matrix and its mitigation actions.

RESULTS AND DISCUSSION

Scope, Context and Criteria

The PLTS project at PLN Nusantara Power UP Gresik is located in the golf course area and the operational area of the unit, namely the Oil Storage Tank. The project is located at the very back of the UP Gresik area with an area of ± 45,000 m2 as stated in figure 3.2. The path to the project ± 1,500 meters from the main gate by passing through operational areas such as generation areas, transmission areas, overhaul areas and office areas where many personnel carry out activities in these areas.

The solar power plant project is an assignment from PLN Holding to PLN Nusantara Power as a Sub-Holding. PLN Nusantara Power as the project implementer formed a team from within the company to carry out the project and appointed a subsidiary of PLN Nusantara Power Construction as the implementing contractor. Based on the organizational structure and job desk in chapter 3.3 related to the solar power plant construction project, we can find out who is responsible and what is done at the time of implementation.

Based on the scope and context obtained from the project, a survey related to risk agents was conducted using a google form to obtain comparative data related to the relevance of risk agent variables mapped by the author to conditions in the field. A preliminary survey was conducted on project personnel as listed in Table 1. The results obtained from the preliminary survey and interviews in the field are in the form of a risk breakdown structure as follows:

Table 1. Risk Breakdown Structure Results based on preliminary survey

Risk Number	Risk Event (Incident)	Number	Variabel (Risk Agent)	Risk status (Relevant/Irrelevant)	Remarks
E1	Risiko Catastropic	A1	Fire	Relevant	
		A2	H2 Explosion / Gas	Relevant	
		A3	Sabotage	Relevant	
		A4	Terrorists	Irrelevant	
		A5	Extreme Weather Changes	Relevant	
		A6	Demonstration	Irrelevant	
		-	Technology Failure	Relevant	New
		-	Natural Disasters (Earthquakes, Landslides, Floods, Pandemics)	Relevant	New
E2	Risk Policy	A7	Changes in Government Policy / Holding	Relevant	
		A8	Regulation	Relevant	
		A9	Licensing	Relevant	
		A10	Land Status	Relevant	
		-	Change of Leadership of the Board of Directors / Head of Unit	Relevant	New
E3	Risk K3L	A11	Work Accidents	Relevant	
		A12	Security Disturbances (Theft, Traffic Jams)	Relevant	
		A13	Environmental Problems (Waste, Logging)	Relevant	
		-	Changes to EIA, Proper	Relevant	New
		-	Security Schema Enhancement	Relevant	New
E4	Material and Equipment Risk	A14	Material Loss	Relevant	
		A15	Material Damage	Relavan	
		A16	Material not up to specification	Relevant	
		A17	Project Equipment Breakdown	Relavan	
		A18	Unit Equipment Damage	Relavan	
		-	Inadequate Laydown Area	Relavan	New
		-	Material selection errors	Relavan	New
		-	Improper material warranty handling	Relavan	New
		-	Delay in the arrival of materials/tools	Relavan	New
E5	Technology and Design Risks	A19	Design Changes	Relavan	
		A20	Incomplete Data Design	Relavan	
		A21	Ambiguity of Design Images	Relavan	
		A22	Equipment performance when commissioning is not up to the specifications	Relavan	
		-	A feasibility study that is not comprehensive	Relieves	New
		-	Approval design is inaccurate	Relieves	New
		-	Location Change	Relieves	New
E6	Management and Construction Risks	A23	Construction Methods	Relieves	
		A24	Changes in the Implementation Schedule	Relevant	
		A25	Communication between project teams	Relevant	
		A26	Communication between the Owner and the Contractor	Relevant	
		A27	Changes in Scope of Work	Relevant	
		A28	Quality Control	Relevant	
		A29	Execution Errors	Relevant	

	A30	Contractor Capabilities	Relevant	
	A31	Incomplete administration	Relevant	
	A32	Increased unit operating costs (Electricity and Water Consumption)	Irrelevant	
	-	The Procurement process is not on schedule	Relieves	New
	-	Absence of a project implementation schedule agreed in advance between the contractor and the owner	Relieves	New
	-	Lack of human resources in implementation and supervision	Relieves	New

Source: Primary Data Processed (2024)

In Table 1, it can be seen that there are 3 irrelevant risk agents, namely terrorists, demonstrations and increased operational costs (Electricity and Water Consumption) and the addition of 15 risk agents. There is no additional risk event based on a preliminary survey given to the specified personnel.

A. Risk Measurement

After conducting the main survey on the subject concerned, risk measurement is carried out based on the possibility (occurrence) and impact (severity). The calculation of probability (occurrence) was carried out using a qualitative approach which was converted to a scale of 1-5. The recapitulation of the survey results for determining the level of occurrence is presented in Table 2.

Table 2. Results Measurement of probability value (Occurrence)

Code	Risk Agent	Occurrence
A1	Fire	2
A2	H2/Gas Explosion	1
A3	Sabotage	2
A4	Extreme Weather Changes	3
A5	Technology Failure	3
A6	Natural Disasters (Earthquakes, Landslides, Floods, Pandemics)	3
A7	Changes in Government Policy / Holding	3
A8	Regulation	3
A9	Licensing	4
A10	Land Status	4
A11	Change of Leadership of the Board of Directors / Head of Unit	2
A12	Work Accidents	3
A13	Security Disturbances (Theft, Traffic Jams)	3
A14	Environmental Problems (Waste, Logging)	3
A15	Changes in the EIA and Proper	3
A16	Security Schema Enhancement	2
A17	Material Loss	3
A18	Material Damage	3
A19	Material not up to specification	2
A20	Project Equipment Breakdown	3
A21	Unit Equipment Damage	3
A22	Inadequate Laydown Area	3

A23	Material Selection Errors	3
A24	Improper material warranty handling	3
A25	Delay in arrival of materials/tools	3
A26	Design Changes	3
A27	Incomplete Data Design	3
A28	Ambiguity of Design Images	2
A29	Equipment performance when commissioning is not up to specification	3
A30	A feasibility study that is not comprehensive	4
A31	Approval design is inaccurate	3
A32	Location Change	4
A33	Construction Methods	3
A34	Changes in the Implementation Schedule	4
A35	Communication between project teams	4
A36	Communication between the Owner and the Contractor	2
A37	Changes in Scope of Work	4
A38	Quality Control	4
A39	Execution Errors	2
A40	Contractor Capabilities	4
A41	Incomplete Administration	3
A42	Procurement Process Not on Schedule	3
A43	There is no project implementation schedule agreed upon in advance between the contractor and the owner	1
A44	Lack of human resources in implementation and supervision	3

Source: Primary Data Processed (2024)

The calculation of the impact (severity) is carried out using a qualitative approach and considers the effect on any impact and then converted to a scale of 1-5. The recapitulation of the survey results for the determination of the level of impact (severity) is presented in Table 3.

Table 3. Results Measurement of impact values (Severity)

Code	Risk Event	Severity
E1	Catastropic	3
E2	Politics	4
E3	K3L	4
E4	Materials and Equipment	3
E5	Technology and Design	4
E6	Management and Construction	3

Source: Primary Data Processed (2024)

Based on the results of the calculation of occurrence and severity, a risk level mapping was carried out based on the risk matrix contained in Figure 2.3. The results of the calculation between the possibility and the impact can be seen at:

Table 4. Risk Level in Solar Power Projects in UP Gresik

Tingkat Kemungkinan		1 Tidak Signifikan	2 Minor	3 Medium	4 Signifikan	5 Sangat Signifikan
Sangat Besar	E	Moderat	Moderat	Tinggi	Sangat tinggi	Ekstrem
Besar	D	Rendah	Moderat	Tinggi (6)	Sangat tinggi (2, 5)	Ekstrem
Sedang	C	Rendah	Moderat	Tinggi (1, 4)	Tinggi (3)	Sangat tinggi
Kecil	B	Rendah	Rendah	Moderat	Tinggi	Sangat tinggi
Sangat Kecil	A	Rendah	Rendah	Moderat	Tinggi	Tinggi
		Tingkat Dampak				

Source: Primary Data Processed (2024)

Based on the results of the calculation of occurrence and impact (severity) displayed in Table 4 related to the level of risk, 4 high category risks were obtained, namely Catastrophic Risk (E1), K3L Risk (E3), Material and Equipment Risk (E4), Management and Construction Risk (E6) and 2 Very High Risks, namely Political Risk and Technology and Design Risk (E5). In conditions where the risk level is high and very high, the most appropriate risk treatment action is to reduce the possible causes and impacts of the losses caused.

Furthermore, an assessment of the relationship between risk events and risk agents is carried out using a scale that has been determined according to the stages in the House of Risk phase 1, namely (0) no relationship, (1) low relationship, (3) medium relationship and (9) high relationship. The process of providing relational value was carried out through data collection using Google Form-based survey instruments which were then strengthened through focused discussions with respondents who were directly involved in the implementation of the project. The results of the survey are then validated through a discussion process to obtain the most representative relationship value, with the most frequently emerging value approach (mode) as the final value used in the analysis. The data on the relationship between risk events and risk agents is then included in the House of Risk phase 1 working paper to calculate the Aggregate Risk Potential of each agent (j) (ARPj) in accordance with the formula in the previous chapter 2.1. The ARPj value is the result of multiplying the level of probability of occurrence of risk agent j and the overall impact of the risk event which has been multiplied by the relationship between the risk event and the risk agent. Table 4.5 is the result of data obtained from the survey and ARP calculation for all risks in the solar power plant construction project in UP Gresik. Here are the results of one of the ARP calculations:

$$ARP_j = O_j \sum_i S_i R_{ij}$$

ARP32 = (4 x {(3x9) + (4x9) + (4x9) + (3x3) + (4x9) + (3x9)})

ARP32 = (4 x (27 + 36 + 36 + 9 + 36 +27)

ARP32 = 4 x 171

ARP32 = 68

The results of the sequencing in phase one of the House of Risk were obtained by 2 risk agents who had the same priority because the Aggregate Risk Potential (ARP) value had the same value, which was 210. The risk agent is the wrong selection of materials (A23) and the handling of inappropriate material warranty (A24). Based on these results, a follow-up discussion was held with the project manager as a validation stage to prioritize risk agents who have the same value. The results of the discussion were decided to change the order of the risk agents by prioritizing the wrong selection of materials (Rank 16) and then the handling of the material warranty incorrectly (Rank 17).

The next stage is to evaluate the risk by prioritizing the risk cause or risk agent (Ai) based on the Aggregate Risk Potential value. The values of the ARP are sorted from the largest to the smallest value and then ranked to prioritize the cause of the risk. The method used in determining priorities is the Pareto principle where 80% of the problems that arise are the result of the causes that arise by 20%. The determination of the percentage was also discussed with one of the main respondents responsible for the solar power plant project in UP Gresik based on the pareto that had been made. Figure 4.1 is a pareto view of the ARP value in House of Risk phase 1.

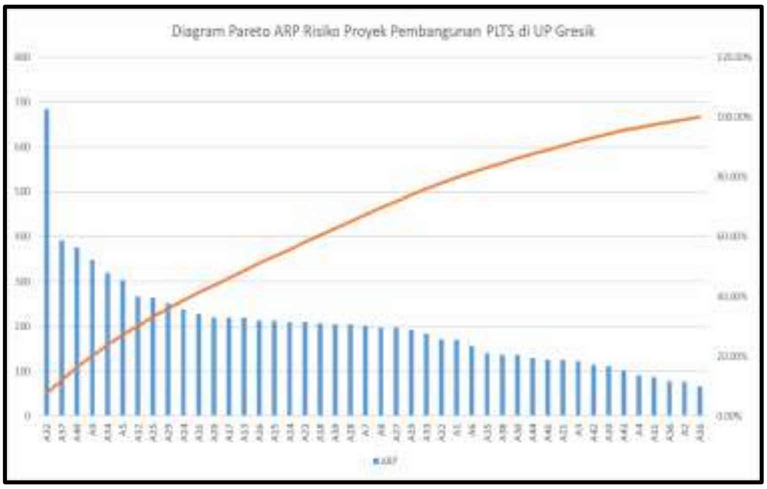

Figure 2. Pareto ARP Chart of Solar Power Plant Construction Project Risks in UP Gresik

Source: Primary Data Processed (2024)

Based on Figure 2, namely the ARP Pareto Chart of the Risk of the Solar Power Plant Development Project in UP Gresik, it can be seen that the leftmost blue bar is the highest value and the rightmost bar is the lowest value from the ARP calculation results. The orange line shows the cumulative percentage of risk causes that have been sorted based on the priority of the ARP value. Based on the pareto results that have been sorted, 20% related to the cause of the risk was chosen as a consideration in determining risk management at the House of Risk phase 2 stage. The causes of these risks are changes in location (A32), changes in the scope of work (A37), contractor capabilities (A40), permits (A9), and changes in implementation schedules (A34). Table 4.6 is a list of selected risk causes.

Table 6. ARP Calculation Results in House of Risk Phase 1

Risk Agent	Risk Causes	ARP
A32	Location Change	684
A37	Changes in Scope of Work	392
A40	Contractor Capabilities	376
A9	Licensing	348
A34	Changes in the Implementation Schedule	320

Source: Primary Data Processed (2024)

B. Risk Treatment

In risk conditions with high and very high-risk levels, the most relevant risk treatment action is to reduce the possible causes and impacts of the losses caused. There is risk treatment by transferring risk, namely using insurance services to reduce the impact, but the risk treatment approach in the research of the solar power plant construction project in UP Gresik by reducing the level of risk is more relevant because the handling actions are focused on the internal project and the company.

House of Risk Phase 2 determination of effective risk management actions based on the prioritized causes as a result of the ARP calculation in House of Risk phase 1. The first step is to identify risk management actions obtained from literature references and brainstorming with the main parties responsible for the solar power plant construction project in UP Gresik. Risk management measures are in the form of mitigation programs by considering resources such as time, budget, and labor owned by the company. The following are the risk management measures for the solar power plant construction project in UP Gresik as shown in Table 4.7.

Table 7. Risk Management Measures in Solar Power Projects

Code	Risk Handling Measures	Source
PA1	Actively communicate with external *stakeholders* (Vendors, Government and the community and others)	PMBOK 5th (2013)
PA2	Actively communicate with internal *stakeholders* (Procurement, K3, Engineering, and others)	PMBOK 7th (2021)
PA3	Appoint an experienced project leader with a leadership spirit	5th Anniversary (2013)
PA4	Create reports on each job checkpoint	5th Anniversary (2013)
PA5	Create *Key Performance Indicators* (KPIs) in each process	7th (2021)
PA6	Develop a work schedule from start to finish	5th Anniversary (2013)
PA7	Create a project information dashboard	7th (2021)
PA8	Forming and engaging an experienced internal team	Prihandono, Mahadipta and Putra (2024)
PA9	The use of technology in planning, implementation and supervision	Prihandono, Mahadipta and Putra (2024)
PA10	Conduct regular monitoring meetings	Prihandono, Mahadipta and Putra (2024)
PA11	Conducting market surveys related to the cost of procurement of goods and services	Brainstorming with the project manager

PA12	Prepare technical and non-technical requirements for the qualification of goods and services providers	Brainstorming with the project manager
PA13	Include a penalty clause in the contract of the provider of goods and services	Brainstorming with the project manager
PA14	Conducting surveys and location mapping	Brainstorming with the project manager
PA15	Mapping related to government and corporate regulations	Brainstorming with the project manager
PA16	Create detailed whitepapers	Brainstorming with the project manager
PA17	Prepare and Implement Regular Supervision and Checking Schedules	Brainstorming with the project manager
PA18	Looking for various references related to solar PV technology	Brainstorming with the project manager
PA19	Prepare Standard Operating Procedures (SOPs) for all construction work	Brainstorming with the project manager
PA20	Make a Cost & Benefit study to find out more profitable projects	Brainstorming with the project manager

Source: Primary Data Processed (2024)

The results of the identification related to risk management that have been carried out by searching literature and discussions with the person in charge of the project are then assessed the effectiveness of the implementation of risk management. The effectiveness of each action was calculated using the House of Risk phase 2 method. In HOR phase 2, the assessment of the effectiveness of each risk management action for each risk cause (*Ejk*) consists of four values, namely (0) ineffective, (1) low effectiveness, (3) moderate effectiveness and (9) high effectiveness. After filling in the level of effectiveness between the risk agent and risk management (Preventive Action), the total effectiveness (*TEk*) is calculated for each action using formula 2.2.

Then after obtaining the total effectiveness value, the difficulty level (Dk) is measured in each handling action. The difficulty level of each action uses a scale of 1 to 5. In risk management (PA10), the level of difficulty (D10) in the implementation of the action is given a scale of 2. In the final stage before prioritization, the total effectiveness of the implementation of the action, namely Effectiveness to Difficulty of Ratio (ETDk), is calculated using the formula 2.3.

The results of the calculation of the total effectiveness of the implementation of measures (ETDk) in the House of Risk Phase 2 were prioritized based on the largest to the smallest values. Table 4.8 is the result of the calculation for the effectiveness of risk management and its priorities in accordance with the House f Risk Phase 2 method.

The results of the calculation from House of Risk phase 2 were sequenced according to the total effectiveness of the implementation of the action (ETDk). The results of the calculation were obtained for 4 risk management with the same total effectiveness of action implementation (ETD). Handling these risks is to conduct routine monitoring with (PA10) an ETD value of 5136, make a report at each work checkpoint (PA4) with an ETD value of 5136, conduct a location mapping survey (PA14) with an ETD value of 2072 and include a fine clause in the contract for providing goods and services (PA13) with an ETD value of 2072. Based on the results of the discussion, a change in the order of risk management actions was obtained by prioritizing conducting regular monitoring meetings (Rank 1) then making reports at each work checkpoint (Rank 2). In the risk management action related to conducting a location mapping survey (Rank 11), it is a priority first and then includes a fine clause in the contract for providing goods and services (Rank 12). The following Table 8 is a table of risk management based on the results of the sequencing of the largest to smallest ETD values.

Table 8. Risk Handling by ETD Value

Code	Risk Handling Measures	ETDk	Ranking
PA10	Conduct regular monitoring meetings	5316.00	1
PA4	Create reports on each job checkpoint	5316.00	2
PA2	Actively communicate with internal *stakeholders* (Procurement, K3, Engineering, and others)	4356.00	3
PA17	Prepare and implement regular supervision and checking schedules	3280.00	4
PA1	Actively communicate with external *stakeholders* (Vendors, Government and the community and others)	2950.00	5
PA5	Create *Key Performance Indicators* (KPIs) in each process	2856.00	6
PA15	Mapping related to government and corporate regulations	2790.00	7
PA6	Develop a work schedule from start to finish	2528.00	8
PA3	Appoint an experienced project leader with a leadership spirit	2226.00	9
PA16	Create detailed whitepapers	2178.00	10
PA14	Conduct surveys and location mapping	2072.00	11
PA13	Include a penalty clause in the contract of the provider of goods and services	2072.00	12
PA12	Prepare technical and non-technical requirements for the qualification of prospective providers of goods and services	1994.00	13
PA8	Forming and engaging an experienced internal team	1980.00	14
PA20	Make *a Cost & Benefit* study to find out more profitable projects	1590.00	15
PA19	Prepare *Standard Operating Procedures* (SOPs) for all construction work	1432.00	16
PA9	The use of technology in planning, implementation and supervision	1416.00	17
PA7	Create *a* Project Information Dashboard	1181.33	18
PA11	Conducting market surveys related to the cost of procurement of goods and services	957.33	19
PA18	Looking for many references related to solar PV technology	886.00	20

Source: Primary Data Processed (2024)

The results of the calculation using the House of Risk method obtained recommendations for risk management actions according to the ranking with the value of the effectiveness of the largest to the smallest actions in the solar power plant construction project in UP Gresik. In this study, the greatest value of risk management measures in PA10 was obtained, namely handling actions by conducting regular monitoring meetings and the smallest value in PA18, namely looking for references related to technology in solar PV.

The results of data processing related to risk management using the House of Risk method can be used as a basis for risk mitigation measures that refer to the prioritization of the value of the effectiveness of risk management actions. Risk management measures will be able to allow reducing the level of likelihood and the level of impact. The following are recommendations for risk mitigation actions based on the calculation results:

1. The risk management action carried out is to conduct regular monitoring meetings (PA10) because it has an effectiveness value (TE) of 10632 with a difficulty level (D) of 2 so that the total effectiveness of the implementation of actions (ETD) is 5316. Handling actions are able to reduce the possibility of risk causes in changes in location (A32), changes in the scope of work (A37), contractor capabilities (A40), permits (A9), and changes in implementation schedules (A34).
2. The risk management action carried out is to make a report at each work checkpoint (PA4) because it has an effectiveness value (TE) of 10632 with a difficulty level (D) of 2 so that the total effectiveness of the implementation of actions (ETD) is 5316. Handling actions are able to reduce the possibility of risk causes in changes in location (A32), changes in the scope of work (A37), contractor capabilities (A40), permits (A9), and changes in implementation schedules (A34).
3. The risk management action carried out is to actively communicate with Internal Stakeholders (Procurement, K3, Engineering, and others) (PA2) because it has an effectiveness value (TE) of 8712 with a difficulty level (D) of 2 so that the total effectiveness of the implementation of actions (ETD) is 4356. Handling actions are able to reduce the possibility of risk causes in changes in location (A32), changes in the scope of work (A37), contractor capabilities (A40), permits (A9), and changes in implementation schedules (A34).
4. The risk management action carried out is to prepare and implement a routine supervision and checking schedule (PA17) because it has an effectiveness value (TE) of 9840 with a difficulty level (D) of 3 so that the total effectiveness of the implementation of actions (ETD) is 3280. Handling actions are able to reduce the possibility of risk causes in changes in location (A32), changes in the scope of work (A37), contractor capabilities (A40), and changes in implementation schedules (A34).
5. The risk management actions carried out are actively communicating with External Stakeholders (Vendors, Government and the community and others) (PA1) because it has an effectiveness value (TE) of 11800 with a difficulty level (D) of 4 so that the total effectiveness of the implementation of actions (ETD) is 2950. Handling actions are able to reduce the possibility of risk causes in changes in location (A32), changes in the scope of work (A37), permits (A9), and changes in implementation schedules (A34).
6. The risk management action carried out is to create Key Performance Indicators (KPIs) in each process (PA5) because it has an effectiveness value (TE) of 8568 with a difficulty level (D) of 3 so that the total effectiveness of implementing actions (ETD) is 2856. Handling actions are able to reduce the possibility of risk causes in changes in the scope of work (A37), contractor capabilities (A40), and changes in implementation schedule (A34).
7. The risk management action carried out is to make a mapping related to government and company regulations (PA15) because it has an effectiveness value (TE) of 6216 with a difficulty level (D) of 3 so that the total effectiveness of the implementation of the action (ETD) is 2072. Handling actions are able to reduce the possibility of risk causes in changes in location (A32), changes in the scope of work (A37), and permits (A9).
8. The risk management action carried out is to prepare a work schedule from start to finish (PA6) because it has an effectiveness value (TE) of 7584 with a difficulty level (D) of 3 so that the total effectiveness of the implementation of actions (ETD) is 2528. Handling actions

are able to reduce the possibility of risk causes in changes in location (A32), changes in the scope of work (A37), contractor capabilities (A40), and changes in implementation schedules (A34).

9. The risk management action carried out is to appoint an experienced project leader who has a leadership spirit (PA3) because it has an effectiveness value (TE) of 8904 with a difficulty level (D) of 4 so that the total effectiveness of the implementation of the action (ETD) is 2226. Handling actions are able to reduce the possibility of risk causes in changes in the scope of work (A37), contractor capabilities (A40), and changes in implementation schedule (A34).
10. The risk management action carried out is to make a detailed technical document (PA16) because it has an effectiveness value (TE) of 8712 with a difficulty level (D) of 4 so that the total effectiveness of the implementation of the action (ETD) is 2178. Handling actions are able to reduce the possibility of risk causes in changes in location (A32), changes in the scope of work (A37), contractor capabilities (A40), permits (A9), and changes in implementation schedules (A34).

Other handling actions can be carried out by the company by creating an experienced internal team to conduct location surveys, create and compile technical requirements for the qualifications of prospective providers of goods and services, seek information and references related to solar PV, make Standard Operational Procedures (SOP) and use and develop technology such as web base dashboards, drones and others in the process of planning, implementation, and supervision.

D. Managerial Implications

In the implementation of solar power projects, risk management has an important role in project management and runs hand in hand as an instrument of managerial control in ensuring the success of the project. Risk management identifies, analyzes and controls uncertainties that have the potential to arise and hinder project performance so as to affect the goals of project performance, especially in terms of time, cost, quality and scope. Companies in carrying out a project are required to conduct risk mapping in order to know future challenges and opportunities.

Based on research on the solar power plant construction project in UP Gresik, several main risks were obtained, namely catastrophic risk, political risk, K3L risk, material and equipment risk, technology and design risk, and management and construction risk. Risk identification and grouping is carried out by referring to the Risk Breakdown Structure (RBS) framework, so that risk sources and criteria can be analyzed systematically. Furthermore, the risk analysis and evaluation process is carried out using a risk matrix to determine the level of risk based on the level of likelihood and the level of impact that affects the performance of the project. The results of the evaluation show that there are 4 risks in the high category and the very high category, so the most appropriate treatment is to reduce the level of possibility and the level of impact. In the study, there is an alternative to risk treatment in the form of transferring risk by using insurance services to reduce the level of impact. The researcher focuses more on internal mitigation measures that are under the direct control of project management. The selection is focused on reducing the level of risk internally so that the resulting recommendations can be implemented operationally by the company without dependence on external parties.

At the risk management stage, the House of Risk (HOR) method is used to produce risk management actions based on the level of effectiveness based on the Effectiveness to Difficulty of Ratio (ETD) value. The House of Risk (HOR) approach allows project management to determine mitigation measures that are not only effective in lowering the level of risk, but also considering ease of implementation in the field.

The results of the House of Risk (HOR) identification show that the mitigation actions with the highest priority are the implementation of routine monitoring meetings (PA10) and the preparation of reports at each work checkpoint (PA4) as well as communication of internal stakeholders (PA1) and external stakeholders (PA2). Managerially, these four actions can be outlined in formal or informal communication mechanisms as project control instruments. This action to strengthen communication can increase the extent to which the work on the project is known so that it can reduce the possibility of problems that arise such as schedule deviations, licensing constraints and changes in scope. Strengthening communication also has an internal and external impact where with the improvement of internal communication across fields of work such as K3, engineering, maintenance, operations and procurement, it is hoped that when technical implementation in the field will be easier and more orderly. Strengthening communication externally is also very important, such as for vendors, communities, local governments and companies. Strengthening communication is the main element in supporting the sustainability of project implementation and effectiveness in managing risks in projects.

Project management based on research results requires strengthening the project performance system through the preparation of a structured work schedule (PA6), the implementation of supervision and inspection (PA17), and the implementation of Key Performance Indicators (KPIs). The integration of these three actions allows project management to ensure the compatibility between the project implementation plan and the relays of the existing project work in the field and provide objective performance measurement. In this case, the company allows to make working papers related to the schedule of project activities and their achievements at each stage of work. Through a routine supervision and monitoring mechanism based on performance indicators, process irregularities and implementation inconsistencies in the field can be detected early so that management can take corrective actions.

From the regulatory and technical aspects, it is necessary to carry out regulatory mapping (PA15) and the preparation of detailed technical documents (PA16) in the project. Management is required to have standardization of technical documents and compliance with regulations. Standardization of technical documents and compliance with regulations are key factors in maintaining the stability of the project scope and can reduce the level of possible design changes at the implementation stage.

In addition to system and procedure factors, human resource competence is also an aspect of success in carrying out risk management actions. The appointment of an experienced project leader with good leadership competencies (PA3) has an important role in the effectiveness of coordination between teams in the project as well as speed and accuracy in decision-making. Therefore, management needs to implement a strict selection system because it is an important part of the governance of the solar power plant development project.

The use of supporting technology is a form of innovation that can speed up administrative processes such as reporting, monitoring and can also make field checks easier using drones. The use of technology can increase the accuracy of data entering the project, speed up decision-making, transparency of project management and even increase efficiency and effectiveness of work.

The results of the research are in line with the ISO 31000:2018 framework where the risk management process has an important role in the organizational process as one of the main knowledge areas in project management according to PMBOK. Risk management shows can contribute to risk control on project technicalities and can improve the quality of governance on the project as well as overall managerial performance on the project. The House of Risk method can be used as a managerial decision-making tool in managing the risk of solar PV construction projects. The method is able to connect the causes, impacts and priorities of mitigation actions that are easy to implement on projects in the company. The results of the research are not only theoretical but can be used as a reference for practitioners in managing the risks of the construction of solar power projects.

CONCLUSION

Based on the results of research on the solar power plant construction project in UP Gresik, 6 main risks (catastrophic, political, K3L, materials and equipment, technology and design, and management and construction) were identified, with 4 high category risks (E1, E3, E4, E6) and 2 very high risks (E2, E5) based on the risk matrix; The optimal treatment is to reduce the likelihood and impact. House of Risk phase 1 analysis of 44 risk agents resulted in 5 main causes via Pareto (A32: change of location ARP 684; A37: change in the scope of ARP 392; A40: ARP 376 contractor capability; A9: ARP 348 permit; A34: changes to the ARP 320 schedule), followed by phase 2 with 20 handling actions. The ETD calculation prioritizes 10 actions, including 5 priority mitigation recommendations: internal/external checkpoint meetings, plan and KPI working papers, technical/regulatory standard documents, project manager selection, and technological innovation. For companies and researchers subsequently, it is recommended to expand the scope to multi-case studies on various solar projects or other plants to increase the representation and flexibility of risk management. In addition, integrate financial risk analysis quantitatively and systematically for a comprehensive picture of the impact on project performance.

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