

## Article

# Risk Assessment of Renewable Energy Investments: The Case of Saudi Arabia

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## Abstract

Renewable energy plays a vital role in global sustainability goals, yet investment in this sector remains exposed to numerous uncertainties that may hinder project success. While the subject has attracted greater attention from scholars and policymakers, the lack of specific structures for prioritizing investment risks in renewable energy in Saudi Arabia persists. This study investigates and prioritizes the risks associated with renewable energy investments in Saudi Arabia. A three-stage methodological approach was used: risks were first identified through a comprehensive literature review and organized into eight categories; experts from academia, the private sector, and the government assessed these risks using the Fuzzy Group Decision-Making (FGDM) method to incorporate both probability and impact; and response strategies were developed for the most significant risks. Among the 23 risk factors analyzed, 11 were categorized as high-level. The top risks include insufficient supporting policy frameworks and incentives (0.6025), complex approval systems (0.5873), and environmental impact on solar panel efficiency (0.5738). The findings emphasize the importance of streamlining regulatory frameworks and enhancing technical and infrastructural readiness. This study provides a new evidence-based framework for informed decision-making and improving the planning of investments in renewable energy in Saudi Arabia.

**Keywords:** renewable energy; Saudi Arabia; risk assessment; risk response; fuzzy; FGDM



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## 1. Introduction

Renewable energy has become a central pillar of global strategies to reduce greenhouse gas emissions and ensure long-term energy security. As nations intensify their commitments to sustainability, investments in renewable technologies have expanded rapidly. According to the International Energy Agency (IEA), global renewable capacity grew by nearly 510 GW in 2023, the highest annual increase in history [1]. Solar and wind power dominate this expansion, supported by declining technology costs and improving policy frameworks. However, despite this progress, renewable energy investments remain exposed to complex and interrelated risks that can hinder project development, financing, and operation.

Saudi Arabia has recognized renewable energy as a key driver in its economic transformation under the Vision 2030 initiative, which seeks to diversify the economy and reduce dependence on fossil fuels. The Kingdom aims to generate 50% of its electricity from

renewable sources by 2030 [2]. Favorable natural conditions, including high direct normal irradiation and vast available land, offer significant potential for solar and wind energy projects. Yet, despite these advantages, renewable energy deployment in Saudi Arabia is still at an early stage, and investments remain constrained by regulatory uncertainty, limited technical capacity, environmental challenges, and evolving market structures.

### *1.1. Global Renewable Energy Risk Assessments*

Globally, numerous studies have explored renewable energy risks using quantitative and multi-criteria approaches. Nuriyev et al. [3] assessed nine key risk factors in Azerbaijan and identified policy instability and limited financial incentives as the primary barriers. Ref. [4] applied an Analytic Network Process (ANP) cloud model to assess renewable energy investment risks in Belt and Road countries, highlighting political and economic uncertainty as key influences. Ref. [5] conducted a lifecycle-based assessment in Russia, emphasizing the need for integrated risk management across project phases. Ref. [6] used a multi-criteria decision-making (MCDM) framework to evaluate renewable risks in Turkey, showing that economic and regulatory issues dominate investor perceptions. Ref. [7] expanded on this research by classifying renewable risks into policy, technical, financial, and environmental categories, confirming that context-specific factors strongly influence investment feasibility.

### *1.2. Risk Assessment Methodologies*

While the literature highlights the diversity of risk factors, few studies provide a structured, quantitative prioritization framework that captures expert-judgment uncertainty. In this respect, Fuzzy Group Decision-Making (FGDM) has emerged as a particularly effective approach. FGDM integrates fuzzy set theory with group decision-making principles to quantify uncertainty and subjectivity in expert assessments [8–10]. Unlike deterministic MCDM methods such as the Analytical Hierarchy Process (AHP) or Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), FGDM allows linguistic variables to be converted into Fuzzy Triangular Numbers (FTNs), capturing nuanced differences in expert perceptions. This makes it particularly suited to complex decision environments, such as renewable energy investment, where precise data are often unavailable and expert consensus is required.

### *1.3. Fuzzy Group Decision Making Techniques*

Several studies have successfully applied fuzzy-based decision-making models to energy project contexts. Ref. [9] employed a fuzzy risk evaluation method for wind energy projects, demonstrating its ability to integrate probabilistic uncertainty into expert judgments [11]. Ref. [12] extended FGDM applications to engineering, procurement, and construction (EPC) risk assessment, illustrating its flexibility across sectors. Similarly, Ref. [13] highlighted that weighting expert competence improves the precision of aggregated fuzzy results. These developments underscore FGDM's adaptability in combining qualitative insights with quantitative rigor.

Recent work has gone beyond classical fuzzy sets by developing intuitionistic and Pythagorean fuzzy models that handle expert hesitation more clearly and support multi-criteria decisions. In intuitionistic fuzzy models, new similarity and entropy measures, together with interval-valued versions, have been linked with methods such as AHP and TOPSIS to help with risk evaluation and investment analysis. At the same time, Pythagorean and fuzzy set development has led to new information measures, aggregation tools, and full decision-making procedures that are now used in supplier selection, sustainability assessment, and diagnostics. Overall, these developments point to fuzzy decision

models that are better able to deal with uncertainty, hesitation, and differences in expert opinion in complex energy and investment problems [14–16].

#### 1.4. Gap

However, in Saudi Arabia, the application of FGDM to renewable energy risk analysis remains limited. Previous research on the Kingdom's energy transition has primarily focused on policy reviews, technology assessments, and macroeconomic modeling, often overlooking integrated risk-prioritization frameworks. Given the region's distinctive environmental, policy, and market conditions, a fuzzy group decision approach can offer valuable clarity on risk hierarchies and the most urgent areas for intervention.

Accordingly, this study aims to address this research gap by applying FGDM to identify, evaluate, and prioritize renewable energy investment risks in Saudi Arabia. The methodology captures both the uncertainty inherent in expert judgment and the complexity of interdependent risk factors. Specifically, this study seeks to:

- Identify renewable energy investment risks through an extensive literature review;
- Assess and prioritize these risks using the Fuzzy Group Decision-Making method, incorporating expert competence weighting; and
- Propose tailored response strategies for the highest-priority risks within Saudi Arabia's renewable energy sector.

This research contributes to the literature by providing a systematic, context-specific risk assessment framework using FGDM. It enhances understanding of how fuzzy-based decision models can support policymaking and investment planning in emerging renewable energy markets and offers practical recommendations for reducing risk and improving investor confidence.

## 2. Materials and Methods

### 2.1. Methodology

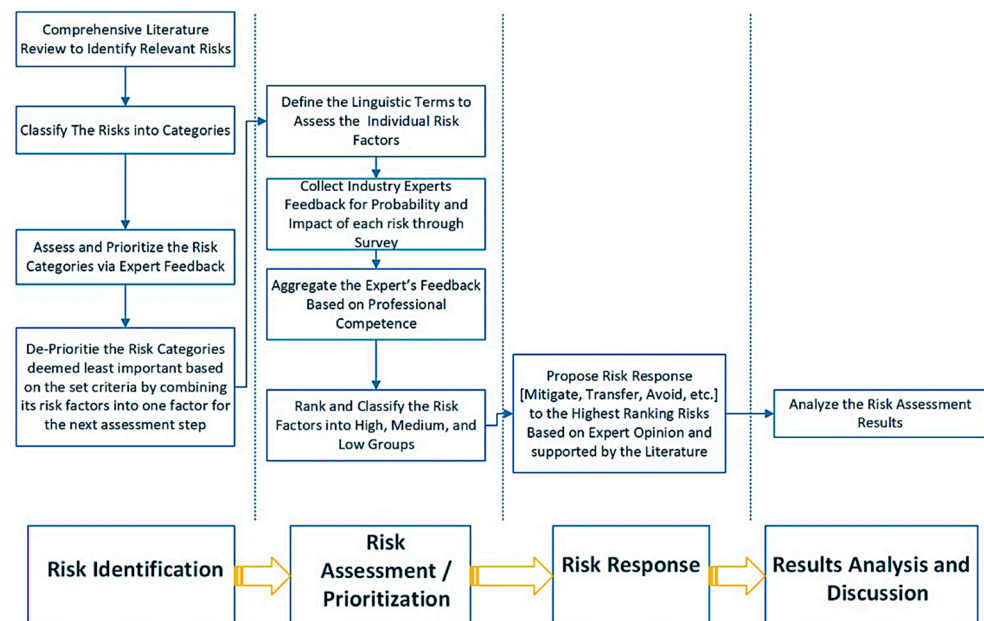
This research followed a structured three-stage methodology designed to identify, assess, and prioritize renewable energy investment risks in Saudi Arabia. The process integrated both qualitative insights and quantitative analysis through the Fuzzy Group Decision-Making (FGDM) approach, ensuring a comprehensive evaluation of expert judgment under uncertainty [17]. The three stages are illustrated conceptually in Figure 1 and described as follows.

**Stage 1: Risk Identification.** A comprehensive literature review was undertaken to identify potential risk factors associated with renewable energy investments [18–20]. Twenty-eight distinct risks were compiled from prior studies, covering eight major categories: social, environmental, policy and regulatory, political, economic/finance, market, technical, and curtailment. These risk factors served as the foundation for expert assessment in the subsequent stages.

**Stage 2: Risk Assessment and Prioritization.** Expert judgment was used to evaluate each identified risk based on its probability and impact. To address the inherent uncertainty and variability in human perception, linguistic evaluations were transformed into Fuzzy Triangular Numbers (FTNs) [21,22]. The FGDM model was applied to aggregate these inputs, producing weighted fuzzy scores for each risk factor. The outcomes of this stage provided a ranked hierarchy of risk factors according to their perceived significance in the Saudi Arabian context.

**Stage 3: Risk Response Development.** For high-priority risks, a separate expert consultation was conducted to propose mitigation and response strategies. Both empirical evidence and literature-based best practices informed these strategies [23]. The iterative

structure of the methodology enabled consistent feedback across stages, ensuring that results from earlier steps informed subsequent analysis.



**Figure 1.** Methodology Process Diagram.

## 2.2. Data Collection and Participants

Data for this research were collected through structured online surveys distributed to domain experts working in academia, government, and the private sector. The study followed a three-phase data collection process aligned with the methodological stages. In the first phase, 12 experts evaluated the relevance of the 8 risk categories identified in the literature. In the second phase, 21 experts assessed the refined list of 23 individual risk factors derived from the high-priority categories. In the third phase, the same expert group was consulted again to develop appropriate mitigation strategies for the most critical risks. Participation was voluntary, and informed consent was obtained from all participants prior to data collection.

Experts were selected based on professional experience and involvement in renewable energy development, financing, or policy. A minimum of two years of relevant experience was required for participation. Information on educational background, years of experience, and organizational position was collected to calculate an expert competence score, which was later used as a weighting factor in the FGDM model. The participant pool included energy engineers, project managers, policy specialists, and academic researchers. Although the number of participants was limited, their combined expertise provided a strong representation of Saudi Arabia's renewable energy sector.

## 2.3. Instruments

The main instruments supported data collection and analysis:

- **Structured Questionnaires.** Developed in Google Forms, the questionnaires were designed to capture expert evaluations using predefined linguistic terms for both probability and impact. The survey design enabled efficient, remote data collection across different professional sectors.
- **Fuzzy Scoring Scales.** A 5-point Likert-type linguistic scale was employed to capture expert opinions, later transformed into fuzzy values (see Section 2.5). This allowed qualitative judgments to be expressed quantitatively, maintaining consistency in interpretation.

- Analytical Tools. Data analysis was performed in Microsoft Excel (MS Office Version 2508), which was configured to support fuzzy logic operations and defuzzification. Visualizations, such as risk matrices and comparative charts, were generated to illustrate ranking outcomes.
- The snowball sampling technique was used to expand the pool of experts. Initial respondents were encouraged to nominate other qualified experts, thereby improving diversity in professional backgrounds and reducing potential bias. Ethical considerations were observed by maintaining participant anonymity and using aggregated data for analysis.

#### 2.4. Fuzzy Group Decision-Making (FGDM)

The FGDM method was selected because of its suitability for decision-making under uncertainty and its ability to synthesize multiple expert opinions. Traditional quantitative approaches, such as AHP or TOPSIS, often assume deterministic data, which can be limiting when dealing with subjective evaluations [24]. FGDM overcomes this limitation by integrating fuzzy set theory to represent linguistic variables as Fuzzy Triangular Numbers (FTNs) [25].

Each expert's evaluation of probability and impact for every risk factor was converted into an FTN, defined by three parameters: lower (L), middle (M), and upper (U) bounds. These values reflect the range of possible assessments for each risk. To account for variations in expertise, each expert was assigned a competence weight ( $W_i$ ) based on educational level (EL), experience years (EY), and professional role (PP); each criterion is given equal weight (0.33); and global competence weights are computed to sum to one. These are calculated as follows:

$$W_i^{\text{Indv}} = (W_{\text{PP}} + W_{\text{EY}} + W_{\text{EL}})_i \quad (1)$$

$$W_i^g = (W_i^{\text{Indv}}) / (\sum_{i=1}^n \times W_i^{\text{Indv}}), \quad \sum_{i=1}^n \times W_i^g = 1 \quad (2)$$

where  $W_i^{\text{Indv}}$  is the competence weight of an individual,  $W_{\text{PP}}$  is the weight for professional position,  $W_{\text{EY}}$  is the weight for experience years, and  $W_{\text{EL}}$  is the weight for educational level.

The Fuzzy Decision Matrix (FDM) for each risk factor (f) was then constructed as:

$$FDM_{if} = \begin{bmatrix} L_1 & M_1 & U_1 \\ \vdots & \vdots & \vdots \\ L_n & M_n & U_n \end{bmatrix} \quad (3)$$

Weighted fuzzy scores (FS) were computed for each risk based on the aggregated expert judgments:

$$FS_{pf} = \left( \sum_{i=1}^n L_i W_i^g, \sum_{i=1}^n M_i W_i^g, \sum_{i=1}^n U_i W_i^g \right) \quad (4)$$

Defuzzification was then performed to convert fuzzy scores into crisp values for ranking:

$$f(x_i) = (FRS_f)_{def} = \frac{(FRS_f)_L + 4(FRS_f)_M + (FRS_f)_U}{6} \quad (5)$$

Finally, risk levels were categorized as Very High, High, Medium, Low, or Very Low based on their defuzzified scores. The FGDM model thus provided a structured, transparent mechanism for ranking risk factors by perceived significance while preserving the uncertainty inherent in human judgment.

The group risk score can be calculated by applying the following equation:

$$RSG_a = \frac{1}{m} \sum_{r=1}^m (FRS_r)_{def}. \quad \%RSG_a = \frac{RSG_a}{\sum_{a=1}^n RSG_a} \quad (6)$$

### 2.5. Probability and Impact Scales

To ensure consistency in expert evaluation, predefined linguistic variables were used for both probability and impact ratings. These linguistic terms were associated with corresponding Fuzzy Triangular Numbers (FTNs) to translate subjective expert opinions into quantitative form. Tables 1 and 2 present the scales applied in this study.

**Table 1.** Probability linguistic variables and corresponding FTNs [8,22,26].

| Probability Term | FTN (L, M, U)   | Description           |
|------------------|-----------------|-----------------------|
| Rare             | (0, 0.1, 0.3)   | Unlikely to happen    |
| Unlikely         | (0.1, 0.3, 0.5) | Possible but unlikely |
| Medium           | (0.3, 0.5, 0.7) | Moderate probability  |
| Likely           | (0.5, 0.7, 0.9) | Almost sure to happen |
| Almost Certain   | (0.7, 0.9, 1)   | Sure to happen        |

**Table 2.** Impact linguistic variables and corresponding FTNs [8,22,26].

| Impact Term   | FTN (L, M, U)   | Description          |
|---------------|-----------------|----------------------|
| Insignificant | (0, 0.1, 0.3)   | No serious effect    |
| Minor         | (0.1, 0.3, 0.5) | Mild negative effect |
| Significant   | (0.3, 0.5, 0.7) | Significant damage   |
| Major         | (0.5, 0.7, 0.9) | Major damage         |
| Severe        | (0.7, 0.9, 1)   | Severe damage        |

## 3. Results

### 3.1. Risk Identification

Following the methodological process outlined in Section 2, 28 risk factors were initially identified through an extensive literature review (Refer to Appendix A). These risks were distributed among eight major categories: social, environmental, policy and regulatory, political, economic/finance, market, technical, and curtailment. Each category was subsequently assessed by experts for its overall impact and probability to determine its relative importance. The outcomes of this preliminary evaluation are presented in Table 3, which summarizes the average risk scores for each category.

**Table 3.** Risk category score averages.

| Category                    | Average Overall Risk Value |
|-----------------------------|----------------------------|
| Social Risks                | 2.75                       |
| Curtailment Risks           | 6.22                       |
| Environmental Risks         | 9.24                       |
| Policy and Regulatory Risks | 9.97                       |
| Political Risks             | 4.38                       |
| Economic/Finance Risks      | 9.51                       |
| Market Risks                | 7.78                       |
| Technical Risks             | 9.44                       |

The analysis revealed an average score of 7.41 across all categories. Categories with scores above this threshold were retained for detailed analysis. As shown in Table 3,

the categories of environmental, policy and regulatory, economic/finance, market, and technical risks exceeded the threshold and were therefore prioritized for the next phase of the study. Social, political, and curtailment risks, though relevant, were deprioritized based on their lower overall ratings.

### 3.2. Risk Prioritization and Assessment

The refined list of 23 risks was evaluated by 21 experts using the FGDM model (as explained in Section 2), which aggregated weighted linguistic judgments into fuzzy triangular numbers. The detailed results are shown in Table 4, where each risk factor is presented with its corresponding fuzzy score, rank, and risk level classification.

**Table 4.** Risk factors score, rank, and level.

| Risk Code | Risk Category               | Risk Factor                                                                                                                | Risk Score | Ranking | Risk Level |
|-----------|-----------------------------|----------------------------------------------------------------------------------------------------------------------------|------------|---------|------------|
| R18       | Policy and Regulatory Risks | Insufficient supporting policy frameworks and incentives, uncertainty of regulations, and an unattractive regulated tariff | 0.6025     | 1       | High       |
| R9        | Policy and Regulatory Risks | Complex approval system                                                                                                    | 0.5873     | 2       | High       |
| R5        | Environmental Risks         | Effect of the environment on the solar panels' efficiency and reliability                                                  | 0.5738     | 3       | High       |
| R21       | Technical Risks             | Grid access                                                                                                                | 0.5696     | 4       | High       |
| R6        | Environmental Risks         | Waste management for the renewable energy equipment                                                                        | 0.5425     | 5       | High       |
| R19       | Technical Risks             | Limited technical skills and capacity in operations and maintenance                                                        | 0.5275     | 6       | High       |
| R15       | Technical Risks             | Research & development capacity                                                                                            | 0.5181     | 7       | High       |
| R12       | Economic/Finance Risks      | Decommission costs                                                                                                         | 0.5131     | 8       | High       |
| R16       | Market Risks                | Market competitiveness and distortion issues                                                                               | 0.5124     | 9       | High       |
| R11       | Economic/Finance Risks      | High initial cost                                                                                                          | 0.5085     | 10      | High       |
| R3        | Environmental Risks         | Natural disasters cause force majeure                                                                                      | 0.5025     | 11      | High       |
| R13       | Economic/Finance Risks      | Limited access to affordable finance and high Interest Rates                                                               | 0.4971     | 12      | Medium     |
| R20       | Technical Risks             | Limitations in the quality control and availability of hardware                                                            | 0.4961     | 13      | Medium     |
| R7        | Environmental Risks         | Resource extraction impact                                                                                                 | 0.4954     | 14      | Medium     |

Table 4. Cont.

| Risk Code | Risk Category          | Risk Factor                                   | Risk Score | Ranking | Risk Level |
|-----------|------------------------|-----------------------------------------------|------------|---------|------------|
| R17       | Market Risks           | Limited market and consumer data availability | 0.4946     | 15      | Medium     |
| R18       | Technical Risks        | Technology maturity                           | 0.4922     | 16      | Medium     |
| R2        | Curtailment Risks      | Lower revenue due to unexpected curtailment   | 0.4727     | 17      | Medium     |
| R23       | Technical Risks        | Resource and demand assessment risk           | 0.4654     | 18      | Medium     |
| R10       | Political Risks        | Political Risks                               | 0.4551     | 19      | Medium     |
| R22       | Technical Risks        | Transport/construction/completion Risk        | 0.4542     | 20      | Medium     |
| R14       | Economic/Finance Risks | Poor economic conditions and currency risk    | 0.4237     | 21      | Medium     |
| R4        | Environmental Risks    | Project's influence on the local environment  | 0.3988     | 22      | Medium     |
| R1        | Social Risks           | Social Risks                                  | 0.3328     | 23      | Medium     |

Among the identified risks, eleven were classified as high-level and twelve as medium-level. Policy-related risks emerged as the most significant, with policy uncertainty and tariff unattractiveness (R18) and complex approval systems (R9) ranking first and second, respectively. Technical and environmental risks followed, including solar panel efficiency loss due to the effect of the environment (R5) and waste management (R6). Economic and market-related risks, such as high initial cost (R11) and market distortions (R16), also ranked among the top ten. These findings are visually represented in Figure 2 (risk heatmap) and Figure 3 (risk score ranking chart).

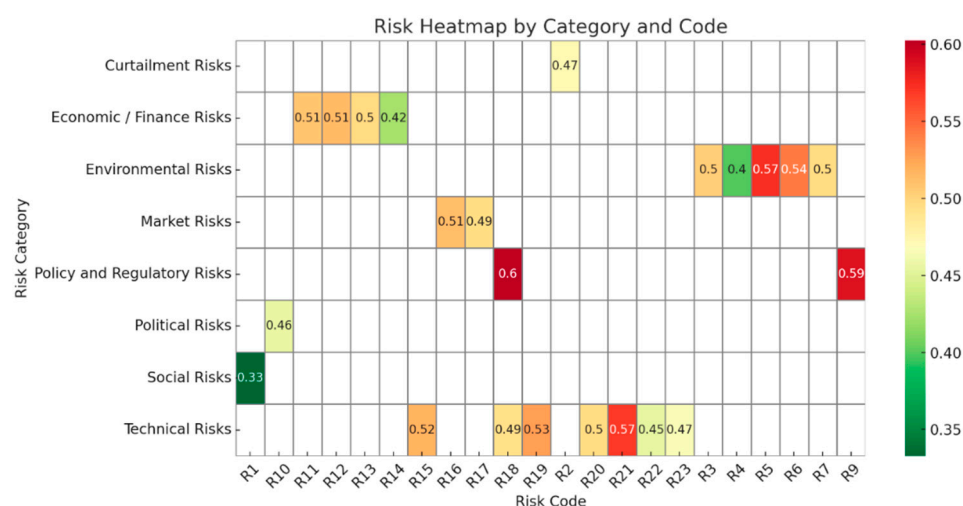


Figure 2. Risk factor heatmap.

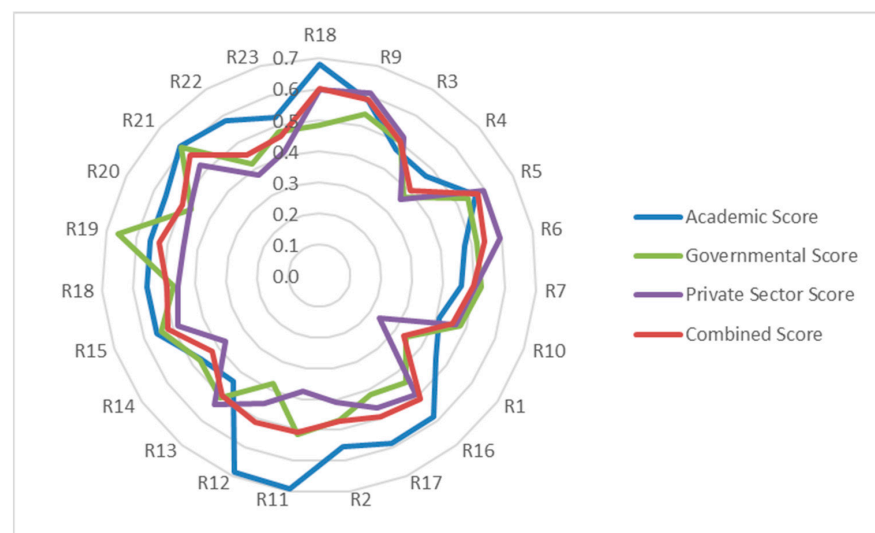
The FGDM results demonstrate that the most severe risks in the Saudi renewable energy sector are interrelated, combining policy, technical, and environmental dimensions. The integration of fuzzy logic enabled the incorporation of uncertainty into expert assessments, thereby improving the reliability and interpretability of the ranking outcomes.



**Figure 3.** Risk factor scores.

### 3.3. Sensitivity Analysis

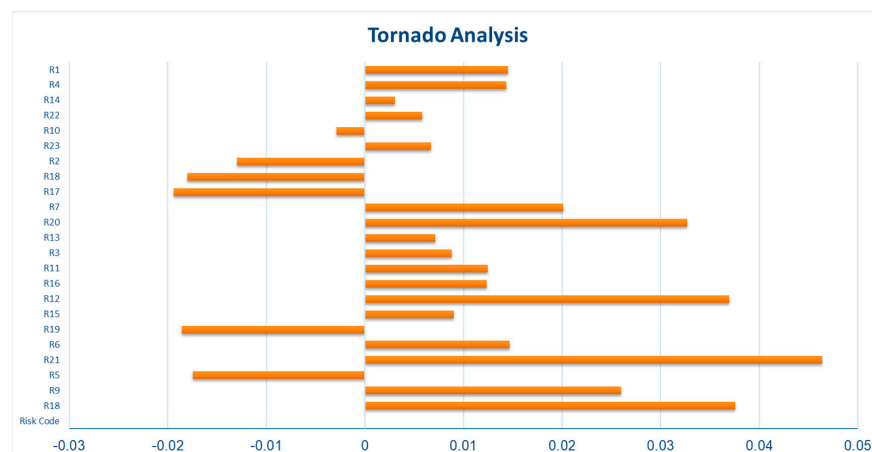
To validate the robustness of the FGDM results, a sensitivity analysis was conducted by examining variations in expert weighting and subgroup perceptions. Experts were grouped into three sectors—academic, government, and private—to explore differences in prioritization. The comparative results are visualized in Figure 4.



**Figure 4.** Sensitivity analysis of the risk factors comparing different perspectives of stakeholders.

The analysis indicated some divergence in how stakeholder groups perceive risks. Academic experts tended to emphasize economic and lifecycle risks, such as high initial cost and decommissioning costs (R11 and R12). Government experts prioritized technical capability and grid access challenges (R19 and R21), reflecting their operational perspective. Private sector experts, on the other hand, rated policy complexity and waste management as their top concerns, focusing on regulatory feasibility and implementation barriers. Figure 5 (tornado chart) compares weighted and unweighted FGDM results, illustrating

that although minor variations exist, the overall ranking of high-priority risks remains stable, confirming the model's consistency.



**Figure 5.** Tornado chart for the risk scores with and without the expert weightings.

The results were tested using the Kruskal–Wallis H test whether the expert groups differ for each risk item, the test indicated that there is a significant difference in the dependent variable between the different groups,  $H(2) = 8.61$ ,  $p = 0.014$ , with a mean rank score of 44.83 for Academic Group, 31.78 for Governmental Group, 28.39 for Private Sector Group, this confirms the subgroup variation. Additionally, the results were tested using Kendall's W for consensus metrics; Kendall's coefficient of concordance showed moderate agreement among the three stakeholder groups across the 23 risk items ( $W = 0.51$ ). However, this was not statistically significant at the 0.05 level ( $p = 0.054$ ), which suggests that agreement was limited and that the groups did not fully share the same views.

This divergence in experts' perspectives, based on their backgrounds, can be attributed to differences in knowledge, background bias, contextual and perspective variance, and varying levels of judgment ability.

### 3.4. Risk Response Strategies

Based on expert consultations and literature synthesis [27–31], targeted response strategies were developed for the 11 high-priority risks. These strategies are summarized in Table 5. They include recommendations for regulatory enhancements, improvements in technical capacity, environmental mitigation measures, and financial support mechanisms.

**Table 5.** Summary of risk responses according to participants.

| Risk Factor                                                                                                                 | Participant 1     | Participant 2     | Participant 3     | Participant 4     |
|-----------------------------------------------------------------------------------------------------------------------------|-------------------|-------------------|-------------------|-------------------|
| Grid access                                                                                                                 | Mitigate the Risk | Mitigate the Risk | Mitigate the Risk | Mitigate the Risk |
| Effect of the environment on the solar panels' efficiency and reliability                                                   | Mitigate the Risk | Accept the Risk   | Mitigate the Risk | Mitigate the Risk |
| Complex approval system                                                                                                     | Escalate the Risk | Escalate the Risk | Escalate the Risk | Accept the Risk   |
| Insufficient supporting policy frameworks and incentives, uncertainty of regulations, and an unattractive regulated tariff. | Escalate the Risk | Mitigate the Risk | Escalate the Risk | Mitigate the Risk |

Table 5. *Cont.*

| Risk Factor                                                         | Participant 1     | Participant 2     | Participant 3     | Participant 4     |
|---------------------------------------------------------------------|-------------------|-------------------|-------------------|-------------------|
| Waste management for the renewable energy equipment                 | Mitigate the Risk | Transfer the Risk | Escalate the Risk | Mitigate the Risk |
| Limited technical skills and capacity in operations and maintenance | Mitigate the Risk | Mitigate the Risk | Escalate the Risk | Mitigate the Risk |
| Research & development capacity                                     | Escalate the Risk | Escalate the Risk | Mitigate the Risk | Mitigate the Risk |
| Decommission costs                                                  | Accept the Risk   | Transfer the Risk | Transfer the Risk | Transfer the Risk |
| Market competitiveness and distortion issues                        | Accept the Risk   | Mitigate the Risk | Mitigate the Risk | Accept the Risk   |
| High initial cost                                                   | Transfer the Risk | Transfer the Risk | Transfer the Risk | Mitigate the Risk |
| Natural disasters cause force majeure                               | Accept the Risk   | Accept the Risk   | Accept the Risk   | Accept the Risk   |

For instance, addressing policy uncertainty requires establishing a long-term, transparent policy framework with clear tariff mechanisms and consistent incentives. Complex approval procedures can be mitigated through administrative streamlining and the creation of unified permitting bodies. On the technical front, capacity-building initiatives and localized R&D are critical to reducing dependence on external expertise. Environmental challenges, including dust and heat impacts on solar panels, call for region-specific technology adaptation and regular maintenance protocols, as well as a focus on research and development programs.

Complete set of data sheets and analysis sheets has been attached as Supplementary Material.

#### 4. Discussion

The findings from the FGDM analysis provide a structured understanding of the relative importance and interrelationships among renewable energy investment risks in Saudi Arabia. The multi-stage approach not only identified and ranked risks but also revealed their systemic connections, underscoring the multidimensional nature of investment uncertainty in emerging energy markets. In terms of relevance to Saudi Arabia, these results are highly relevant given the changing regulatory environment under Vision 2030. While much has been done to develop renewable energy policies, the relatively recent introduction of large-scale renewable energy initiatives highlights the evolving nature of the environment. This supports the argument posed by the International Energy Agency [1], which highlights the importance of policy clarity for sustaining investor confidence in changing energy markets.

The findings confirm several observations found in previous international studies. For example, the prominence of policy and regulatory risks aligns with findings by Wu et al. [4] and Abba et al. [7], who emphasized that inconsistent or ambiguous policy frameworks remain a major barrier to renewable energy growth in developing regions. Similarly, the significance of technical challenges and environmental effects is echoed by Kul et al. [6], who noted that operational inefficiencies and climatic factors can substantially reduce the reliability of renewable energy systems. The results also parallel those of Chebotareva et al. [5], who emphasized that lifecycle risk management and operational risks, especially those related to maintenance and reliability issues, are major success drivers in project development. In the case of Saudi Arabia, the risks are compounded by the need to incorporate renewable energy in a system that has traditionally relied on fossil fuels.

Environmental risks, such as the impact of harsh climatic conditions on solar panel performance, were also identified as major contributors to overall investment risks. This is in line with the studies by Islam et al. [9], which showed that environmental uncertainty is an essential factor influencing project risks. In an arid environment like Saudi Arabia's, environmental factors such as dust accumulation, temperature, and sandstorms can negatively affect solar panel performance.

The FGDM model proved effective in synthesizing subjective expert judgments into quantitative, comparable outcomes. By incorporating fuzzy triangular numbers and competence-based weighting, the model accounted for uncertainty and variability in expert assessments. In contrast to traditional deterministic approaches like AHP and TOPSIS, which require crisp numerical inputs, fuzzy-based approaches can incorporate linguistic judgments and ambiguity. This has been widely acknowledged in the literature, especially by Kahraman [22], who noted that fuzzy multi-criteria decision-making approaches are more suitable for complex environments where data may be imprecise or incomplete. Similarly, Chen [26] has shown that employing triangular fuzzy numbers can improve the robustness of a group decision-making process. The consistency between weighted and unweighted rankings, as shown in Figure 5, further validates the robustness of the results.

The limitations of the FGDM model include the need to find suitable linguistic expressions for risk evaluation and appropriate rules to aggregate and quantify the linguistic terms into risk rankings [9]. Furthermore, the accuracy of expert-based evaluations depends heavily on the selection of qualified participants and the proper weighting of their inputs based on their professional competence. This has been mitigated through conduction of sensitivity analysis, as well as transparent weighting.

From a policy perspective, the analysis underscores the importance of prioritizing structural and procedural enhancements to further gain investor confidence. The high ranking of policy-related and technical risks suggests that improvements in regulatory clarity, institutional efficiency, and technical preparedness are likely to yield significant benefits for the performance of renewable energy investments. Moreover, the stakeholder sensitivity analysis (Section 3.3) reveals the need for collaborative engagement among policymakers, developers, and researchers to ensure balanced risk mitigation strategies. Similar observations have been made by Erfani and Tavakolan [12], who noted that applying fuzzy group decision-making methods yields stable prioritization outcomes despite changes in expert information.

Finally, the integration of expert-derived response strategies (Table 5) bridges the gap between analytical evaluation and actionable planning. By translating ranked risks into targeted interventions, the study offers a practical roadmap for improving investment readiness in Saudi Arabia's renewable energy sector.

In summary, the results and subsequent discussion highlight how combining fuzzy logic and expert judgment enables a comprehensive understanding of complex investment risks. The approach adopted in this study contributes not only to the academic literature on renewable energy risk assessment but also provides actionable insights for policymakers and investors seeking to enhance the sustainability and resilience of the Kingdom's renewable energy transition.

## 5. Conclusions

This study presented a comprehensive evaluation of renewable energy investment risks in Saudi Arabia using the Fuzzy Group Decision-Making (FGDM) approach. By combining expert judgment with fuzzy logic, the research provided a structured, practical framework for identifying, prioritizing, and addressing the key risks influencing renewable energy development in the Kingdom.

The analysis revealed that policy and regulatory, technical, and environmental dimensions are the most influential areas shaping investment outcomes. Among the 23 risk factors evaluated, 11 were identified as high-priority, including policy uncertainty and tariff unattractiveness, complex approval systems, and environmental effects on solar panel efficiency. These findings highlight opportunities for continuous policy refinement, streamlined administrative coordination, and tailored technical strategies to enhance project implementation and long-term performance.

The FGDM method proved to be a valuable tool for supporting decision-making under uncertainty. It enabled expert insights to be translated into measurable outcomes, enabling transparent, evidence-based risk prioritization. The inclusion of competence-based expert weighting strengthened the credibility of the aggregated results and reinforced FGDM's suitability for guiding practical investment and policy decisions.

From a policymaking perspective, the results underline the value of sustained collaboration between government entities, industry stakeholders, and researchers. Continued efforts to align policies, simplify regulatory processes, and expand technical and institutional capacity will encourage greater private sector participation and investment confidence. Integrating environmental considerations early in project planning and strengthening local R&D initiatives will further enhance Saudi Arabia's resilience in renewable energy.

While the study provides a comprehensive overview of sectoral risks, its scope was limited by the relatively small pool of experts available, reflecting the emerging stage of the national renewable energy industry. Future research may benefit from a broader and more diverse expert base, renewable energy technology-specific assessments, and longitudinal analyses to capture evolving risk trends. The adopted cross-sectional design approach means the findings reflect expert judgments at one point in time and may not capture how renewable energy risks evolve as the Saudi market matures. Additionally, the analysis relies primarily on expert survey data, which limits triangulation, even though the FGDM approach helps structure and aggregate expert opinion.

In conclusion, this study provides a practical, cooperative framework for renewable energy risk assessment in Saudi Arabia. By emphasizing collaboration, transparency, and shared learning, the study supports policymakers and stakeholders in fostering a balanced and adaptive approach to achieving the renewable energy goals outlined in Vision 2030.

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## Appendix A

Description and references for each risk factor identified from the literature.

**Table A1.** Risk factors description and references.

| Risk Category       | No. | Risk Factor                                                                                  | Description                                                                                                                                                                                                                                                                                                 | References  |
|---------------------|-----|----------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| Social Risks        | R1  | The foreign project team's unfamiliarity with the project environment is affecting progress. | Foreign project personnel unfamiliar with the environment and lacking a network may hinder the project's progress and cause delays.                                                                                                                                                                         | [4,32,33]   |
|                     | R1  | Public resistance to Renewable energy projects                                               | Some public resistance to renewable energy projects has been noted in some countries; this is often due to environmental factors in the area or job-market impacts, etc.<br>Other reasons for public resistance include noise emissions or air quality from wind turbines, or water supply from hydropower. | [4,34,35]   |
|                     | R1  | Social instability                                                                           | Instability caused by social events such as Riots or workers' strikes can negatively impact renewable energy projects, leading to delays and investment losses.                                                                                                                                             | [36–38]     |
| Curtailment Risks   | R2  | Lower revenue due to unexpected curtailment                                                  | Due to unplanned curtailments caused by grid bottlenecks, lower revenue is a risk.                                                                                                                                                                                                                          | [36,39]     |
| Environmental Risks | R3  | Natural disasters cause force majeure                                                        | This risk is associated with the impact of natural disasters, which can cause force majeure and stoppages, negatively impacting investments.                                                                                                                                                                | [37,40]     |
|                     | R4  | The project's influence on the local environment.                                            | Renewable energy projects may affect the local environment, for example, by impacting local animals (e.g., wind farms' effects on birds) or hydrology. This may also lead to legal issues for developers.                                                                                                   | [6,7,29,41] |

Table A1. Cont.

| Risk Category               | No. | Risk Factor                                                                                                                 | Description                                                                                                                                                                                                                                                                                                            | References |
|-----------------------------|-----|-----------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| Environmental Risks         | R5  | Effect of the environment on the solar panels                                                                               | Dust and sandstorms reduce the efficiency of solar panels, a risk in countries where such weather is common. Hail may also negatively impact solar panels. Overheating due to extreme temperatures can also reduce the efficiency of solar panels.                                                                     | [42]       |
|                             | R6  | Waste management for the renewable energy equipment                                                                         | This risk is associated with the environmentally appropriate and safe disposal of solar panels or wind turbine materials at the end of the project's life cycle, or biomaterials in the case of bio-generation projects.                                                                                               | [43–45]    |
|                             | R7  | Resource extraction impact                                                                                                  | Renewable energy technologies rely on metals and minerals for their production, which requires mining, processing, and transportation and may negatively impact the environment.                                                                                                                                       | [46]       |
| Policy and Regulatory Risks | R18 | Insufficient supporting policy frameworks and incentives, uncertainty of regulations, and an unattractive regulated tariff. | The efficiency of new technology is usually lower than that of established technology and requires greater investment in research and development to improve it. It also requires a supportive policy that considers the technology's status and the government's incentives for investment during the initial stages. | [7,34,47]  |
|                             | R09 | Complex approval system                                                                                                     | The complexity of the approval and permitting system for installing and operating renewable energy systems may create a less attractive investment environment for developers, as delays add to the overall project cost.                                                                                              | [6,7]      |
| Political Risks             | R10 | Government stability                                                                                                        | Risks associated with the stability of the government and its administrative agencies, and the effects on investments.                                                                                                                                                                                                 | [4]        |
|                             | R10 | Government credit                                                                                                           | The evaluation of a government's trustworthiness and its ability to successfully complete long-term projects.                                                                                                                                                                                                          | [48,49]    |

Table A1. Cont.

| Risk Category          | No. | Risk Factor                                                     | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | References |
|------------------------|-----|-----------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| Political Risks        | R10 | Bribery and Corruption                                          | Risks associated with the spread of bribery and corruption in a country and their effect on the implementation of projects.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | [48,50]    |
|                        | R10 | Political events that adversely impact the value of investments | Some political events, such as war, non-honoring of obligations, or currency devaluation, can adversely impact the value of investments.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | [7,37]     |
| Economic/Finance Risks | R11 | High initial cost                                               | This risk refers to the high initial capital costs of investing in renewable energy projects and the difficulty of collecting and paying those costs upfront.                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | [7,49,51]  |
|                        | R12 | Decommission costs                                              | This risk is associated with the expense of removing the solar or wind equipment at the end of the project life and restoring the site. In this study, it is a risk because these costs may be higher than expected and can affect the project's final profitability.                                                                                                                                                                                                                                                                                                                                                                  | [41]       |
|                        | R13 | Limited access to affordable finance and high Interest Rates    | This risk refers to the difficulty in accessing affordable finance from the private and public sectors to fund projects, including limited domestic investor capital available for investment. This also includes the financial sector's inexperience in funding renewable energy projects due to the technology's emerging status, as well as the domestic investors' inexperience in this sector. Also, the negative effect high interest rates have on funding renewable energy projects. Since high interest rates increase the cost of borrowing, they also raise the project's cost, making it less attractive as an investment. | [7]        |

Table A1. Cont.

| Risk Category          | No. | Risk Factor                                                         | Description                                                                                                                                                                                                                                                                                                                                             | References |
|------------------------|-----|---------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| Economic/Finance Risks | R14 | Poor economic conditions and Currency risk                          | This risk refers to the poor economic conditions in the country due to recessions or depressions, causing unwillingness or inability to invest in new projects or to continue funding ongoing projects, as well as Currency risk due to fluctuations in a country's currency, which negatively affect the economics of the projects.                    | [4,35,52]  |
|                        | R15 | Research & development capacity                                     | This risk concerns the lack of fiscal support for research and development of renewable energy technologies, which impacts project development.                                                                                                                                                                                                         | [6]        |
| Market Risks           | R16 | Market competitiveness and distortion issues                        | This risk refers to market competitiveness and the lack of subsidies for renewable energy compared to other technologies and options, monopolistic behavior in the energy market, and market distortion issues due to access barriers stemming from a lack of legal, financial, and institutional frameworks supporting the development of RE projects. | [6,7]      |
|                        | R17 | Limited market and consumer data availability                       | This risk refers to the unavailability of data needed to study the market and the consumer, which makes it difficult to plan and predict trends.                                                                                                                                                                                                        | [7]        |
| Technical Risks        | R18 | Technology maturity                                                 | This risk relates to whether the renewable energy technology has reached its efficiency limits or is still developing and improving, as continued efficiency gains are more attractive to investors.                                                                                                                                                    | [53]       |
|                        | R19 | Limited technical skills and capacity in operations and maintenance | This risk refers to the impact of limited technical skills and capacity in operation and maintenance due to the novelty of the technology and its unpredictability, leading to higher costs                                                                                                                                                             | [7,47]     |

Table A1. Cont.

| Risk Category   | No. | Risk Factor                                                     | Description                                                                                                                                                                                                                                                                                                                                    | References |
|-----------------|-----|-----------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| Technical Risks | R20 | Limitations in the quality control and availability of hardware | This risk refers to the effects of limited hardware availability and poor quality control on the implementation of renewable energy projects. This risk is also exacerbated by market uncertainty stemming from rapid price changes driven by increased installations and new renewable energy projects.                                       | [6,7,35]   |
|                 | R21 | Grid access                                                     | Grid access risk relates to the ability to integrate and connect renewable energy projects into the grid, due to factors such as a lack of rules governing grid connections or the adequacy of the grid to accommodate and integrate increasing renewable energy generation.                                                                   | [6,54]     |
|                 | R22 | Transport/construction/completion Risk                          | Risks resulting from project start-up and completion delay, causing revenue losses, due to disruptions in the transportation and/or construction stages. Development delay can also be caused by failure to obtain all required licenses to start the project and access the grid.                                                             | [29]       |
|                 | R23 | Resource and demand assessment risk                             | This risk is associated with inaccurate assessment of project resources, such as irradiation in the case of solar or wind speed and frequency in the case of wind, which will lead to lower revenue, operational issues, and ultimately the failure of the project. As well as the variability in demand, leading to an uncertain load profile | [6,39,52]  |

## Appendix B

**Table A2.** Breakdown of Expert Respondents.

| Expert Respondent | Background        | Educational Level | Experience Years   | Position Within the Organization                                   |
|-------------------|-------------------|-------------------|--------------------|--------------------------------------------------------------------|
| 1                 | Academic          | PhD               | More than 15 years | Mid Level (Project Manager, Associate Professor, Consultant, etc.) |
| 2                 | Academic          | PhD               | More than 15 years | Upper Level (Executive, Director, Professor, etc.)                 |
| 3                 | Private Sector    | PhD               | More than 15 years | Upper Level (Executive, Director, Professor, etc.)                 |
| 4                 | Private Sector    | Bachelor's Degree | 2–5 years          | Starting Level (Project Engineer, Assistant Professor, etc.)       |
| 5                 | Private Sector    | Master's Degree   | 2–5 years          | Starting Level (Project Engineer, Assistant Professor, etc.)       |
| 6                 | Governmental Role | Bachelor's Degree | 5–10 years         | Mid Level (Project Manager, Associate Professor, Consultant, etc.) |
| 7                 | Private Sector    | Master's Degree   | 2–5 years          | Starting Level (Project Engineer, Assistant Professor, etc.)       |
| 8                 | Private Sector    | Bachelor's Degree | 10–15 years        | Mid Level (Project Manager, Associate Professor, Consultant, etc.) |
| 9                 | Private Sector    | Bachelor's Degree | 5–10 years         | Starting Level (Project Engineer, Assistant Professor, etc.)       |
| 10                | Private Sector    | Bachelor's Degree | 5–10 years         | Starting Level (Project Engineer, Assistant Professor, etc.)       |
| 11                | Academic          | PhD               | More than 15 years | Upper Level (Executive, Director, Professor, etc.)                 |
| 12                | Private Sector    | Bachelor's Degree | 10–15 years        | Mid Level (Project Manager, Associate Professor, Consultant, etc.) |
| 13                | Governmental Role | Master's Degree   | 10–15 years        | Mid Level (Project Manager, Associate Professor, Consultant, etc.) |
| 14                | Private Sector    | Bachelor's Degree | 2–5 years          | Starting Level (Project Engineer, Assistant Professor, etc.)       |
| 15                | Academic          | PhD               | 5–10 years         | Starting Level (Project Engineer, Assistant Professor, etc.)       |
| 16                | Governmental Role | Bachelor's Degree | 5–10 years         | Starting Level (Project Engineer, Assistant Professor, etc.)       |
| 17                | Governmental Role | Master's Degree   | 10–15 years        | Starting Level (Project Engineer, Assistant Professor, etc.)       |
| 18                | Private Sector    | Master's Degree   | 2–5 years          | Starting Level (Project Engineer, Assistant Professor, etc.)       |

Table A2. Cont.

| Expert Respondent | Background        | Educational Level | Experience Years | Position Within the Organization                                   |
|-------------------|-------------------|-------------------|------------------|--------------------------------------------------------------------|
| 19                | Private Sector    | Master's Degree   | 2–5 years        | Starting Level (Project Engineer, Assistant Professor, etc.)       |
| 20                | Private Sector    | Master's Degree   | 10–15 years      | Mid Level (Project Manager, Associate Professor, Consultant, etc.) |
| 21                | Governmental Role | Bachelor's Degree | 5–10 years       | Mid Level (Project Manager, Associate Professor, Consultant, etc.) |

## References

1. International Energy Agency Overview and Key Findings—World Energy Investment 2023—Analysis. Available online: <https://www.iea.org/reports/world-energy-investment-2023/overview-and-key-findings> (accessed on 23 November 2024).
2. Council of Economic and Development Affairs. *Saudi Vision 2030*; Council of Economic and Development Affairs: Riyadh, Saudi Arabia, 2016.
3. Nuriyev, M.N.; Mammadov, J.; Mammadov, J. Renewable Energy Sources Development Risk Analysis and Evaluation: The Case of Azerbaijan. *Renew. Energy* **2019**, *5*, 11. [\[CrossRef\]](#)
4. Wu, Y.; Wang, J.; Ji, S.; Song, Z. Renewable Energy Investment Risk Assessment for Nations along China's Belt & Road Initiative: An ANP-Cloud Model Method. *Energy* **2020**, *190*, 116381. [\[CrossRef\]](#)
5. Chebotareva, G.; Strielkowski, W.; Streimikiene, D. Risk Assessment in Renewable Energy Projects: A Case of Russia. *J. Clean. Prod.* **2020**, *269*, 122110. [\[CrossRef\]](#)
6. Kul, C.; Zhang, L.; Solangi, Y.A. Assessing the Renewable Energy Investment Risk Factors for Sustainable Development in Turkey. *J. Clean. Prod.* **2020**, *276*, 124164. [\[CrossRef\]](#)
7. Abba, Z.Y.I.; Balta-Ozkan, N.; Hart, P. A Holistic Risk Management Framework for Renewable Energy Investments. *Renew. Sustain. Energy Rev.* **2022**, *160*, 112305. [\[CrossRef\]](#)
8. Tavakkoli-Moghaddam, R.; Mousavi, S.M.; Hashemi, H. A Fuzzy Comprehensive Approach for Risk Identification and Prioritization Simultaneously in EPC Projects. In *Risk Management in Environment, Production and Economy*; Savino, M., Ed.; In Tech: Rijeka, Croatia, 2011; ISBN 978-953-307-313-2.
9. Islam, M.S.; Nepal, M.P.; Skitmore, M. Modified Fuzzy Group Decision-Making Approach to Cost Overrun Risk Assessment of Power Plant Projects. *J. Constr. Eng. Manag.* **2019**, *145*, 04018126. [\[CrossRef\]](#)
10. Abdelalim, A.; Tantawy, M.; Saeed, S.; Mohamed, S.K. Risk Management of Highly Constrained Construction Projects. *Eng. Res. J.* **2024**, *183*, 121–141. [\[CrossRef\]](#)
11. Islam, M.S.; Nepal, M.P.; Skitmore, M.; Kabir, G. A Knowledge-Based Expert System to Assess Power Plant Project Cost Overrun Risks. *Expert Syst. Appl.* **2019**, *136*, 12–32. [\[CrossRef\]](#)
12. Erfani, A.; Tavakolan, M. Risk Evaluation Model of Wind Energy Investment Projects Using Modified Fuzzy Group Decision-Making and Monte Carlo Simulation. *Arthaniti J. Econ. Theory Pract.* **2023**, *22*, 7–33. [\[CrossRef\]](#)
13. Jung, J.H.; Kim, D.Y.; Lee, H.K. The Computer-Based Contingency Estimation through Analysis Cost Overrun Risk of Public Construction Project. *KSCE J. Civ. Eng.* **2016**, *20*, 1119–1130. [\[CrossRef\]](#)
14. Atanassov, K.T. Review and New Results on Intuitionistic Fuzzy Sets, Mathematical Foundations of Artificial Intelligence Seminar, Sofia, Preprint IM-MFAIS-1-88. Reprinted in *Int. J. Bioautomation* **2016**, *20*, S7–S16. Available online: [https://www.biomed.bas.bg/bioautomation/2016/vol\\_20.s1/files/20.s1\\_03.pdf](https://www.biomed.bas.bg/bioautomation/2016/vol_20.s1/files/20.s1_03.pdf) (accessed on 19 July 2026).
15. Peng, X.; Selvachandran, G. Pythagorean fuzzy set: State of the art and future directions. *Artif. Intell. Rev.* **2019**, *52*, 1873–1927. [\[CrossRef\]](#)
16. Zhang, X.; Xu, Z. Extension of TOPSIS to Multiple Criteria Decision Making with Pythagorean Fuzzy Sets. *Int. J. Intell. Syst.* **2014**, *29*, 1061–1078. [\[CrossRef\]](#)
17. Zimmermann, H.-J. Individual Decision Making in Fuzzy Environments. In *Fuzzy Sets, Decision Making, and Expert Systems*; Springer Netherlands: Dordrecht, The Netherlands, 1987; pp. 15–44, ISBN 978-94-010-7957-0.
18. Aven, T. Risk Assessment and Risk Management: Review of Recent Advances on Their Foundation. *Eur. J. Oper. Res.* **2016**, *253*, 1–13. [\[CrossRef\]](#)
19. Rezakhani, P. Classifying key risk factors in construction projects. *Bul. Institutului Politeh. Din Lasi. Sect. Constr. Arhit.* **2012**, *58*, 27–38.
20. Abd El-Karim, M.S.B.A.; Mosa El Nawawy, O.A.; Abdel-Alim, A.M. Identification and Assessment of Risk Factors Affecting Construction Projects. *HBRC J.* **2017**, *13*, 202–216. [\[CrossRef\]](#)
21. Mardani, A.; Jusoh, A.; Zavadskas, E.K. Fuzzy Multiple Criteria Decision-Making Techniques and Applications—Two Decades Review from 1994 to 2014. *Expert Syst. Appl.* **2015**, *42*, 4126–4148. [\[CrossRef\]](#)
22. Kahraman, C.; Onar, S.C.; Oztaysi, B. Fuzzy Multicriteria Decision-Making: A Literature Review. *Int. J. Comput. Intell. Syst.* **2015**, *8*, 637. [\[CrossRef\]](#)
23. Hillson, D. *Managing Risk in Projects*, 2nd ed.; Routledge: London, UK, 2024; ISBN 978-1-00-343195-4.
24. Alharbi, A.; Alosaimi, W.; Alyami, H.; Alouffi, B.; Almulihi, A.; Nadeem, M.; Sayeed, M.A.; Khan, R.A. Selection of Data Analytic Techniques by Using Fuzzy AHP TOPSIS from a Healthcare Perspective. *BMC Med. Inform. Decis. Mak.* **2024**, *24*, 240. [\[CrossRef\]](#) [\[PubMed\]](#)
25. Wang, F. Preference Degree of Triangular Fuzzy Numbers and Its Application to Multi-Attribute Group Decision Making. *Expert Syst. Appl.* **2021**, *178*, 114982. [\[CrossRef\]](#)

26. Chen, C.-T. Extensions of the TOPSIS for Group Decision-Making under Fuzzy Environment. *Fuzzy Sets Syst.* **2000**, *114*, 1–9. [\[CrossRef\]](#)
27. Weckend, S.; Wade, A.; Heath, G. *End of Life Management: Solar Photovoltaic Panels*; NREL/TP–6A20-73852; T12-06:2016; 1561525; National Renewable Energy Laboratory: Golden, CO, USA, 2016.
28. Ali, A.; Islam, M.T.; Rehman, S.; Qadir, S.A.; Shahid, M.; Khan, M.W.; Zahir, H.; Islam, A.; Khalid, M. Solar Photovoltaic Module End-of-Life Waste Management Regulations: International Practices and Implications for the Kingdom of Saudi Arabia. *Sustainability* **2024**, *16*, 7215. [\[CrossRef\]](#)
29. Gatzert, N.; Kosub, T. Risks and Risk Management of Renewable Energy Projects: The Case of Onshore and Offshore Wind Parks. *Renew. Sustain. Energy Rev.* **2016**, *60*, 982–998. [\[CrossRef\]](#)
30. Jordaens, P.J. *Overview of Natural Disasters Risks for Renewable Energy*; Sirris: Brussels, Belgium, 2021.
31. Maryland Department of Natural Resources. *Review of Decommissioning Considerations for Solar Energy Projects in Maryland*; Maryland Department of Natural Resources: Annapolis, MD, USA, 2021.
32. Sim, J. The Economic and Environmental Values of the R&D Investment in a Renewable Energy Sector in South Korea. *J. Clean. Prod.* **2018**, *189*, 297–306. [\[CrossRef\]](#)
33. Williams, N.J.; Jaramillo, P.; Taneja, J.; Ustun, T.S. Enabling Private Sector Investment in Microgrid-Based Rural Electrification in Developing Countries: A Review. *Renew. Sustain. Energy Rev.* **2015**, *52*, 1268–1281. [\[CrossRef\]](#)
34. Hu, J.; Harmsen, R.; Crijns-Graus, W.; Worrell, E. Barriers to Investment in Utility-Scale Variable Renewable Electricity (VRE) Generation Projects. *Renew. Energy* **2018**, *121*, 730–744. [\[CrossRef\]](#)
35. Malhotra, A.; Schmidt, T.S.; Haelg, L.; Waissbein, O. Scaling up Finance for Off-Grid Renewable Energy: The Role of Aggregation and Spatial Diversification in Derisking Investments in Mini-Grids for Rural Electrification in India. *Energy Policy* **2017**, *108*, 657–672. [\[CrossRef\]](#)
36. Ke, L.; Xiaoliu, S.; Zhongfu, T.; Wenyan, G. Grey Clustering Analysis Method for Overseas Energy Project Investment Risk Decision. *Syst. Eng. Procedia* **2012**, *3*, 55–62. [\[CrossRef\]](#)
37. Qiu, D.; Dinçer, H.; Yüksel, S.; Ubay, G.G. Multi-Faceted Analysis of Systematic Risk-Based Wind Energy Investment Decisions in E7 Economies Using Modified Hybrid Modeling with IT2 Fuzzy Sets. *Energies* **2020**, *13*, 1423. [\[CrossRef\]](#)
38. Tang, B.-J.; Song, X.-T.; Cao, H. A Study on Overseas Oil and Gas Investment to Avoid the Risk of the Changes in Tax Policies: A Case in China. *J. Pet. Sci. Eng.* **2018**, *160*, 35–46. [\[CrossRef\]](#)
39. Egli, F. Renewable Energy Investment Risk: An Investigation of Changes over Time and the Underlying Drivers. *Energy Policy* **2020**, *140*, 111428. [\[CrossRef\]](#)
40. Zhang, R.; Andam, F.; Shi, G. Environmental and Social Risk Evaluation of Overseas Investment under the China-Pakistan Economic Corridor. *Environ. Monit. Assess.* **2017**, *189*, 253. [\[CrossRef\]](#) [\[PubMed\]](#)
41. Ioannou, A.; Angus, A.; Brennan, F. Risk-Based Methods for Sustainable Energy System Planning: A Review. *Renew. Sustain. Energy Rev.* **2017**, *74*, 602–615. [\[CrossRef\]](#)
42. Shariah, A.; Al-Ibrahim, E. Impact of Dust and Shade on Solar Panel Efficiency and Development of a Simple Method for Measuring the Impact of Dust in Any Location. *J. Sustain. Dev. Energy Water Environ. Syst.* **2023**, *11*, 1110448. [\[CrossRef\]](#)
43. Kahraman, C.; Kaya, İ.; Cebi, S. A Comparative Analysis for Multiattribute Selection among Renewable Energy Alternatives Using Fuzzy Axiomatic Design and Fuzzy Analytic Hierarchy Process. *Energy* **2009**, *34*, 1603–1616. [\[CrossRef\]](#)
44. Pappas, C.; Karakosta, C.; Marinakis, V.; Psarras, J. A Comparison of Electricity Production Technologies in Terms of Sustainable Development. *Energy Convers. Manag.* **2012**, *64*, 626–632. [\[CrossRef\]](#)
45. Streimikiene, D.; Balezentis, T.; Krisciukaitienė, I.; Balezentis, A. Prioritizing Sustainable Electricity Production Technologies: MCDM Approach. *Renew. Sustain. Energy Rev.* **2012**, *16*, 3302–3311. [\[CrossRef\]](#)
46. Shamoon, A.; Haleem, A.; Bahl, S.; Javaid, M.; Garg, S.B.; Sharma, R.C.; Garg, J. Environmental Impact of Energy Production and Extraction of Materials—A Review. *Mater. Today Proc.* **2022**, *57*, 936–941. [\[CrossRef\]](#)
47. Schmidt, T.S.; Blum, N.U.; Wakeling, R.S. Attracting Private Investments into Rural Electrification—A Case Study on Renewable Energy Based Village Grids in Indonesia. *Energy Sustain. Dev.* **2013**, *17*, 581–595. [\[CrossRef\]](#)
48. Abdullahi, D.; Suresh, S.; Renukappa, S.; Oloke, D. Key Barriers to the Implementation of Solar Energy in Nigeria: A Critical Analysis. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2017; Volume 83, p. 012015. [\[CrossRef\]](#)
49. Bhattacharyya, S.C. Mini-Grids for the Base of the Pyramid Market: A Critical Review. *Energies* **2018**, *11*, 813. [\[CrossRef\]](#)
50. Ouedraogo, N.S. Opportunities, Barriers and Issues with Renewable Energy Development in Africa: A Comprehensive Review. *Curr. Sustain./Renew. Energy Rep.* **2019**, *6*, 52–60. [\[CrossRef\]](#)
51. Ohunakin, O.S.; Adaramola, M.S.; Oyewola, O.M.; Fagbenle, R.O. Solar Energy Applications and Development in Nigeria: Drivers and Barriers. *Renew. Sustain. Energy Rev.* **2014**, *32*, 294–301. [\[CrossRef\]](#)
52. Williams, N.J.; Jaramillo, P.; Taneja, J. An Investment Risk Assessment of Microgrid Utilities for Rural Electrification Using the Stochastic Techno-Economic Microgrid Model: A Case Study in Rwanda. *Energy Sustain. Dev.* **2018**, *42*, 87–96. [\[CrossRef\]](#)

53. Liu, X.; Zeng, M. Renewable Energy Investment Risk Evaluation Model Based on System Dynamics. *Renew. Sustain. Energy Rev.* **2017**, *73*, 782–788. [[CrossRef](#)]
54. Soshinskaya, M.; Crijns-Graus, W.H.; Guerrero, J.M.; Vasquez, J.C. Microgrids: Experiences, Barriers and Success Factors. *Renew. Sustain. Energy Rev.* **2014**, *40*, 659–672. [[CrossRef](#)]

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