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RESEARCH ARTICLE

Risk Assessment of Solar Power Plant Development in Indonesia Utilizing the Analytic Hierarchy Process Method

Frederick Sakaja Ginting* and Iwa Garniwa

Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Depok, Indonesia
*Corresponding author. Email: blue.frederick@gmail.com

Abstract

The Ministry of Energy and Mineral Resources is dedicated to constructing a Solar Power Plant, aimed at elevating the country's national electrification rate and guaranteeing equal access to energy, particularly for those who have previously lacked electricity. The objective of this research is to identify the risk factors associated with the construction of a Solar Power Plant and perform a risk analysis utilizing the Analytic Hierarchy Process (AHP) methodology. The analysis reveals the presence of 7 criteria and 38 subcriteria related to risk. The project risk criterion has the highest weight with an expert value of 25.2%, self-assessment 36.9% and employees 2.2%. In the subcriteria, the provider is late in completing the work, it has the highest weight with an expert value of 6.7%, self-assessment 10.6% and employees 0.1%.

Keywords: Solar Power Plant, Risk Management, Analytic Hierarchy Process (AHP)

1. Introduction

The Indonesian government has implemented Law Number 30 of 2007, which guarantees the right of all citizens to access energy, but many remote regions remain without electricity due to the high cost and complexity of extending the electricity grid [1]. As a tropical country, Indonesia possesses significant solar energy potential, estimated at 3,286.07 GW, with only 739.3 MW installed as of 2024[2]. This substantial disparity between the potential and actual solar energy usage highlights the pressing need for effective risk management in the development of solar power plants.

To address electrification gaps, the Directorate General of New, Renewable Energy, and Energy Conservation is developing off-grid and grid-connected solar power plants to improve energy equity across Indonesia. The development of solar power plants is crucial for achieving Indonesia's renewable energy goals and reducing its reliance on fossil fuels. Despite this potential, solar power plant projects face numerous risks across the planning, procurement, and operational stages, which can have severe consequences if left unmanaged.

Proper risk identification and management are essential to ensure timely, cost-effective, and sustainable outcomes. In the context of infrastructure development, risk refers to the effect of uncertainty on the objectives. The Analytic Hierarchy Process (AHP), developed by Saaty, is a multi-criteria decision-making tool used to prioritize complex alternatives based on expert judgment. This method is particularly suitable for structured risk evaluation, allowing for a comprehensive assessment of the risks involved in solar power plant development.

This study aims to identify and assess the key risks involved in solar power plant development in Indonesia using the AHP method, based on expert, self-assessment, and employee perspectives. The AHP method will provide a structured framework for evaluating and prioritizing risks, enabling stakeholders to make informed decisions and mitigate potential issues.

There are various approaches to obtaining weights for each criterion and combining the scores for each option criterion into a unified multiple completeness score. For example, weighted sums or weighted products, hierarchical analysis methods, and mining techniques for weighting and scoring based on pairwise comparisons, can be used to combine the results. Several methods can be used in MCDA.

According to Sabaei et al., policymakers can decide how to weight each of these criteria based on specific concerns to make more accurate policy decisions. The subjective preferences of decision makers can sometimes impact the weighting problem. Saaty (2008) employs a numerical rating system spanning from 1 to 9, with a score of 1 signifying equal importance and 9 representing extreme importance. Data processing methods, i.e. compensatory or non-compensatory, availability of quality and data, and preferences of policy makers essentially determine the strategy to be used. (2015) Sabaei et al. According to Polatidis et al. (2006), no technique in MCDA is better or worse to adopt; rather, it all depends on the circumstances and status of the research. With the knowledge that, based on the conceptualization of the method, the answers to be obtained are undoubtedly consistent with the approach taken[3][4].

2. Analytic Hierarchy Process (AHP)

Saaty developed the Analytic Hierarchy Process (AHP) decision-making framework. Saaty (1993) defines a hierarchy as a multilevel structure used to represent complex problems, with the objective at the initial level, followed by the levels of factors, criteria, subcriteria, and ultimately the alternatives. According to Saaty (1993), a hierarchy is a representation of complex problems in a multilevel structure, with the first level being the goal, followed by the level of factors, criteria, subcriteria, and so on up to the alternative level. Hierarchies allow difficult problems to be broken down into groups, which are then arranged in a hierarchical form to make the problem appear more structured and systematic[5]. The following is the hierarchical structure of AHP[6], as shown in Figure 1.

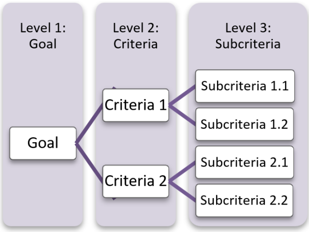


Figure 1. AHP Hierarchy Structure

The AHP method involves the following sequential steps, as detailed in [7][8].

1. Identify the key issues to be addressed and outline the desired outcomes.
2. The hierarchy begins at the top with goals viewed from the decision-maker's perspective, then extends to middle-level provisions that are subordinate, and finally reaches the bottom level.
3. Develop a pairwise comparison matrix using the measurement scale outlined in Table 1, which will detail the relative impact or influence that each element has on the objectives or criteria at the level above it.

Table 1. Pairwise Comparison Scale

1	=	Both elements hold equal importance
3	=	One of the elements stands out as being somewhat more significant than the others
5	=	One factor stands out as more significant than the others
7	=	One factor is significantly more crucial than the other one
9	=	One factor stands out as significantly more crucial than the others
2,4,6,8	=	Values fall between two adjacent consideration values
The opposite	=	If activity i has a larger value than activity j, then activity j has a smaller value compared to activity i

4. To find the total number of assessments, perform pairwise comparisons based on the definition, resulting in a total of n times [(n-1)/2] evaluations.
5. Determine the eigenvalues and verify their accuracy. Data collection is repeated if it is inconsistent.
6. Repeat the process of steps 3, 4, and 5 for each subsequent level in the hierarchy.
7. Verify the level of organisation within the hierarchy. The AHP calculates the consistency ratio by employing a consistency index. To produce decisions that are close to valid, the expected consistency must be perfect. Although it is difficult to achieve perfection, the consistency ratio is predicted to be less than or equal to 10%.

The results of Remon Fayek Aziz Eskander's research entitled "Risk assessment influencing factors for Arabian construction projects using analytical hierarchy process" show that economic risk was identified as the highest risk, and design risk was ranked second, followed by political and construction risks. The most important sub-parameters include insufficient client funds and changes in design standards[9]. The results of Emre Akusta, Ali Ari, and Raif Cergibozan's research entitled "Barriers to renewable energy investments in Turkey: A fuzzy AHP approach" show that it is important to overcome political and regulatory obstacles as well as improve the technical infrastructure and financial support to facilitate renewable energy investments in Turkey. Collaboration between the government, the private sector, and society is necessary to devise effective strategies for overcoming these hurdles[10]. The results of Kamal M. Al-Subhi Al-Harbi's research entitled "Application of the AHP in project management" show that the AHP is an effective tool for decision making in project management, especially in the contractor pre-qualification process. It is anticipated that the implementation of AHP will motivate project management professionals to adopt this method [11].

Specifically, in solar energy, AHP is used for various purposes by different authors: Assessing performance of photovoltaic solar power plants: Chafiq, Benabbou, Dagdougui, Belhaj, Djdiaa, Bouzekri, and Berrado aimed to present an approach for assessing Key Performance Indicators (KPIs) using the AHP methodology for photovoltaic solar power plants. Their methodology identifies relevant aspects for evaluating plant performance, considering specific needs and evaluation contexts [12], Potential survey of photovoltaic power plants: Azizkhani, Vakili, Noorollahi, and Naseri used AHP to investigate the most suitable locations for establishing photovoltaic power stations in Iran [**gin13**], Recognition and prioritization of challenges in solar energy growth: Sindhu, Nehra, and Luthra utilized AHP to identify and prioritize the challenges hindering the growth of solar energy in India[**gin14**], Modeling and analysis of risk factors: Al Shouny, Issa, Sayed, Rezk, Abdelkareem, Miky, and Olabi used AHP in their modeling and analysis of risk factors affecting the operation of photovoltaic power plants [**gin15**].

3. Research Methodology

The stages of research implementation are divided into four stages: preparation, data collection, data processing, analysis, and conclusion. The Analytic Hierarchy Process method is utilised in this study to evaluate the risk factors associated with solar power plant development. This research combines qualitative and quantitative data to produce comprehensive knowledge to solve problems. Qualitative data is used from the results of expert questionnaires, while quantitative data is used for data derived from respondents' opinions. The research flowchart is presented in Figure 2.

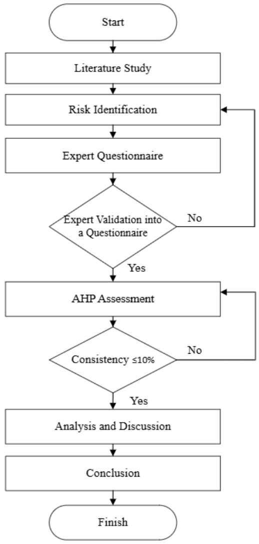


Figure 2. Research Flow Chart

3.1 Risk Identification

The risk identification stage using secondary data is the first step in creating a questionnaire that will be used later. From the literature study carried out, it was found that the types of risks that make it possible for these risks to occur. Table 2 shows the results of the risks that have been identified.

Table 2. Risk Identification

No	Criteria	ID	Subcriteria
1	Project Risk	PR.1	Preparation of technical specifications is too general/detailed
		PR.2	Inaccuracy in drafting contract clauses
		PR.3	The provider is late in completing the work
		PR.4	Prospective providers who applied did not meet the requirements
		PR.5	The selected supplier candidate resigns from carrying out the work
		PR.6	The results of the solar power plant location survey are not feasible/cannot be installed according to plan
		PR.7	Components produced/ordered do not comply with specifications in the contract
		PR.8	Imported materials arrive late at the assembly facility
		PR.9	Damage and/or loss of goods during delivery to the work location
		PR.10	Delay in delivery of goods to the location
		PR.11	Change of solar power plant construction location point
2	Technical Risk	TR.1	Solar panel efficiency
		TR.2	The quality of the solar power plant (components and foundation construction) does not comply with specifications
		TR.3	Availability of solar power plant components
		TR.4	The solar power plant installed cannot function
		TR.5	Delay in commissioning tests

No	Criteria	ID	Subcriteria
3	Social Risk	SR.1	Threats from other parties who do not agree with the construction of solar power plant
		SR.2	Land conflict
		SR.3	Negative perception of new technology
		SR.4	There is intervention in project implementation from external parties (such as requests for work to be carried out by certain parties)
		SR.5	Solar power plant components lost stolen
4	Economic Risk	ER.1	Availability of compensation funds from the Government
		ER.2	Bank loan interest rates are high
		ER.3	High inflation
		ER.4	Basic costs of providing electricity
		ER.5	Provider working capital limitations
5	Legal Risk	LR.1	Licensing
		LR.2	Land ownership
		LR.3	Breach of contract
		LR.4	Obstacles in the grant process to Regional Government
		LR.5	Difficulty in obtaining a certificate of eligibility for operation
6	Natural Risk	NR.1	Extreme weather conditions
		NR.2	Natural disasters
		NR.3	Geographic conditions
7	Human Resources Risk	HR.1	Lack of personnel
		HR.2	Low personnel productivity
		HR.3	Inadequate personnel
		HR.4	Frequent personnel turnover occurs

4. Risk Analysis and Results

At this stage, the results of the questionnaire assessment are presented based on the responses received from the participants. This process entails the collection and analysis of data from the participants to identify their opinions and preferences. The following example illustrates the calculation of the paired comparisons for the Expert 1 respondent.

a) Defining the pairwise comparison

Table 3. Expert 1 Respondent Pairwise Comparison Matrix

Criteria	Project	Technical	Social	Economic	Legal	Natural	Human Resources
Project	1	2	4	1	3	0,5	5
Technical	0,5	1	3	0,2	0,5	2	3
Social	0,25	0,33	1	0,2	0,5	0,33	2
Economic	1	5	5	1	4	3	5
Legal	0,33	2	2	0,25	1	0,33	3
Natural	2	0,5	3	0,33	3	1	3
Human Resources	0,2	0,33	0,5	0,2	0,33	0,33	1
Sum	5,28	11,17	18,5	3,18	12,33	7,5	22

b) Calculating the criteria eigenvalues and testing consistency
   1) Matrix normalization
   2) Calculate the eigenvalues of the criteria

Table 4. Normalization of Criteria Matrix

Criteria	Project	Technical	Social	Economic	Legal	Natural	Human Resources
Project	1/(5,28)	2/(11,17)	4/(18,5)	1/(3,18)	3/(12,33)	0,5/(7,5)	5/(22)
Technical	0,5/(5,28)	1/(11,17)	3/(18,5)	0,2/(3,18)	0,5/(12,33)	2/(7,5)	3/(22)
Social	0,25/(5,28)	0,33/(11,17)	1/(18,5)	0,2/(3,18)	0,5/(12,33)	0,33/(7,5)	2/(22)
Economic	1/(5,28)	5/(11,17)	5/(18,5)	1/(3,18)	4/(12,33)	3/(7,5)	5/(22)
Legal	0,33/(5,28)	2/(11,17)	2/(18,5)	0,25/(3,18)	1/(12,33)	0,33/(7,5)	3/(22)
Natural	2/(5,28)	0,5/(11,17)	3/(18,5)	0,33/(3,18)	3/(12,33)	1/(7,5)	3/(22)
Human Resources	0,2/(5,28)	0,33/(11,17)	0,5/(18,5)	0,2/(3,18)	0,33/(12,33)	0,33/(7,5)	1/(22)
Sum	1	1	1	1	1	1	1

Table 5. Criteria Eigenvalues

Criteria	Project	Technical	Social	Economic	Legal	Natural	Human Resources	Sum	Average
Project	0,19	0,18	0,22	0,31	0,24	0,07	0,23	1,44	0,21
Technical	0,09	0,09	0,16	0,06	0,04	0,27	0,14	0,85	0,12
Social	0,05	0,03	0,05	0,06	0,04	0,04	0,09	0,37	0,05
Economic	0,19	0,45	0,27	0,31	0,32	0,40	0,23	2,17	0,31
Legal	0,06	0,18	0,11	0,08	0,08	0,04	0,14	0,69	0,10
Natural	0,38	0,04	0,16	0,10	0,24	0,13	0,14	1,20	0,17
Human Resources	0,04	0,03	0,03	0,06	0,03	0,04	0,05	0,27	0,04
Sum	1	1	1	1	1	1	1	7	1

After getting the average value, the comparison matrix is multiplied by the matrix at the average value, so the result is:

$$\begin{bmatrix} 1 & 2 & 4 & 1 & 3 & 0,5 & 5 \\ 0,5 & 1 & 3 & 0,2 & 0,5 & 2 & 3 \\ 0,25 & 0,33 & 1 & 0,2 & 0,5 & 0,33 & 2 \\ 1 & 5 & 5 & 1 & 4 & 3 & 5 \\ 0,33 & 2 & 2 & 0,25 & 1 & 0,33 & 3 \\ 2 & 0,5 & 3 & 0,33 & 3 & 1 & 3 \\ 0,2 & 0,33 & 0,5 & 0,2 & 0,33 & 0,33 & 1 \end{bmatrix} \times \begin{bmatrix} 0,21 \\ 0,12 \\ 0,05 \\ 0,31 \\ 0,1 \\ 0,17 \\ 0,04 \end{bmatrix} = \begin{bmatrix} 1,55 \\ 0,95 \\ 0,39 \\ 2,48 \\ 0,76 \\ 1,32 \\ 0,29 \end{bmatrix}$$

c) Calculating hierarchical consistency

1) Calculate Consistency Index (CI), λMax=7,74, n=7

$$CI = \frac{(\lambda Max - n)}{(n-1)} \qquad CI = \frac{7{,}74-7}{7-1} = 0,12 \tag{1}$$

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I	0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51	1,48	1,56	1,57	1,59

2) Calculate Consistency Rasio (CR), n=7, RI=1,32

$$CR = \frac{CI}{RI} \qquad CR = \frac{0{,}12}{1{,}32} = 0,09 \tag{2}$$

Pairwise comparison values for criteria and subcriteria are processed using the Expert Choice application. After the comparison values from the respondents are entered, the results of the weight calculation of each respondent's assessment and its combination appear.

4.1 Test Consistency

The paired comparison questionnaire was evaluated using a consistency test to identify the extent of inconsistency in the respondents' assessment responses. Respondents consisted of 3 types, namely expert respondents, independent assessment respondents and employee respondents. The inconsistency results for each respondent show a value below 10% so that the respondents' assessments are consistent. The inconsistency ratio levels for each respondent are presented in Table 6.

Table 6. Respondent Consistency Ratio

No	Respondents	Individual Inconsistency Ratio	Consistent	Overall Inconsistency Ratio	Consistent
1	Expert 1	0.09	Yes		
2	Expert 2	0.10	Yes		
3	Expert 3	0.09	Yes	0.02	Yes
4	Self-Assessment	0.09	Yes		
5	Employee	0.09	Yes		

4.2 Criteria and Subcriteria Weights

Criteria and subcriteria weights resulting from the AHP calculations in the Expert Choice application. The weights obtained are the result of a combination of 3 expert respondents, self-assessment respondents and employee respondents in the form of local weights and global weights. In the AHP hierarchical model, local weights are determined at the second level, whereas global weights are calculated at the first level. This research employs weights to establish an importance ranking for each criterion and sub-criterion in the process of conducting risk assessments. The higher the weight value, the higher the risk factors and risk subfactors.

a) Weight of criteria and subcriteria for expert respondents

The results of calculating pairwise comparisons of criteria and subcriteria for expert respondents can be seen in Figure 3.a and 3.b.

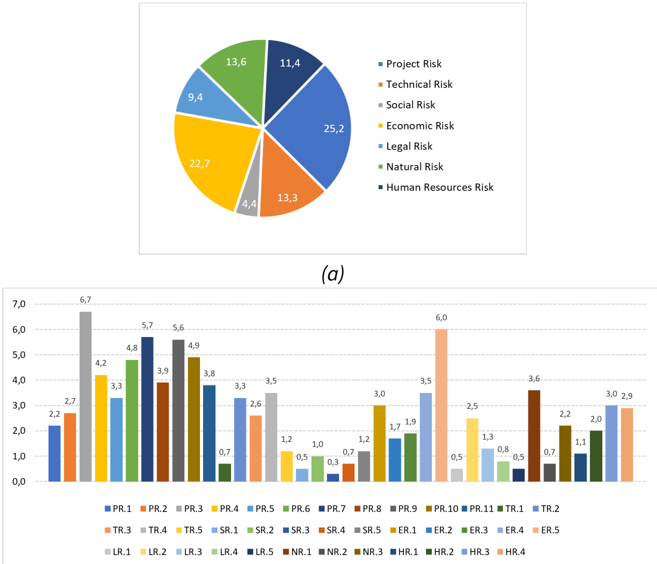
b) Weight of criteria and subcriteria for self-assessment respondents

The results of calculating pairwise comparisons of criteria and subcriteria for respondents' self-assessment can be seen in Figure 4.a and 4.b

c) Weight of criteria and subcriteria for employee respondents The results of calculating pairwise comparisons of criteria and subcriteria for employee respondents can be seen in Figure 5.a and 5.b.

4.3 Discussion

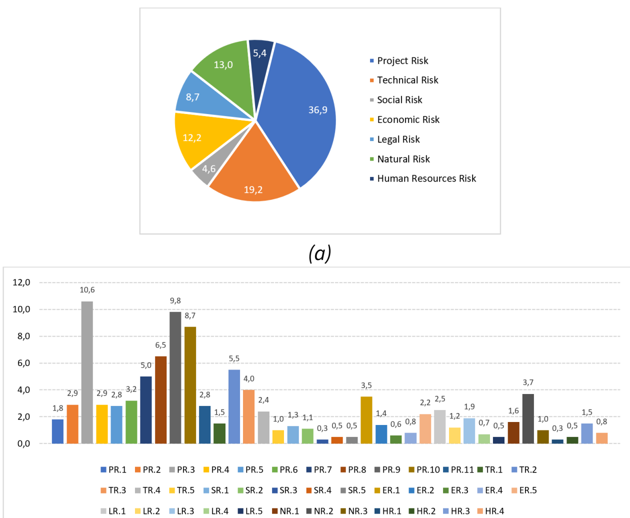
Based on the results in Figure 6, project risk criteria have the highest weight in expert calculations at 25.2% and in independent assessments at 36.9% while for employees



(a)

(b)

Figure 3. (a) Weight of Criteria for Expert Respondents, (b) Weight of Subcriteria for Expert Respondents

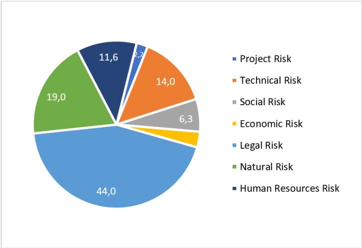


(a)

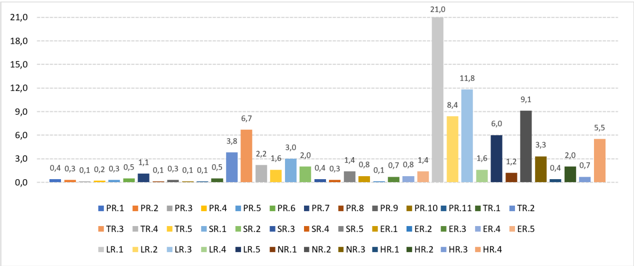
(b)

Figure 4. (a) Weight of Criteria for Self-Assessment Respondents, (b) Weight of Subcriteria for Self-Assessment Respondents

at 2.2%. This shows that project risk is considered the main risk. In second place, experts assessed economic risks higher at 22.7% compared to independent assessments at 12.2% and employees at 3%. Natural risk criteria have the same third rank be-



(a)



(b)

Figure 5. (a) Weight of Criteria for Employee Respondents, (b) Weight of Subcriteria for Employee Respondents

tween experts at 13.6% and independent assessment at 13.0% while employees at 19%. The next order is experts assessing technical risk at 13.3%, independent assessment at 19.2% and employees at 14%. The fifth rank of experts assessed the risk of human resources at 11.4%, independent assessment at 5.4% and employees at 11.6%. In sixth place there is a significant difference in legal risk perception between experts at 9.4%, independent assessment at 8.7% and for employees at 44%. The social risk criterion had the lowest weight among all respondents with an expert rating of 4.4%, an independent assessment of 4.6% and an employee rating of 6.3%.

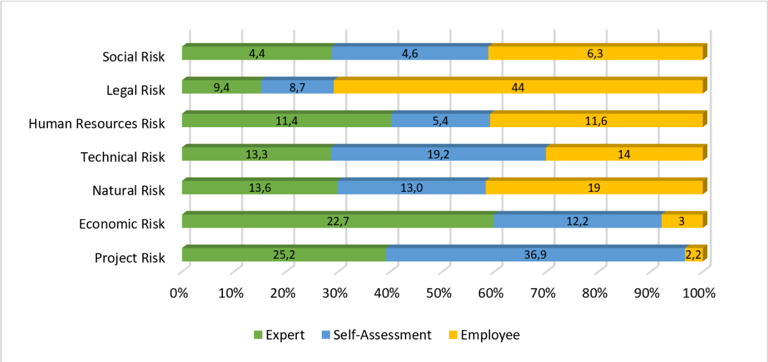


Figure 6. Comparison of Calculation Results Between Criteria Between Respondents

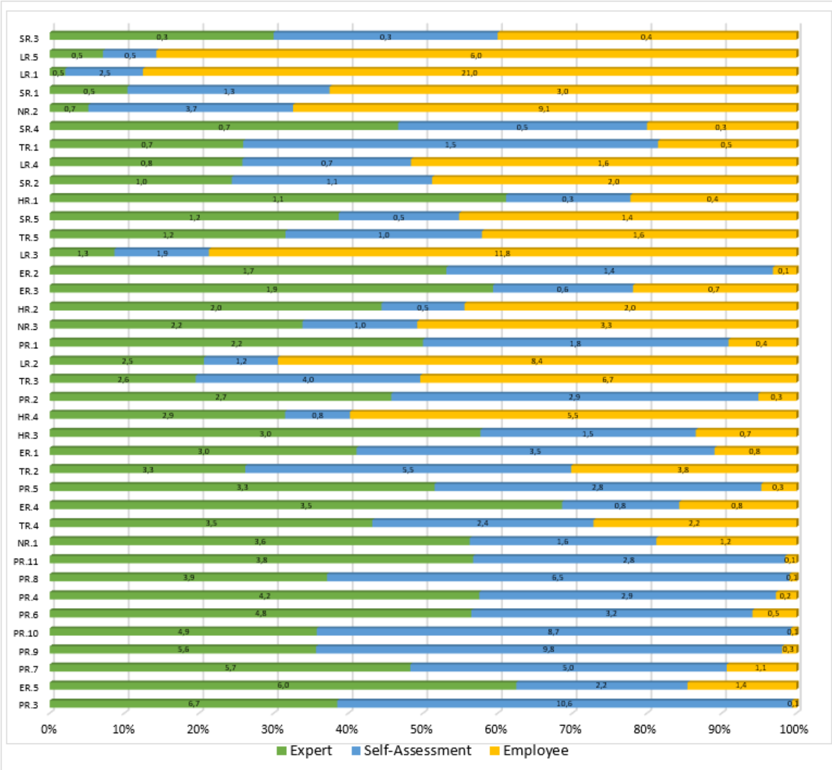


Figure 7. Comparison of Calculation Results Between Subcriteria Between Respondents

According to the data in Figure 8, the subcriteria for providers being late in completing work has the highest weight in expert calculations at 6.7%, independent assessment at 10.6% and for employees at 0.1%. This shows that experts and independent assessments consider providers being late in completing work as a major risk sub-criterion. The negative perception subcriteria toward new technology had the lowest weight in expert calculations at 0.3%, independent assessment at 0.3% and employees at 0.4%.

5. Conclusion

This study used the Analytic Hierarchy Process (AHP) to evaluate risks in solar power plant development projects. Seven major risk categories and 38 subcriteria were identified and ranked. Project risk criteria have the highest weight in expert calculations at 25.2% and in independent assessment at 36.9% while for employees at 2.2%, this shows that project risk is considered the main risk. Second place was the economic risk criteria with an expert score of 22.7%, an independent assessment of 12.2% and an employee score of 3%. The third place was the natural risk criteria with an expert score of 13.6%, an independent assessment of 13.0% and an employee score of

19%. Fourth place was the technical risk criteria with an expert score of 13.3%, an independent assessment of 19.2% and an employee score of 14%. The fifth place was the human resource risk criteria with an expert score of 11.4%, an independent assessment of 5.4% and an employee score of 11.6%. The fifth place was the legal risk criteria with an expert score of 9.4%, an independent assessment of 8.7% and an employee score of 44%. The social risk criterion had the lowest weight among all respondents with an expert rating of 4.4%, an independent assessment of 4.6% and an employee rating of 6.3%.

In the subcriteria, The provider is late in completing the work had the highest weight with an expert score of 6.7%, an independent assessment of 10.6%, and an employee's score of 0.1%. This shows that experts and independent assessments assess providers completing work late as the main risk sub-criterion. The lowest weight was in the subcriteria for negative perceptions of the new technology with an expert count of 0.3%, an independent assessment of 0.3% and an employee's count of 0.4%.

Acknowledgement

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