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ORIGINAL RESEARCH

Risk Management in Engineering, Procurement, and Construction (EPC) Projects for Green Ammonia Using Renewable Energy

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Abstract

The government's efforts to achieve the Net Zero Emission (NZE) target by 2060 include setting near-term goals, such as the National Energy General Plan (RUEN), which aims for a 23% contribution from renewable energy in the national energy mix by 2025. As a result, companies currently relying on fossil fuel-based power plants are gradually transitioning to renewable energy sources. One example is fertilizer and petrochemical plants, which traditionally use gray ammonia derived from natural gas but are now shifting to Renewable Energy Green Ammonia (REGA), produced through electrolysis using water as the primary input and renewable energy as the utility source. These plants are developed by Engineering, Procurement, and Construction (EPC) companies within a mutually agreed timeframe between contractors and owners, making effective risk management essential to mitigate potential project delays. Statistical analysis including validity, normality, Mann-Whitney, and Spearman tests was conducted using SPSS software. The findings identify 14 dominant risk variables affecting project delays, categorized into three phases: Engineering / Design (7 risks), Procurement (3 risks), and Construction (4 risks). By implementing the recommended risk management strategies, this study aims to minimize risk impacts and serve as a practical guide for contractors in effectively managing risks in EPC projects for Renewable Energy Green Ammonia plants.

KEYWORDS:

EPC Projects, Renewable Energy Green Ammonia , Risk Mangement, Power Plant

1 | INTRODUCTION

The Indonesian government's commitment to achieving the Net Zero Emission (NZE) target by 2060 reflects a serious effort to transition toward renewable energy. One of the nearest milestones is the National General Energy Plan (Rencana Umum Energi Nasional/RUEN), which targets a 23% contribution from renewable energy to the national energy mix by 2025. In alignment

FIGURE 1 Green Ammonia Process.

with this goal, several fertilizer production plants have begun pursuing Renewable Energy Green Ammonia projects to achieve carbon neutrality and near-zero greenhouse gas (GHG) emissions. These projects are executed by Engineering, Procurement, and Construction (EPC) contractors under strict timelines mutually agreed upon with clients. To meet deadlines and avoid delays, contractors must proactively identify and address potential risks inherent in such projects particularly those specific to Renewable Energy Green Ammonia plants. Risks may emerge across various engineering stages, necessitating systematic categorization and mitigation strategies led by the Project Manager and their team. Therefore, rigorous risk management is essential to prevent project delays, which could otherwise result in financial penalties and reputational damage for the contractor.

2 | THE DATA

Green ammonia produced using renewable energy represents an emerging technology that is set to be implemented in fertilizer plants across Indonesia. As this field is still in its early stages, no specific journal or study addressing its risk management has yet been published. Therefore, the author has drawn upon theoretical frameworks and findings from various related research sources and journals as the basis for this study.

2.1 | Green Ammonia

Green ammonia is defined as ammonia produced from non-hydrocarbon feedstocks using renewable or non-hydrocarbon energy sources. One of the primary production processes involves reacting hydrogen generated through water electrolysis with nitrogen extracted from the air. The green ammonia production process is outlined as follows Figure 1 .

Green ammonia is produced using hydrogen (H_2) obtained from water electrolysis (green hydrogen), powered entirely by renewable energy sources, and nitrogen extracted from the air. The implementation of green ammonia systems is expected to eliminate CO_2 emissions, which are typically associated with conventional methods (gray ammonia) that rely on natural gas. Although green ammonia is produced through the Haber-Bosch process, its key distinction from gray ammonia and blue ammonia lies in the source of H_2, which is derived from renewable energy. The primary water electrolysis technologies for large-scale hydrogen production are based on alkaline electrolysis and polymer electrolyte membrane (PEM) electrolysis [1, 2].

2.2 | Renewable Energy

Renewable energy is derived from natural resources that are continuously replenished within a relatively short period of time. Unlike fossil fuels such as petroleum, coal, and natural gas, which take millions of years to form renewable energy draws from resources that are constantly available or rapidly restored, including sunlight, wind, water, and biomass. Several types of renewable energy sources are utilized to generate electricity, each contributing differently to the overall energy supply alongside non-renewable sources such as fossil fuels and nuclear energy. Commonly used renewable energy types include solar energy, wind, hydropower, and others. The provision and capacity of renewable energy fall under the jurisdiction of PLN, while the contractor is responsible for the integration and interconnection of these sources, designed for high voltage (HV) transmission at 150 kV. This will subsequently be distributed through the 150 kV Gas Insulated Switchgear (GIS) system covering the entire green ammonia facility. Accordingly, the required capacity for the solar power system assuming a power factor of approximately 0.8 in accordance with IEEE Std 141 is calculated as follows:

$$\begin{aligned} \mathrm{kW} &= \mathrm{kVA} \times \mathrm{PF} \\ \mathrm{kW} &= 150 \times 0.8 \\ \mathrm{kW} &= 120\ \mathrm{kW} \end{aligned}$$

The daily energy requirement, if 120 kW is the continuous demand, is:

$$120\ \mathrm{kW} \times 24\ \mathrm{Hours} = 2.880\ \mathrm{kWh} / \mathrm{Day}$$

With the assumption of 4 hours of effective sunlight (Peak Sun Hours) per day:

$$\mathrm{PLTS\ Capacity} = \frac{2.880}{4} = 720\ \mathrm{kWp}$$

Thus, the power supply for 150 kVA ~ 120 kW continuously requires approximately a PLTS capacity of 720 kWp.

2.3 | Engineering, Procurement and Construction Project (EPC)

Engineering, procurement, and construction are three essential phases that constitute the overall workflow of a construction project. In an EPC (Engineering, Procurement, and Construction) project, the project owner does not engage separate consultants or contractors for each phase instead, the entire responsibility for design, procurement, and construction is assigned to a single entity the EPC contractor. This approach enables more efficient cost management and stronger quality assurance, as all activities are carried out within one integrated management system. The overall project workflow encompassing these three phases is illustrated in the Figure 2 .

2.4 | Risk Managemenet

Risk is an inseparable element in every organization, whether in banking, industry, or project management. It is therefore essential to have management systems in place to mitigate potential risks, with the expectation that such risks can be identified and addressed by all members of the organization or project team. Several experts have offered varying definitions of risk. Risk is defined as the combination of the probability of an event and its consequences, whereby a single event may yield more than one consequence either positive or negative [3]. Alternatively, risk is described as a condition involving exposure to adversity, while risk management refers to the application of management functions in addressing risks faced by organizations, companies, families, or communities [4]. This perspective highlights the dual nature of risk: a positive effect, referred to as an opportunity, and a negative effect, referred to as a threat. The risk management process outlined in the PMBOK (Project Management Body of Knowledge) consists of several systematic steps to identify, analyze, and respond to risks throughout a project lifecycle. The stages of risk management as defined by PMBOK are as follows:

FIGURE 2 Stage of EPC.

1. **Plan Risk Management**
   The first stage aims to plan how risk management will be conducted throughout the project. This includes planning the methodology, tools to be used, required resources, and how to involve relevant stakeholders in risk management.

2. **Identify Risks**
   At this stage, the process is carried out to identify potential risks that may affect the project, both positive (opportunities) and negative (threats). Risks can be identified through various techniques such as brainstorming, interviews, and historical data analysis.

3. **Perform Qualitative Risk Analysis**
   After risks are identified, the next step is to analyze risks based on their impact and likelihood to prioritize which risks need further management. This analysis is subjective and focuses more on general understanding of the risks.

4. **Perform Quantitative Risk Analysis**
   At this stage, a more in-depth analysis is performed to measure the impact of risks quantitatively, such as calculating the probability and its effects on the project's schedule, cost, and quality. This often uses statistical techniques or simulation models like Monte Carlo.

5. **Plan Risk Responses**
   After identifying the most critical risks, this stage focuses on developing plans to reduce or take advantage of those risks. Response strategies may include risk avoidance, transfer, mitigation, or acceptance.

6. **Implement Risk Responses**
   This stage involves executing the planned risk responses, ensuring that mitigation actions or other strategies are applied as intended.

7. **Monitor Risks**
   Risk monitoring is carried out continuously throughout the project. This process includes monitoring whether identified risks have occurred, whether new risks have emerged, and whether the implemented risk responses are effective or need adjustment.

Each of these stages is essential to ensure that risks affecting the project are identified, analyzed, and managed effectively to achieve project objectives.

3 | METHOD

This study focuses on the challenges encountered in projects executed by Engineering, Procurement, and Construction (EPC) companies, particularly the delays experienced in the Renewable Energy Green Ammonia project at a petrochemical company in Indonesia. Therefore, this section elaborates on the risk management process, from identification to control, in accordance with the IEEE standards as outlined in the PMBOK (Project Management Body of Knowledge) 5th Edition. The risk management process is structured into the following stages:

3.1 | Plan Risk Management

This initial stage involves developing a comprehensive plan for conducting all aspects of risk management throughout the project lifecycle. It includes the establishment of policies and procedures for risk identification, analysis, response planning, monitoring, and reporting. Furthermore, it outlines how risk-related information will be documented and communicated to stakeholders.

3.2 | Risk Identifications

At the risk identification stage, the researcher gathers risks previously encountered in earlier EPC projects, as well as those found in relevant literature sources, such as academic journals and books. Naturally, a wide range of risks may be associated with project implementation; however, the researcher will carefully select and filter those risks that are most relevant to EPC projects. Furthermore, this risk identification stage serves as the process for collecting secondary data, which will subsequently be used as the basis for developing a questionnaire aimed at obtaining primary data in the following stages.

3.3 | Perform Qualitative Risk Analysis

The expert questionnaire is a data collection technique conducted at this stage, involving professionals with expertise in the relevant field. The content and design of the questionnaire are derived from the risk identification process carried out in the previous stage through literature review and other references. These experts will provide validation for the questionnaire to be administered. The researcher will pose questions related to potential risks that may occur and affect project timelines, including the extent to which each risk factor impacts project duration. The expert questionnaire will be distributed to three subject-matter experts. An example of the expert questionnaire design for Variable X is presented in the Table 1 - 2 .

Criteria for Expert Respondents for participating in this study as respondents for validation must meet the following criteria:

- Possess a minimum of 10 years of professional experience in their respective field.
- Hold at least a bachelor's degree (equivalent to S1) in a relevant discipline.

3.4 | Perform Quantitative Risk Analysis

In this sage, the Respondent Questionnaire will be used. This questionnaire has been previously verified and validated by experts, and serves as the basis for the questionnaire to be distributed to the respondents. The respondents are employees who have prior work experience in EPC projects, with the following criteria:

- • Currently employed by an EPC company or have previous work experience in an EPC company.
- • Have a minimum of one year of relevant work experience.

TABLE 1 Example of Expert Questionnaire Design for Variable X

No	EPC Phase	Risk Variable	Risk Code	Risk Variable Grouping According to EPC Phases		These risk variables can affect the project's time performance		Remarks (Comments / Suggestions for Improvement):
				Yes	No	Yes	No	
1	Engineering	Design changes during the project	X1					
2		…	X2					
3		…	X3					
4	Procurement	Delay in vendor quotation submission	X4					
5		…	X5					
6		…	X6					
7	Construction	Discrepancy between engineering design and on-site conditions	X7					
8		…	X8					
9		…	X9					

TABLE 2 Example of Expert Questionnaire Design for Variable Y

Scale	Time Performance Level	Criteria	Do you agree that the range above accurately represents the definition of project time performance?		Remarks (Comments / Suggestions for Improvement):
			Yes	No	
1	Poor	Delayed by more than 16% or more than 8 weeks			
2	Slightly Delayed	Delayed between 8% and 16%, or between 4 to 8 weeks			
3	Average	Delayed by up to 8% or delayed up to 4 weeks or less			
4	Slightly Ahead	Early by 0%–4%, or on time to up to 2 weeks ahead of schedule			
5	Good	Early by more than 4%, or more than 2 weeks ahead of schedule			

Respondents are expected to have a thorough understanding of the questionnaire provided and to assess both the likelihood of each identified risk occurring and its potential impact on the timeliness of EPC project execution specifically, whether such risks would result in project delays or, conversely, contribute to improved schedule performance. A sample of the respondent questionnaire is presented in the Table 3 - 4 .

TABLE 3 Example of Responden Questionnaire Design for Variable X

No	EPC Phase	Risk Variable	Risk Code	Risk Frequency Scale					Risk Impact Scale on Schedule				
				1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
1	Engineering	Design changes during the project	X1										
2		…	X2										
3		…	X3										
4	Procurement	Delay in vendor quotation submission	X4										
5		…	X5										
6		…	X6										
7	Construction	Discrepancy between engineering design and on-site conditions	X7										
8		…	X8										
9		…	X9										

TABLE 4 Example of Responden Questionnaire Design for Variable Y

Scale	Time Performance Level	Criteria	Remarks
1	Poor	Delayed by more than 16% or more than 8 weeks	
2	Slightly Delayed	Delayed between 8% and 16%, or between 4 to 8 weeks	
3	Average	Delayed by up to 8% or delayed up to 4 weeks or less	
4	Slightly Ahead	Early by 0%–4%, or on time to up to 2 weeks ahead of schedule	
5	Good	Early by more than 4%, or more than 2 weeks ahead of schedule	

TABLE 5 Risk Frequency Scale

Scale	Description	Explanation
1	Very Low	Rarely occurs, only under specific conditions
2	Low	Occasionally occurs under certain conditions
3	Moderate	Occurs under certain conditions
4	High	Frequently occurs under most conditions
5	Very High	Almost always occurs under any condition

In the Variable Y questionnaire, respondents evaluate project time performance using a predefined scale, where a score of 1 indicates severely poor performance specifically, a delay of more than two months while a score of 5 indicates that the project was completed ahead of schedule by more than two weeks. For each risk identified in the questionnaire, respondents are required to assign both a frequency scale based on Table 5 and a time impact scale based on Table 6 . The weighting criteria for the risk frequency scale are presented in the Table 5 .

In the Risk Frequency Scale, respondents are asked to rate each identified risk using a weighted scale ranging from 1 to 5, where a score of 1 represents a very low frequency indicating that the risk rarely occurs and a score of 5 represents a very high frequency, indicating that the risk occurs almost always under any condition. The scale for the impact of risks on project time performance can be seen in the Table 6 .

TABLE 6 Impact Scale on Time

Scale	Description	Explanation
1	Very Low	No impact on the schedule
2	Low	Schedule delay of less than 5%
3	Moderate	Schedule delay between 5% and 7%
4	High	Schedule delay between 7% and 10%
5	Very High	Schedule delay of more than 10%

In the Impact Scale on Time, respondents are asked to rate each identified risk using a weighted scale ranging from 1 to 5, where a score of 1 represents a very low impact indicating no effect on the project schedule and a score of 5 represents a very high impact, indicating that the risk causes a schedule delay of more than 10%.

3.5 | Plan Risk Responses

Based on the outcomes of both qualitative and quantitative analyses, appropriate risk response strategies are developed for each significant risk. These strategies encompass measures to avoid, mitigate, transfer, or accept risks, with the overarching goal of minimizing the negative impact of threats while maximizing the potential benefits of opportunities thereby ensuring the project remains on track toward its objectives.

3.6 | Control Risks

In this final stage, continuous monitoring and reassessment of identified risks are conducted to evaluate the effectiveness of the implemented response strategies. Risk control encompasses the identification of new risks, the tracking of existing risks, and the refinement of response plans as necessary. The aim is to proactively manage residual risks and ensure that any adverse effects on the project are minimized through appropriate control measures.

4 | RESULT AND DISCUSSION

4.1 | Risk Identification

The results of the risk variables collected by the researcher, related to the factors contributing to delays in the construction of EPC projects in the Green Ammonia project, are presented in Table 7 . These include 65 risk factor variables.

4.2 | Expert Questionnaire and Validation

The risk variables identified by the author were shared with seven experts for assessment, focusing on the structure and content of the questionnaire to be distributed to respondents. Based on the results of the expert review for Variable X, 15 risk variables were eliminated on the grounds that they were not considered to significantly contribute to delays in EPC projects for Green Ammonia. Among the reasons for exclusion was the finding that certain risk variables unexpectedly fall within the EPC Pre-Proposal Phase, such as variables X4, X8, and X62. The excluded variables are as follows: X3, X4, X8, X11, X16, X19, X20, X26, X32, X40, X41, X50, X51, X53, and X62. Consequently, 50 risk variables remained after the validation process and will be carried forward to the next stage of analysis. With regard to Variable Y, no additional inputs or comments were received from the experts. Therefore, the items listed under Variable Y in Table will serve as the reference framework for classifying project delays in the EPC Green Ammonia project and will be distributed to the broader respondent group. Following the expert validation process, a pilot survey will be conducted. The purpose of this pilot survey is to verify that the questionnaire is clearly understood by respondents and to assess the extent to which each identified risk contributes to delays in the Renewable Energy Green Ammonia EPC project.

TABLE 7 Risk Identification

No	EPC Phase	Risk Description	No	EPC Phase	Risk Description
X1	Engineering	Frequent design changes	X34	Engineering	Engineering design difficult for vendors to understand
X2		Delays in document submission	X35		Some materials sourced from overseas
X3		Insufficient data from the owner	X36		Complexity delay in receiving vendor quotation
X4		Lack of experience with relevant technology	X37		Specification discrepancies in vendor proposals to contractors
X5		Client requests design work beyond the original scope	X38		Need for experienced local technicians
X6		Delayed client feedback after contractor document submission	X39		Necessity for over-ordering due to uncertainties
X7		Re-design due to construction errors	X40		Client mandates use of preferred vendors
X8		Limited technical data or field information	X41		Local contractor requirements necessitating strategy adjustments
X9		Poor inter-discipline integration causing asynchrony	X42		Additional costs for importing goods
X10		Software license limited to one user at a time	X43		Client requests for FAT (Factory Acceptance Test) at original manufacturing site
X11		High design complexity	X44		Special materials or equipment requiring testing and certification
X12		Difficult access hindering design implementation	X45		Local requirements forcing contractors to adjust their strategies
X13		Inconsistencies between specifications and drawings	X46	Construction	Delays in material delivery
X14		Infeasible design to accommodate potential project needs	X47		Community protests or demonstrations
X15		Changes in engineering standards during the engineering phase	X48		Mismatch between engineering documents and actual field conditions
X16		Potential energy requirements exceeding estimates	X49		Subcontractor strikes
X17		Delays in document review (3D or P&ID) during preliminary phase	X50		Difficult site access impacting material transport
X18		Frequent changes from client or owner	X51		Quality issues in construction
X19		Inadequate manpower	X52		Lack of coordination with other disciplines
X20		Poor design quality	X53		Difficulties installing specialized technologies
X21		Calculation and estimation errors	X54		On-site criminal activities (e.g., theft)
X22	Procurement	Delayed quotation submission from vendors	X55		Equipment damage
X23		Unfinalized design during the engineering phase	X56		Workplace accidents
X24		Difficulty in finding vendors that meet requirements	X57		Force majeure events (e.g., natural disasters)
X25		Lengthy tender process	X58		Heavy equipment maneuver limitations
X26		Price increases over exchange rate fluctuations	X59		Limited space for heavy equipment and large vehicles
X27		Overly demanding vendor requirements	X60		Material wastage by workers or technicians
X28		Local content requirements that are difficult for vendors to meet	X61		Mismatch between engineering documents and actual field conditions
X29		Inflated material prices due to limited supplier access	X62		Lack of utility or power sources on site
X30		Difficulty in finding suitable vendors	X63		Shortage of skilled labor
X31		Challenges in meeting acceptable delivery times	X64		Poor coordination and collaboration among disciplines
X32		Difficulty finding vendors with agreeable payment terms	X65		Design changes during ongoing construction phase
X33		Changes to vendor or contractor scope			

4.3 | Respondent Questionnaire

In the respondent questionnaire phase, the questionnaire was distributed to 30 participants, with the following profile in Table 8 .

The following is the data obtained from the results of the respondent questionnaire in Table 9 , 10 , 11 , 12 .

TABLE 8 Respondent Profile

No	Position	Experience (Years)	Last Education	No	Position	Experience (Years)	Last Education
1	Instrument Engineer	15	S1	21	Instrument Engineer	6	S1
2	Instrument Engineer	4	S1	22	Instrument Engineer	8	S1
3	Electrical Commissioning	5	S1	23	Commissioning Engineer	4	S1
4	Instrument Engineer	18	S1	24	Commissioning Engineer	5	S1
5	Process Engineer	5	S1	25	Electrical Designer	11	S1
6	Project Engineer	6	S1	26	Commissioning Engineer	11	S1
7	Project Control	5	S1	27	Instrument & Control Engineer	14	S2
8	HSE Officer	6	S1	28	Instrument & Control Engineer	4	S1
9	Lead Engineer	20	S1	29	Project Engineer	21	S1
10	Civil Structure Engineer	6	S1	30	Project Engineer	2.5	S1
11	Instrument Engineer	3	S1	31	Drafter	3	SMA
12	Construction Supervisor	5	D4	32	Instrument & Control Engineer	1	S1
13	HSE Officer	6	S1	33	Instrument & Control Engineer	1	S1
14	Instrument & Control Engineer	5	S1	34	Instrument & Control Engineer	2	S1
15	Drafter	6	SMA	35	Drafter	2	SMA
16	Operational Engineer	5	S1	36	Instrument Engineer	8	D3
17	Commissioning Manager	13	S1	37	Instrument & Control Engineer	6	S1
18	Technical Support Engineer	20	S1	38	Instrument & Control Engineer	5	S1
19	Process Engineer	14	S1	39	Instrument & Control Engineer	12	S1
20	Mechanical Engineer	1	S1	40	Instrument & Control Engineer	15	S1

The questionnaire data yielded two sets of values: X and Y. Value X is obtained by multiplying each risk variable by the combined product of the Risk Frequency Scale and the Risk Impact Scale on Time. Value Y, on the other hand, is derived from a scale reflecting the respondents' experience in EPC projects, particularly in the field of Renewable Energy.

4.4 | Respondent Questionnaire Analysis

Subsequently, the data from Table 14 to Table 20 will be analyzed using SPSS software, and the analysis will be conducted using the following methods:

1. Validity and Reliability Test
2. Normality Test
3. Mann-Whitney Test
4. Spearman Test

4.4.1 | Validity Test

The validity test is conducted to verify the accuracy of the responses provided by respondents and to assess whether the questionnaire effectively measures what it is intended to measure, ensuring that the data obtained are both representative and reliable. Validity refers to the extent to which a variable measures what it is purported to measure[5]. Sanaky (2021) further defines validity in research as the degree of accuracy of a measuring instrument in capturing the actual content being assessed[6]. A questionnaire is considered valid when its items are capable of revealing what the questionnaire is designed to measure. In the validity test, a variable is deemed valid if the calculated r-value (r-count) exceeds the r-table value. With a total of 40 respondents at a 95% confidence level (5% significance level), the r-table value is established at 0.312, as presented in Table 13 .

TABLE 9 Questionnaire Data Results (1)

No	X1	X2	X5	X6	X7	X9	X10	X12	X13	X14	X15	X17	X18	X21	X22
1	16	16	9	9	9	9	9	9	9	9	9	12	9	9	9
2	9	9	4	9	1	1	12	1	1	4	1	4	16	1	12
3	16	9	4	15	25	25	16	2	4	9	5	15	12	4	16
4	25	25	9	25	20	9	2	1	2	4	4	1	10	12	5
5	20	12	4	8	16	9	1	1	16	9	4	3	15	16	12
6	15	4	4	16	8	4	4	4	4	4	9	9	15	6	4
7	25	9	9	9	9	16	4	4	9	9	9	16	25	16	16
8	10	4	16	4	4	15	1	3	12	2	3	12	25	12	20
9	4	4	9	9	9	4	12	1	1	1	1	4	6	6	6
10	12	12	6	16	8	8	3	3	3	10	12	10	8	4	6
11	8	6	9	8	4	9	6	3	12	4	5	8	10	6	9
12	9	1	9	12	1	4	2	2	6	6	8	8	12	6	12
13	20	20	20	20	25	25	16	25	20	6	9	9	20	25	9
14	20	25	20	16	16	16	16	20	16	4	16	25	16	4	9
15	16	12	9	16	9	12	9	4	4	4	9	9	16	4	9
16	15	16	20	16	16	16	8	8	12	12	5	4	8	25	10
17	6	9	4	6	12	12	15	12	12	12	10	6	20	12	4
18	12	9	9	9	16	16	9	9	16	9	9	4	9	16	9
19	6	6	4	8	6	6	2	2	8	4	4	12	9	6	9
20	20	15	12	20	10	20	20	6	9	8	4	16	12	20	12
21	12	9	16	12	4	6	4	4	4	2	8	6	12	12	16
22	25	12	1	16	16	25	1	9	25	16	20	25	25	25	9
23	12	12	16	12	8	8	6	9	15	12	4	15	15	15	25
24	8	6	12	10	5	2	3	4	4	6	15	3	16	6	15
25	16	12	16	16	12	16	25	16	16	16	16	12	16	20	20
26	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
27	15	25	20	25	10	20	9	4	10	9	10	25	25	4	25
28	10	5	15	15	15	12	4	9	6	12	4	15	8	9	15
29	6	6	12	6	10	8	4	9	4	4	2	4	4	8	4
30	10	16	10	12	10	4	12	12	3	4	12	10	16	8	8
31	6	1	10	3	12	2	4	2	10	1	3	8	12	6	4
32	10	4	8	5	10	3	1	2	3	2	1	2	4	3	9
33	10	15	12	25	10	8	2	3	4	1	3	15	20	15	16
34	15	5	5	3	3	16	1	6	1	1	10	4	5	2	5
35	20	5	6	12	10	2	3	2	10	3	3	9	1	1	3
36	5	20	6	4	6	9	6	1	3	1	2	6	5	3	16
37	10	10	8	8	3	2	6	2	2	6	2	10	20	15	15
38	4	8	8	12	4	10	8	2	1	2	9	1	4	2	3
39	10	3	6	10	8	3	2	3	1	1	1	1	25	10	3
40	10	1	6	4	8	2	8	1	6	2	3	2	1	1	1

If the calculated r-value (r-count) is greater than the critical r-value (r-table), then the variable can be considered valid[7]. The validity test uses the Product Moment correlation technique, with the following formula (Sujarweni, 2018):

$$r_{xy} = \frac{n\sum XY - (\sum X)(\sum Y)}{\sqrt{\{n\sum X^2 - (\sum X)^2\}\{n\sum X^2 - (\sum Y)^2\}}}$$

Explanation:
r = Correlation Coefficient
n = Number of Samples
X = Score of Individual Questionnaire Item
Y = Total Score of the Questionnaire Item

By conducting the validity test using SPSS software, the calculated r-values (r-count) for each risk variable are as follows Table 14 .

TABLE 10 Questionnaire Data Results (2)

No	X23	X24	X25	X27	X28	X29	X30	X31	X33	X34	X35	X36	X37	X38	X39
1	9	9	9	9	9	9	9	9	16	9	9	9	9	9	9
2	4	9	1	1	1	9	4	4	1	4	1	4	16	8	3
3	9	10	12	9	9	16	9	1	9	9	15	6	12	15	9
4	25	15	6	6	9	9	4	4	4	4	4	4	10	4	4
5	4	1	16	1	8	2	1	9	12	8	8	8	2	3	12
6	6	4	9	4	4	9	4	16	9	4	25	4	6	4	4
7	9	9	16	4	9	4	9	16	16	9	9	9	9	9	9
8	6	12	20	1	2	6	12	6	4	9	20	12	10	9	16
9	3	6	2	1	1	4	4	4	2	1	20	4	4	6	4
10	10	15	12	6	8	9	6	9	8	6	12	10	10	12	4
11	12	8	8	4	8	9	8	3	6	9	9	9	16	2	4
12	9	2	12	3	6	2	6	4	8	3	9	9	9	9	6
13	20	4	4	12	1	6	6	4	4	9	20	9	9	9	9
14	9	1	4	1	4	16	4	9	6	4	6	9	9	9	4
15	4	4	4	4	4	9	4	6	9	9	12	9	9	12	9
16	5	4	16	4	1	8	4	8	10	8	10	10	15	9	8
17	6	16	1	8	10	4	9	6	5	6	16	9	6	6	3
18	9	9	9	9	9	9	9	9	16	9	9	9	9	9	9
19	8	12	20	6	6	4	9	12	9	4	12	9	6	6	4
20	25	9	6	12	4	12	12	8	16	16	16	8	12	16	9
21	9	4	6	2	4	2	9	12	16	4	8	4	4	4	12
22	25	4	16	9	9	1	9	4	20	4	4	25	4	4	4
23	20	12	16	9	16	20	16	25	16	20	8	6	16	9	16
24	8	5	8	8	20	1	6	20	15	15	4	12	10	8	6
25	25	16	16	16	16	16	16	25	16	16	16	16	16	12	16
26	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
27	12	10	10	6	10	6	5	5	10	10	9	20	20	20	1
28	20	15	15	12	20	15	20	15	20	20	15	15	20	20	15
29	6	12	16	2	4	4	4	4	6	1	10	4	4	3	4
30	15	8	8	8	8	16	8	8	8	8	16	16	12	4	15
31	4	8	16	2	15	4	4	12	1	2	3	2	12	1	1
32	9	3	6	1	1	9	3	1	3	1	5	15	2	1	6
33	6	3	16	3	3	8	1	1	10	6	6	8	16	1	3
34	3	1	4	1	1	12	1	10	2	12	6	8	8	6	8
35	1	4	3	2	4	1	1	8	1	2	8	3	2	12	3
36	1	2	2	3	3	6	2	3	20	2	12	8	8	6	3
37	1	15	6	2	2	1	2	2	3	1	25	1	3	6	1
38	1	3	4	1	1	3	2	12	1	5	15	3	1	3	12
39	20	5	16	1	3	1	2	12	5	2	1	2	6	1	1
40	3	8	1	2	2	1	10	1	1	1	4	2	1	2	2

Based on the data from the SPSS analysis, the calculated r-value for each risk is greater than the r-table value (0.312). Therefore, no items will be deleted in the validity test and subsequent testing. Thus, the respondent questionnaire in the table above can be considered valid according to the analysis simulated using SPSS.

4.4.2 | Reliability Test

Reliability testing is conducted to assess the consistency of variable measurements across respondents. Reliability refers to the degree to which a research instrument can be trusted as a data collection tool and is capable of yielding accurate and consistent information[5]. In essence, reliability denotes the consistency of a series of measurements or the repeated use of a measuring instrument meaning that repeated measurements using the same tool yield similar results, or in the case of more subjective assessments, that two independent evaluators produce comparable scores (inter-rater reliability). Reliability is distinct from validity. While reliable measurements produce consistent results, those results do not necessarily reflect what the instrument is intended to measure. In a research context, reliability indicates the extent to which measurements remain stable and consistent when repeated under similar conditions with the same subjects. A study is considered reliable when it produces consistent results across repeated measurements, and unreliable when repeated measurements yield varying outcomes. Reliability testing

TABLE 11 Questionnaire Data Results (3)

No	X42	X43	X44	X45	X46	X47	X48	X49	X52	X54	X55	X56	X57	X58	X59
1	9	9	9	9	9	9	9	9	9	16	9	9	9	9	9
2	4	2	5	1	6	4	4	1	1	4	1	4	16	1	1
3	25	9	9	9	16	8	15	6	8	8	16	9	20	9	9
4	4	4	4	4	4	4	4	1	9	1	9	4	4	4	4
5	4	4	8	16	8	5	12	2	10	1	2	1	9	12	8
6	25	12	12	1	20	1	4	2	6	1	9	4	16	9	4
7	4	4	4	4	16	4	9	9	9	9	16	9	9	16	16
8	9	20	4	8	16	4	6	8	9	4	6	12	6	4	9
9	2	2	2	1	4	4	6	2	6	2	1	1	1	6	2
10	6	8	12	16	10	12	8	10	8	12	8	5	10	8	12
11	4	16	10	8	6	5	6	9	4	4	9	4	5	8	12
12	3	2	6	2	20	3	12	9	9	8	6	8	15	6	6
13	9	9	9	9	9	9	12	9	25	16	9	20	12	16	25
14	16	4	4	4	16	16	8	12	16	12	4	6	2	8	8
15	12	6	4	9	4	12	12	16	6	4	4	9	9	4	4
16	8	8	6	8	8	16	8	12	15	8	15	15	9	15	15
17	4	16	12	9	12	8	15	8	9	3	6	15	10	9	9
18	9	9	9	9	9	9	9	9	12	12	12	8	4	6	12
19	6	8	10	4	16	1	4	9	6	4	6	4	5	4	4
20	16	9	12	12	15	15	10	15	15	15	15	20	20	15	20
21	6	2	6	3	20	8	3	12	6	8	4	4	5	6	6
22	4	4	4	4	25	4	25	25	25	16	25	25	9	4	4
23	16	9	9	16	20	5	10	5	15	8	8	5	5	12	12
24	20	16	4	8	9	20	9	2	2	12	12	4	5	8	8
25	16	16	16	16	16	16	12	20	16	16	16	16	12	16	16
26	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
27	4	8	4	10	25	9	10	9	9	12	6	20	20	20	4
28	10	4	9	12	20	15	12	10	15	12	12	16	5	4	12
29	4	6	4	4	20	10	6	5	6	2	4	3	5	4	4
30	8	16	16	16	8	16	10	10	8	20	4	8	5	15	8
31	1	2	5	9	25	1	6	2	10	4	5	8	1	3	4
32	1	6	3	1	1	8	4	6	9	4	9	5	15	8	5
33	4	2	8	1	10	6	8	3	6	5	12	2	3	5	2
34	5	10	5	10	1	15	2	9	4	3	6	5	6	5	5
35	2	1	3	6	1	2	12	2	10	6	2	3	6	6	5
36	2	2	2	3	3	6	2	3	20	2	12	6	8	6	3
37	1	15	6	2	2	1	2	2	3	1	25	1	3	6	1
38	1	3	4	1	1	3	2	12	1	5	15	3	1	3	12
39	20	5	16	1	3	1	2	12	5	2	1	2	6	1	1
40	3	8	1	2	2	1	10	1	1	1	4	2	1	2	2

is further used to determine whether the risk factors identified can be trusted to reflect actual conditions. If the Cronbach's Alpha value exceeds 0.60, the instrument is considered reliable [8]. Reliability can be assessed using the Cronbach's Alpha formula, as follows:

$$\alpha = \left(\frac{k}{k-1}\right)\left(1 - \frac{\sum \alpha_i^2}{\alpha_t^2}\right)$$

Explanation:

α = Instrument reliability
k = Number of question or statement items
$\sum \alpha_i^2$ = Sum of item variances
α_t^2 = Total variance

The reliability value obtained from the test using SPSS software is as follows Figure 3 .

TABLE 12 Questionnaire Data Results (4)

No	X60	X61	X63	X64	X65	Y	No	X60	X61	X63	X64	X65	Y
1	16	9	9	9	9	9	21	2	12	4	9	8	1
2	4	6	8	9	3	4	22	4	4	25	25	4	1
3	15	6	12	15	9	25	23	9	10	12	12	12	3
4	4	4	4	4	4	4	24	8	8	3	6	20	3
5	8	8	2	3	12	4	25	16	16	16	16	16	1
6	25	4	6	4	4	25	26	25	25	25	25	25	3
7	9	9	9	9	9	4	27	9	16	16	16	16	1
8	20	12	10	9	16	9	28	9	9	3	15	15	2
9	6	6	6	4	9	1	29	2	4	2	6	8	3
10	8	8	8	8	9	3	30	15	15	12	12	16	3
11	3	9	9	9	8	2	31	2	1	4	8	20	3
12	4	15	8	6	9	1	32	4	3	1	5	1	3
13	16	16	9	9	9	2	33	1	8	2	3	10	4
14	8	8	10	10	10	4	34	3	12	1	10	1	1
15	4	16	4	6	9	1	35	3	2	3	2	3	1
16	15	15	15	15	8	2	36	6	15	5	12	12	1
17	6	12	20	9	12	2	37	3	2	6	2	2	3
18	8	6	6	12	12	3	38	4	10	1	2	8	2
19	2	4	6	6	6	2	39	8	3	2	3	1	2
20	9	12	9	12	15	3	40	1	2	15	1	1	1

TABLE 13 R Table Pearson

N	Level of Significance		N	Level of Significance		N	Level of Significance		N	Level of Significance	
	5%	1%		5%	1%		5%	1%		5%	1%
3	0.997	0.999	21	0.433	0.549	39	0.316	0.408	80	0.220	0.286
4	0.950	0.990	22	0.423	0.537	40	0.312	0.403	85	0.213	0.278
5	0.878	0.959	23	0.413	0.526	41	0.308	0.398	90	0.207	0.270
6	0.811	0.917	24	0.404	0.515	42	0.304	0.393	95	0.202	0.263
7	0.754	0.874	25	0.396	0.505	43	0.301	0.389	100	0.195	0.256
8	0.707	0.834	26	0.388	0.496	44	0.297	0.384	125	0.176	0.230
9	0.666	0.798	27	0.381	0.487	45	0.294	0.380	150	0.159	0.210
10	0.632	0.765	28	0.374	0.478	46	0.291	0.376	175	0.149	0.194
11	0.602	0.735	29	0.367	0.470	47	0.288	0.372	200	0.138	0.191
12	0.576	0.708	30	0.361	0.463	48	0.284	0.368	300	0.113	0.181
13	0.553	0.684	31	0.355	0.456	49	0.281	0.364	400	0.098	0.148
14	0.532	0.661	32	0.349	0.449	50	0.279	0.361	500	0.088	0.128
15	0.514	0.641	33	0.344	0.442	55	0.266	0.345	600	0.080	0.115
16	0.497	0.623	34	0.339	0.436	60	0.254	0.330	700	0.074	0.105
17	0.482	0.606	35	0.334	0.430	65	0.244	0.317	800	0.070	0.091
18	0.468	0.590	36	0.329	0.424	70	0.235	0.306	900	0.065	0.086
19	0.456	0.575	37	0.325	0.418	75	0.227	0.296	1000	0.062	0.081
20	0.444	0.561	38	0.320	0.413						

Based on the results of the reliability analysis above, the value of Cronbach's Alpha is 0.974, with a total of 50 items. As this value exceeds the minimum threshold of 0.6, it can be concluded that the questionnaire demonstrates a high level of reliability and is suitable for use as a valid instrument in identifying risk factors associated with renewable energy green ammonia project development.

TABLE 14 Validity Test Results Using SPSS Software

Risk Variable Codes	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted	Risk Variable Codes	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
X1	428.42	39462.6	.524	–	.974	X35	429.95	39800.7	.367	–	.975
X2	430.92	39296.4	.522	–	.974	X36	432.47	39170.0	.703	–	.974
X5	431.30	39434.7	.585	–	.974	X37	432.52	39161.1	.699	–	.974
X6	429.30	39404.8	.541	–	.974	X38	434.37	39294.2	.680	–	.974
X7	430.87	39295.5	.593	–	.974	X39	434.10	39271.7	.699	–	.974
X9	431.02	38677.3	.718	–	.974	X42	432.95	39396.9	.491	–	.974
X10	433.85	39139.0	.626	–	.974	X43	433.50	39519.8	.533	–	.974
X12	435.22	38867.4	.746	–	.973	X44	434.05	39510.0	.670	–	.974
X13	433.27	38947.3	.695	–	.974	X45	434.07	39125.9	.732	–	.974
X14	435.27	38982.6	.681	–	.973	X46	428.95	39354.1	.436	–	.975
X15	434.27	39210.4	.700	–	.974	X47	433.50	39367.8	.601	–	.974
X17	431.75	38912.0	.679	–	.974	X48	432.75	39261.0	.728	–	.974
X18	428.30	39482.9	.438	–	.974	X49	433.32	39015.8	.738	–	.973
X21	431.50	38837.3	.655	–	.974	X52	432.17	38874.2	.777	–	.973
X22	430.62	39253.8	.585	–	.974	X54	433.80	38994.9	.755	–	.973
X23	431.35	38673.7	.676	–	.974	X55	432.35	38975.3	.728	–	.974
X24	433.65	39551.9	.547	–	.974	X56	433.27	38787.2	.759	–	.973
X25	431.57	39544.4	.479	–	.974	X57	433.90	39047.4	.664	–	.974
X27	436.00	38958.6	.901	–	.973	X58	433.55	39362.1	.768	–	.974
X28	434.50	39217.0	.646	–	.974	X59	433.55	39035.2	.736	–	.973
X29	433.80	39262.2	.641	–	.974	X60	434.67	39055.9	.768	–	.973
X30	434.45	39149.8	.768	–	.973	X61	432.35	39345.2	.661	–	.974
X31	432.07	39292.3	.547	–	.974	X63	433.32	39067.3	.684	–	.974
X33	432.65	39095.2	.659	–	.974	X64	432.47	38918.9	.807	–	.973
X34	433.97	38874.8	.783	–	.973	X65	431.77	39354.8	.615	–	.974

Reliability Statistics

Cronbach's Alpha	N of Items
.974	50

FIGURE 3 Reliability Test Results Using SPSS Software.

4.4.3 | Normality Test

The next test performed is the Normality Test, which aims to determine whether the collected data follows a normal distribution. Several methods can be employed to test normality, including the Kolmogorov-Smirnov and Shapiro-Wilk methods both of which are widely used techniques that can be analyzed using SPSS software. In general, the Shapiro-Wilk method is more appropriate for testing small sample datasets[9]. If the normality test indicates that the data is normally distributed, subsequent analyses may proceed using parametric methods, in accordance with the following guidelines[10]:

- If the significance value or probability value is less than 0.05, then the distribution is not normal.
- If the significance value or probability value is greater than 0.05, then the distribution is normal.

The following are the results of the normality test conducted using SPSS software in Table 15 .

TABLE 15 Normality Test Results Using SPSS Software

Risk	Shapiro-Wilk			Risk	Shapiro-Wilk			Risk	Shapiro-Wilk		
Codes	**Statistic**	**df**	**Sig.**	**Codes**	**Statistic**	**df**	**Sig.**	**Codes**	**Statistic**	**df**	**Sig.**
X1	.930	40	.016	X25	.931	40	.018	X46	.926	40	.012
X2	.917	40	.006	X27	.814	40	.000	X47	.907	40	.003
X5	.924	40	.010	X28	.855	40	.000	X48	.869	40	.000
X6	.927	40	.013	X29	.902	40	.002	X49	.878	40	.000
X7	.926	40	.012	X30	.858	40	.000	X52	.881	40	.001
X9	.911	40	.004	X31	.900	40	.002	X54	.889	40	.001
X10	.867	40	.000	X33	.924	40	.010	X55	.912	40	.004
X12	.771	40	.000	X34	.884	40	.001	X56	.869	40	.000
X13	.890	40	.001	X35	.945	40	.050	X57	.835	40	.000
X14	.860	40	.000	X36	.883	40	.001	X58	.811	40	.000
X15	.879	40	.000	X37	.938	40	.029	X59	.849	40	.000
X17	.899	40	.002	X38	.883	40	.001	X60	.857	40	.000
X18	.945	40	.052	X39	.877	40	.000	X61	.940	40	.035
X21	.899	40	.002	X42	.836	40	.000	X63	.886	40	.001
X22	.930	40	.016	X43	.898	40	.002	X64	.922	40	.009
X23	.859	40	.000	X44	.856	40	.000	X65	.952	40	.090
X24	.916	40	.006	X45	.898	40	.002	Y	.860	40	.000

Based on the normality test results, it can be observed that the majority of variables yielded significance values below 0.05, indicating that the overall distribution of the research variables does not follow a normal distribution. Consequently, parametric statistical tests that assume normality such as the t-test or ANOVA are not appropriate for analyzing this dataset. Therefore, a non-parametric approach is warranted, with the Mann-Whitney test serving as the most commonly used alternative for this type of analysis.

4.4.4 | Mann-Whitney Test

Since it has been determined that the questionnaire data is not normally distributed based on the parametric test, it is necessary to perform the Mann-Whitney test, which is a non-parametric statistical test used to compare two independent groups when the data is not normally distributed, or when the data is ordinal that is, data that has a ranking or order, but inconsistent or immeasurable intervals between values, or is considered relative data. The two groups to be compared are respondents with more than 10 years of work experience and those with less than 10 years of work experience. The following presents the distribution of respondent work experience, using the following codes in Table 16 .

Of the 40 respondents surveyed, 70% have less than ten years of work experience, while 30% have more than ten years of experience. Following the grouping of respondents based on their years of experience, the Mann-Whitney test was conducted to compare the two independent groups and to determine whether a statistically significant difference in perceptions exists between them with respect to work experience. The results of the Mann-Whitney test are evaluated against the following hypotheses [10]: •

H_0 = There is no difference in perception between respondents with less than 10 years of experience and those with more than 10 years of experience.

- H_1= There is a difference in perception between respondents with less than 10 years of experience and those with more than 10 years of experience.

H_0 is accepted if the Asymp. Sig value is greater than the level of significance (α) of 0.05, and H_0 is rejected otherwise. The results of the Mann-Whitney test can be seen in Table 17 .

TABLE 16 Work Experience Codes

No	Respondent	Experience (Years)	No	Respondent	Experience (Years)	No	Respondent	Experience (Years)
1	R1	15	15	R15	6	29	R29	21
2	R2	4	16	R16	5	30	R30	2.5
3	R3	5	17	R17	13	31	R31	3
4	R4	18	18	R18	20	32	R32	3
5	R5	5	19	R19	14	33	R33	1
6	R6	6	20	R20	1	34	R34	2
7	R7	5	21	R21	6	35	R35	2
8	R8	6	22	R22	8	36	R36	8
9	R9	20	23	R23	4	37	R37	6
10	R10	6	24	R24	5	38	R38	5
11	R11	3	25	R25	11	39	R39	12
12	R12	5	26	R26	11	40	R40	15
13	R13	6	27	R27	14			
14	R14	5	28	R28	4			

TABLE 17 Mann–Whitney Test Results Using SPSS Software

Risk Variable Codes	Asymp. Sig. (2-tailed)	Risk Variable Codes	Asymp. Sig. (2-tailed)	Risk Variable Codes	Asymp. Sig. (2-tailed)	Risk Variable Codes	Asymp. Sig. (2-tailed)
X1	.580	X21	.468	X36	.530	X54	.532
X2	.561	X22	.171	X37	.919	X55	.505
X5	.738	X23	.154	X38	.512	X56	.739
X6	.873	X24	.002	X39	.737	X57	.860
X7	.263	X25	.662	X42	.540	X58	.672
X9	.977	X27	.161	X43	.138	X59	.919
X10	.090	X28	.119	X44	.358	X60	.172
X12	.343	X29	.838	X45	.652	X61	.907
X13	.896	X30	.125	X46	.673	X63	.070
X14	.559	X31	.988	X47	.771	X64	.885
X15	.652	X33	.988	X48	.716	X65	.222
X17	.417	X34	.738	X49	.861		
X18	.862	X35	.495	X52	.988		

4.4.5 | Quantitative Analysis of Respondents' Questionnaire

Based on all tests conducted including the Validity Test, Reliability Test, Normality Test, and Mann-Whitney Test along with guidelines drawn from several reference journals, it can be concluded that all variables in this research questionnaire are valid and reliable. Accordingly, a quantitative risk variable analysis can be carried out. The quantitative analysis method is employed to test specific theories by examining the relationships among variables[11]. This study utilized a questionnaire distributed to 30 respondents, encompassing Variable X and Variable Y. The value of Variable X is calculated as the product of the frequency scale weight and the weight of the risk's impact on time. The distribution of Variable X values derived from the questionnaire is presented as follows Table 18 .

From the 60 Risk Variables, it can be observed that the Risk Variables with scores above the mean weighting value of 353.2 are identified. The following are the Risk Variables whose total weighting scores are either above or below 353.2 in Table 19 .

Explanation:

Y = If the Total Weighted Score of the Risk Variable > 353.2
N = If the Total Weighted Score of the Risk Variable < 353.2

TABLE 18 Probability of Questionnaire for Variable X

Rating Frekuensi	Frequency	Impact Rating of Risk Influence on Project Time				
		Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
5	High Frequent	5	10	15	20	25
4	Frequent	4	8	12	16	20
3	Moderate	3	6	9	12	15
2	Low	2	4	6	8	10
1	Very Low	1	2	3	4	5

TABLE 19 Dominant Risk Variable

Risk Variable	X1	X2	X5	X6	X7	X9	X10	X12	X13	X14
Total Weighted Score	523	423	408	488	425	419	306	251	329	256
Result Code	Y	Y	Y	Y	Y	Y	N	N	N	N
Risk Variable	X15	X17	X18	X21	X22	X23	X24	X25	X27	X28
Total Weighted Score	289	390	528	400	435	406	314	397	220	280
Result Code	N	Y	Y	Y	Y	Y	N	Y	N	N
Risk Variable	X29	X30	X31	X33	X34	X35	X36	X37	X38	X39
Total Weighted Score	308	282	377	354	301	462	361	359	285	296
Result Code	N	N	Y	Y	N	Y	Y	Y	N	N
Risk Variable	X42	X43	X44	X45	X46	X47	X48	X49	X52	X54
Total Weighted Score	342	320	298	297	502	320	350	327	373	308
Result Code	N	N	N	N	Y	N	N	N	Y	N
Risk Variable	X55	X56	X57	X58	X59	X60	X61	X63	X64	X65
Total Weighted Score	366	329	304	318	318	273	366	327	361	330
Result Code	Y	N	N	N	N	N	Y	N	Y	Y

Based on the weighting results presented in Table 19 , the following risk variables X1, X2, X5, X6, X7, X9, X17, X18, X21, X22, X23, X25, X31, X33, X35, X36 X37, X46, X52, X55, X61, X64, and X65 are identified as the most dominant risk factors, distributed across three project phases: 9 factors from the Engineering/Design phase, 8 factors from the Procurement phase, and 6 factors from the Construction phase. With regard to Variable Y, the most frequently selected response by respondents was scale 3, corresponding to Average / On Time performance.

4.4.6 | Spearman Test

Having identified the most dominant risk variables, the next step involves examining the correlation between Variable X and Variable Y using the Spearman Test. This method is a non-parametric statistical test used to measure the strength and direction of the relationship between two variables, thereby determining whether a statistically significant correlation exists between them. If the significance value of Variable X in relation to Variable Y is greater than 0.05, it indicates a strong correlation between the two variables, and the same applies in the inverse direction[10][3]. The results of the Spearman test conducted using SPSS software are presented in Table 20 .

TABLE 20 Spearman Test Using SPSS Software

Spearman's rho	Correlation Coefficient	Sig. (2-tailed)	N	Spearman's rho	Correlation Coefficient	Sig. (2-tailed)	N
X1	.046	.780	40	X31	.124	.445	40
X2	.155	.340	40	X33	.010	.950	40
X5	.197	.223	40	X35	.172	.290	40
X6	-.045	.781	40	X36	.044	.786	40
X7	.154	.342	40	X37	.249	.121	40
X9	-.081	.618	40	X46	.136	.402	40
X17	.229	.155	40	X52	.129	.427	40
X18	.273	.088	40	X55	.242	.132	40
X21	.232	.149	40	X61	-.237	.141	40
X22	.142	.382	40	X64	-.024	.884	40
X23	.090	.582	40	X65	.179	.268	40
X25	.320	.044	40	Y	1.000	0.0	40

Table 20 20 shows, that the significance value of Variable X in relation to Variable Y is above 0.05 or > 0.05. Therefore, it can be concluded that in this study, there is a correlation between the two variables, Variable X and Variable Y. This indicates that the risk variables in Variable X, which have been analyzed, have a very strong influence on Variable Y.

4.5 | Risk Impact and Risk Cause Analysis

Based on the analysis of the respondent questionnaires which underwent a comprehensive series of tests including validity, reliability, normality, Mann-Whitney, and Spearman tests it can be concluded that the questionnaire is valid and suitable for analyzing risks in EPC Power Plant and Renewable Energy projects. The subsequent step involves validating the dominant risks, the corresponding response strategies, and the preventive actions implemented. Following a further review conducted by experts on the questionnaire results and analysis particularly with respect to several dominant risk variables certain variables were consolidated into single risk variables due to their similar impacts and classifications. The merged risk variables are as follows: X1-X23-X33, X2-X7, X6-X17, X25-X36 X22-X55, X35-X46, X52-X64, and X61-X65.

The following presents the distribution of impacts, risks, preventive measures, and corrective measures for each identified risk.

Several interrelationships exist among the identified risks, as illustrated in Figure 4 . As shown in the figure, certain causes originate from multiple risks, including P4, P7, P9, P11, P13, P14, P15, P26, and P28. Similarly, a number of common impacts are shared across several risks, namely D1, D2, D3, D6, D7, and D8.

4.6 | Risk Variable Response Analysis

Having reviewed the distribution of each risk variable, along with the associated risk impacts, risk causes, and both preventive and corrective measures, the next step is to analyze each risk variable in accordance with the following response strategies: avoid, mitigate, transfer, and accept. Based on the risk distribution analysis, the identified risks are grouped according to their respective response strategies as follows Table 23 .

From Table 23 , the mitigate risk response applies to the risk variables X1, X2, X6, X9, X18, X21, X23, X25, X37, X52, X55, and X61. Meanwhile, the transfer risk response applies to the risk variables X5 and X46.

4.7 | Research Results

Upon reviewing the actions taken for each risk and their respective impacts, two primary response strategies are applicable: mitigate and transfer. The mitigate strategy indicates that the risk remains controllable and can therefore be minimized. The risk variables categorized under mitigate are X1, X2, X6, X9, X18, X21, X23, X25, X37, X52, X55, and X61. The transfer strategy, on the other hand, involves shifting the impact of the risk to a third party. The risk variables categorized under transfer are X5 and X46. For risk variable X1 (Frequent design changes), the mitigation action is to conduct joint reviews among each discipline or department and allocate spare time to anticipate unavoidable design changes. For X2 (Delay in document submission),

TABLE 21 Causes and Impacts of Risk

Risk Code	Risk Variable	Cause	Cause Code	Impact	Impact Code
X1	Frequent design changes	Contractor's work still contains errors	P1	Delayed approval from the client	D1
X1		Client rejection due to over design (excessive materials/design)	P2	Potential additional material costs	D2
X1		Design changes following HAZOP or SIL Study results	P3	Construction work delays	D3
X1		Unfeasible design due to site conditions	P4	Construction work delays	D3
X2	Delayed document submission	Dependency on other documents	P5	Overall project delay	D4
X2		Incomplete data	P6	Overall project delay	D4
X5	Client requests for out-of-scope design	Lack of initial project clarification	P7	Additional material costs	D5
X6	Delayed client feedback	Client's limited time for corrections	P8	Construction phase delay	D6
X9	Interdisciplinary integration issues	Discipline-specific KPIs	P9	Work repetition	D7
X18	Repeated changes from client	Substandard engineering work quality	P10	Work repetition	D7
X21	Calculation and estimation errors	Poor inter-disciplinary communication	P11	Work repetition	D7
X22	Unfinalized engineering phase	Insufficient time for corrections	P12	Work repetition	D7
X22		Client-initiated design additions	P13	Work repetition	D7
X22		Requisition changes	P14	Work repetition	D7
X25	Prolonged tender process	Lengthy specification verification	P15	Construction delayed due to material changes	D8
X25		Limited time for review	P16	Construction delayed due to material changes	D8
X25		Contractor's limited human resources	P17	Construction delayed due to material changes	D8
X37	Discrepancy in vendor specifications	Unclear tender documents	P18	Specification differences require clarification	D9
X37		Vendor capability limitations	P19	Specification differences require clarification	D9
X37		Post-submission vendor changes	P20	Design revisions needed	D10
X46	Material delivery delays	Vendor bids based on outdated specs	P21	Construction delays	D11
X46		Vendor material production delays	P22	Construction delays	D11
X46		Slow procurement processes	P23	Construction delays	D11
X46		Permit issuance delays	P24	Construction delays	D11
X52	Poor inter-disciplinary coordination	Poor collaboration meetings	P25	Additional time for issue resolution	D12
X52		Divergent discipline priorities	P26	Additional time for issue resolution	D12
X55	Equipment damage	Equipment beyond recommended capacity	P27	Equipment replacement costs	D13
X61	Engineering mismatch with field conditions	Design vs actual field mismatch	P28	Schedule adjustments required	D14
X61		Unidentified physical/environmental obstacles	P29	Schedule adjustments required	D14

during the pre-EPC phase, involve representatives from each discipline along with planning and scheduling teams, since each discipline will perform the work. If delays cannot be avoided, form a special team to accelerate document collection and send reminders to relevant parties. For X5 (Client requests beyond scope), consistent with the transfer action, it is necessary to create contract clauses requiring client approval of Change Orders (CO) for any requests outside the scope, along with schedule adjustments to prevent contractor penalties due to additional items and work delays. For X6 (Delayed client feedback after document submission), due to client review delays, hold joint meetings to establish agreed review and feedback schedules between contractor and client, and send periodic reminders to the client. For X9 (Poor integration causing asynchronous disciplines),

TABLE 22 Preventive and Corrective Actions

Risk Code	Risk Variable	Preventive	Prev. Code	Corrective	Corr. Code
X1	Frequent design changes	Conduct regular design reviews involving all stakeholders	PR1	Implement structured change management	KR1
X1		Establish clear design standards	PR2	Hold coordination meetings to evaluate impacts	KR2
X1		Conduct detailed site surveys	PR3	Hold urgent coordination meetings	KR2
X1		Perform HAZOP and SIL studies	PR4	Hold urgent coordination meetings	KR2
X2	Delayed document submission	Define document collection timeline	PR5	Expedite document collection	KR3
X2		Use integrated tracking systems	PR6	Track using document control systems	KR4
X2		Ensure required data availability	PR7	Send reminders to responsible parties	KR5
X5	Client out-of-scope requests	Clearly define scope of work	PR8	Issue change orders	KR6
X5		Document all change requests	PR9	Issue change orders	KR6
X6	Delayed client feedback	Set clear feedback expectations	PR10	Hold urgent meetings	KR7
X6		Regular follow-up with client	PR11	Expedite client response	KR7
X9	Interdisciplinary issues	Schedule coordination meetings	PR12	Hold emergency coordination meetings	KR8
X9		Centralize project documents	PR13	Improve collaboration tools/resources	KR9
X18	Repeated client changes	Establish change management process	PR14	Analyze root causes	KR10
X18		Ensure engineering meets standards	PR15	Analyze root causes	KR10
X21	Calculation errors	Improve communication between teams	PR16	Hold corrective discussion meetings	KR11
X21		Implement QC validation	PR17	Correct and validate errors	KR12
X21		Develop standard procedures	PR18	Correct and validate errors	KR12
X23	Unfinalized design	Establish review and approval processes	PR19	Accelerate review with stakeholders	KR13
X25	Prolonged tender process	Create tender timeline	PR20	Clarify specifications	KR14
X25		Select reliable vendors	PR21	Accelerate verification	KR15
X25		Assign dedicated review team	PR22	Accelerate verification	KR15
X37	Vendor discrepancies	Ensure tender documents clarity	PR23	Hold clarification meetings	KR16
X37		Clarify specifications before bids	PR24	Revise specifications	KR17
X37		Communicate specification updates	PR25	Revise specifications	KR17
X46	Material delay	Select reliable vendors	PR26	Expedite PO approval / alternative vendor	KR18
X46		Ensure delivery timeline realistic	PR27	Identify alternative vendors	KR19
X46		Identify critical materials early	PR28	Assign delivery coordinator	KR20
X46		Include penalty clauses	PR29	Hold coordination meetings	KR21
X52	Coordination issues	Assign coordinator	PR30	Improve coordination systems	KR20
X52		Schedule cross-discipline meetings	PR31	Hold emergency coordination meetings	KR21
X52		Use collaboration platforms	PR32	Improve coordination systems	KR21
X55	Equipment damage	Store equipment properly	PR33	Repair or replace equipment	KR22
X55		Conduct inspections	PR34	Provide emergency maintenance	KR23
X55		Train technicians	PR35	Provide emergency maintenance	KR23
X61	Engineering mismatch	Conduct site survey	PR36	Re-survey site	KR24
X61		Perform drawing reviews	PR37	Update as-built design	KR25
X61		Develop clear change procedures	PR38	Update as-built design	KR25

conduct daily Toolbox Meetings (TBM) and establish a shared storage for documents from all disciplines, allowing engineers and designers to monitor and review progress in real-time. For X18 (Frequent client changes), analyze the causes of repeated changes, improve communication with the client, and enhance work quality to minimize design errors. For X21 (Calculation and estimation errors), implement strict Quality Control (QC) to inspect work, including calculations and sizing, and develop guidelines with correct formulas and parameters. For X23 (Unfinalized engineering design phase), accelerate review processes by optimizing engineering teams to obtain client approval for tender documents. If changes occur during the tender, clarify them

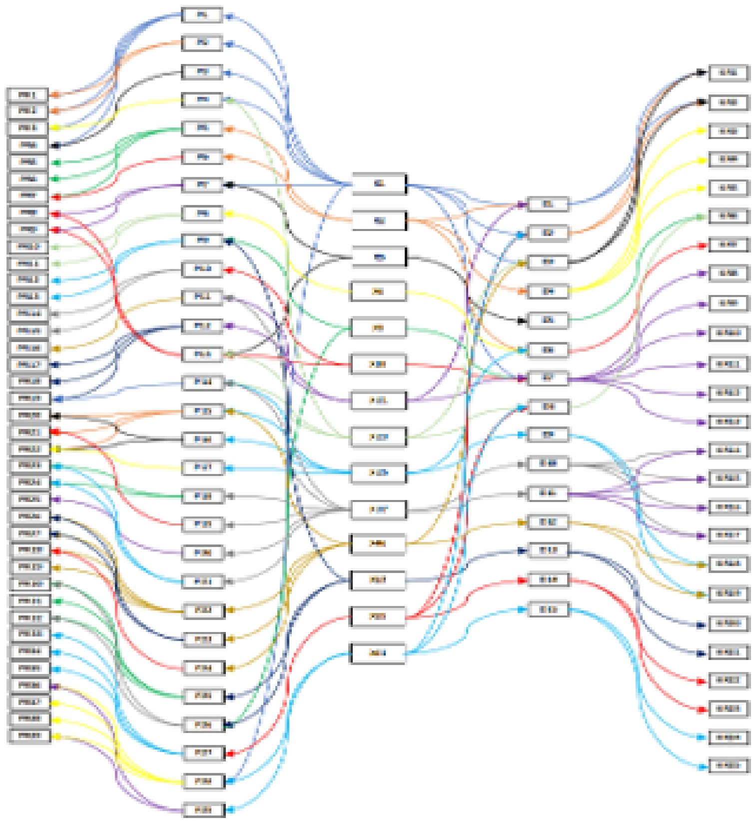

FIGURE 4 Risk Distribution in the EPC Phase.

with the selected vendor to speed up the process. For X25 (Lengthy tender process), long tender durations delay material procurement and construction work. Develop realistic tender schedules and select vendors with good reputations. For X37 (Differences in vendor specification offers), continuous discrepancies prolong vendor clarification and project delays. Ensure tender documents are clearly understood by vendors and invite only reputable vendors with prior collaboration history. If risks persist, apply point deductions during tender evaluations, potentially disqualifying vendors. For X46 (Material delivery delays), if caused by third parties or vendors, include penalty clauses for delays in contracts, seek alternative vendors, or claim compensation. For X52 (Lack of coordination among teams and disciplines), conduct weekly meetings and daily TBMs before construction work begins. Hold emergency meetings to resolve any construction issues promptly. For X55 (Equipment damage), minimize impact by storing equipment safely, performing regular inspections, and providing training on proper use, especially for easily damaged equipment. Replace or repair damaged equipment immediately if unavoidable. For X61 (Mismatch between engineering drawings/documents and actual field conditions), reduce impact by conducting detailed site surveys before engineering phases. If discrepancies are found, issue As-Built documents and obtain client approval promptly.

5 | CONCLUSION

Among the potential risks identified in the EPC Green Ammonia project, the applicable response strategies are as follows: mitigation, applied to risk variables X1, X2, X6, X9, X18, X21, X23, X25, X37, X52, X55, and X61, and transfer, applied to risk variables X5 and X46. Based on the findings of this study, several recommendations are proposed for future research to further improve the assessment of potential risk impacts. First, it is suggested that alternative analytical methods be considered when processing questionnaire results, in order to enhance the accuracy and reliability of data validation. Employing different analytical approaches such as Structural Equation Modeling (SEM), Fuzzy Logic, or Monte Carlo Simulation may provide a more comprehensive understanding of the data, enable deeper analytical insights, and help reduce potential biases. Second, future studies are encouraged to engage a larger number of respondents and subject matter experts, as an expanded participant pool ideally drawn from multiple EPC companies across different regions would contribute to more precise and representative results,

TABLE 23 Risk Response Analysis

Code	Variabel Risiko	Jenis Respon			
		Avoid	*Mitigate*	*Transfer*	*Accept*
X1	Frequent design changes		√		
X2	Delayed document submission		√		
X5	Client requests for out-of-scope design			√	
X6	Delayed client feedback after contractor document submission		√		
X9	Poor interdisciplinary integration leading to asynchrony		√		
X18	Repeated changes from client or owner		√		
X21	Calculation and estimation errors		√		
X23	Unfinalized engineering phase design		√		
X25	Prolonged tender process		√		
X37	Discrepancy in vendor specifications		√		
X46	Material delivery delays			√	
X52	Poor inter-disciplinary coordination		√		
X55	Equipment damage		√		
X61	Engineering documents mismatch with field conditions		√		

thereby strengthening the overall credibility and generalizability of the analysis. Finally, it is recommended that future research incorporate a broader range of risk variables and risk factors, as widening the scope of investigation would enable researchers to capture a more holistic view of potential risks ultimately leading to more robust and comprehensive risk management strategies for EPC projects.

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References

1. International Renewable Energy Agency. Green hydrogen cost reduction: Scaling up electrolyzers to meet the 1.5°C climate goal. Abu Dhabi: IRENA; 2020.
2. Nayak-Luke RM, Forbes C, Cesaro Z, Banares-Alcantara R, Rouwenhorst KHR. Techno-economic Aspects of Production, Storage and Distribution of Ammonia. In: Techno-economic Challenges of Green Ammonia as an Energy Vector Elsevier; 2021.p. 191–207.
3. Santosa B. Manajemen Proyek: Konsep & Implementasi. Graha Ilmu; 2009.
4. Djojosoedarso S. Prinsip-Prinsip Manajemen Risiko Asuransi. Salemba Empat; 2003.
5. Sitinjak S. Lisrel. 1 ed. Graha Ilmu; 2006.
6. Sanaky MM, Saleh LM, Titaley HD. Analisis Faktor-Faktor Penyebab Keterlambatan pada Proyek Pembangunan Gedung Asrama MAN 1 Tulehu Maluku Tengah. Jurnal Simetrik 2021;11(1):1–10.

7. Sujarweni VW. Metodologi Penelitian Bisnis dan Ekonomi. Pustaka Baru Press; 2018.

8. Sujarweni VW. SPSS untuk Penelitian. Pustaka Baru Press; 2014.

9. Razali NM, Wah YB. Power Comparisons of Normality Tests: Shapiro-Wilk, Kolmogorov–Smirnov, Lilliefors and Anderson-Darling. Journal of Statistical Modeling and Analytics 2011;.

10. Hasya A. Risk Management Study. Journal of Engineering 2017;.

11. Siroj RA, Afgani W, Fatimah D, Salsabila GZ. Metode Penelitian Kuantitatif: Pendekatan Ilmiah untuk Analisis Data. Jurnal Review Pendidikan dan Pengajaran 2024;7(3). http://journal.universitaspahlawan.ac.id/index.php/jrpp.

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