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# Integration of fuzzy AHP and fuzzy TOPSIS for green supplier selection of mindi wood raw materials

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**A B S T R A C T**

The current industrial development is related to increasing global action and public awareness of environmental issues with Sustainable Development Goals (SDGs). It makes the implementation of green supply chain management on Green Supplier Evaluation and Selection (GSES) more appreciated because it can affect the company's environmental performance. Companies that can improve their environmental performance will be able to increase their competitive advantage and have an impact on increasing revenue, market share, and a more positive green image of the company. Currently, there is no research about green supplier selection in the furniture industry, especially in Indonesia. So, it is necessary to research the industry because it hugely affects environmental performance. One of the companies engaged in the furniture industry is X company. They are selecting their suppliers only based on the ownership of the environmental certification of each supplier and the quality of the raw materials. Environmental criteria such as the green image in the community and environmental competency have not been considered. On the one hand, X company also wants to realize its mission of environmental sensitivity. This study aims to select the best green supplier of mindi wood raw materials by integrating fuzzy AHP and TOPSIS because these methods can make practical multicriteria decisions and obtain more valid results. The results obtained indicate that the 8th green supplier has the highest preference value of 0.777 so it is called the best alternative for mindi wood raw materials.



## 1. INTRODUCTION

Along with the manufacturing industry's improvement in recent years, causing public awareness and public concern for the environment are increasing. Companies are getting more pressure to implement environmentally friendly production processes [1]. This pressure occurs in developed and developing countries, such as Asia [2]. Developing countries must continue to improve green supply chain management effectiveness to survive in the global market. Meanwhile, the government is also paying attention to environmental issues and proposing various environmental regulations because of the shortage of raw materials. In addition, different types of pressure from consumers make businesses more aware of the negative environmental impact of their business activities

[3]. Thus, providing a major challenge for every manufacturing industry to achieve sustainable development by integrating environmental, social, and economic performance [4]. Various initiatives have been taken to keep this industry competitive, including decisions on a green supply chain such as the procurement of raw materials [5].

Several companies collaborate with their supply chain partners to solve problems, such as green suppliers to develop green supply chain practices [6], [7]. Scholars and practitioners also know that green suppliers play a role in green supply chain management, the competitive advantage also an organization's strategy [8], [9]. Green supplier selection is essential in implementing a green supply chain strategy [10], [11]. Choosing a green supplier should consider environmental, social, and economic aspects. Green Supplier Evaluation and Selection (GSES) processes are becoming increasingly crucial as they can influence a company's environmental performance [12]. Companies that can improve their environmental performance will be able to increase their competitive advantage and have an impact on increasing revenue, market share, and a more positive green image of the company [13].

Information and communication technologies have made it easier for industry professionals to decide when selecting a green supplier [14]. Several studies on green supplier selection have shown that many companies such as International Business Machines (IBM), Toyota, Honda, and General Motors are developing green suppliers [15]. While the research conducted by Payam et al. [16] proposed a hierarchical decision-making structure for selecting environmental providers in construction projects. According to the weighted results, the most important criteria are environmental awareness, responsibility for the social environment, and environmental management system. As the scope of this study is limited to the opinions of public universities and experts, it is necessary to summarize the results carefully.

Previous studies stated that there were limitations in the scope of the research. So, it is necessary to conduct a study with a broader scope, and no research has ever been conducted, one of which is in the furniture industry. Currently, no studies discuss green suppliers in the furniture industry, especially in Indonesia. There are environmental issues stating that forests in Indonesia are starting to experience deforestation due to the excessive use of wood raw materials. The Ministry of Environment and Forestry shows that Indonesia's deforestation area in the 2019-2020 period has decreased by 75%, or 115.5 thousand hectares, compared to the 2018-2019 period, which reached 462.5 thousand hectares. Compared to the 2017-2018 period, this figure has increased by 439.4 thousand hectares. While in 2016-2017, the figure reached 480 thousand hectares. Then the 2015-2016 period had the highest deforestation rate in the last six years, amounting to 629.2 thousand hectares. Over six years, the deforestation rate reached 2.1 million hectares [17].

In addition, the furniture industry is currently multiplying. In the first quarter of 2021, the furniture industry has risen and grown positively by 8.04% [18]. The reason is furniture production is included in the business that drives the global economy the most. Wood furniture production is notable for the high consumption of forest raw materials and the exploitation and uses in a sustainable manner [19]. Therefore, it is necessary to study the environmental suppliers of the furniture industry. The industry in this field is very influential on the environment, which is part of the green supply chain concept. Suppose an industry can choose the best green supplier. In that case, it can indirectly prevent excessive use of wood raw materials and inappropriate logging processes because the best green suppliers will implement the deforestation process correctly according to environmental policies.

X Company is a specialized furniture manufacturing company. Currently, mindi wood is the most widely produced raw material and is in demand by consumers because it has a lightweight, termite resistance, smooth texture, and low price. Regarding the statement in the previous paragraph, it can be seen at X Company that there has been no research on green suppliers. They only choose suppliers based on the ownership of each supplier's environmental certification and quality of raw materials. Meanwhile, environmental criteria such as green image criteria in the community and environmental competency have not been considered. On the one hand, X Company wants to realize its mission of being sensitive to the environment. X Company also has a Forest Stewardship Council (FSC) certification audited every year. FSC certification proves that the raw materials used from responsibly managed forests provide


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environmental, social, and economic benefits. They must select green suppliers to realize green supply chain management, maintain the X company's FSC certification, and other aspects, such as price, speed of delivery, and timeliness, to prevent delivery delays. It significantly affects the production process carried out by X Company to make system order.

Previous research by Freeman et al. [20] is green supplier selection uses a method of Analytical Hierarchy Process (AHP) in the first step to determine the weight criterion in combination with entropy and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method for determining supplier preference evaluation. However, another study conducted green supplier selection with quantitative and qualitative assessment criteria using factual and uncertain data to add fuzzy logic to the method used [21], [22]. This research uses the integration of fuzzy AHP and fuzzy TOPSIS methods. Following the previous statement, fuzzy logic aims to process uncertain data because this research uses data from the results of questionnaires from experts. Fuzzy AHP helps calculate importance criteria and sub-criteria [23].

Meanwhile, fuzzy TOPSIS is used to determine the order of preference in alternative green supplier selection by the distance of an ideal solution [24]. The method of AHP has a disadvantage in that it is not suitable for presenting an alternative valuation method. This condition solves by integrating the AHP method with the TOPSIS method [25]. The method of TOPSIS has a weakness because there is no determination of the weights of the criteria priority, which helps increase the validity of the weight values of the criteria calculations. For this reason, this method is combined with the method AHP to produce maximum output. So, the combination of this method was chosen because it can make practical multicriteria decisions and obtain more valid results. Thus, research regarding selecting green suppliers of Mindi wood raw materials aims to select the best green supplier of Mindi wood raw materials.

## 2. RESEARCH METHODS

This research focuses on choosing the best green supplier in a company in the furniture industry. This research uses a questionnaire as a data collection involving three expert respondents that are the manager of procurement, the head of the procurement department, and an expert wood grader. The respondents were chosen because the field of work follows the research topic, and they understand the supplier selection process. For data processing, it was using fuzzy AHP and fuzzy TOPSIS integration. Fuzzy AHP helps determine the level of importance of each criterion and sub-criteria.

Meanwhile, Fuzzy TOPSIS is used to get the green supplier priority order. The addition of fuzzy logic in this method aims to solve the problem with the results of a more subjective questionnaire [26]. The research uses the fuzzy AHP method because it can make effective decisions in solving complex problems by simplifying the problem in the form of a hierarchical arrangement. In the fuzzy AHP method, an eigenvector concept is also used to perform the priority ranking process for each sub-criteria based on a pairwise comparison matrix. Meanwhile, the research uses the fuzzy TOPSIS method because this method is the notion that the chosen alternatives are the shortest distance from the positive ideal solution and an enormous distance from the negative ideal solution. So, it can assist companies in selecting and evaluating green suppliers according to the criteria and sub-criteria.

### 2.1. Fuzzy analytical hierarchy process (AHP)

This method was proposed in 1996, namely by combining fuzzy on AHP. Because the AHP method has a drawback, it is less accurate in minimizing uncertainty. The use of the fuzzy AHP method is one solution to overcome the weaknesses of the conventional AHP method. This method also has limitations: relying on expert opinion to prioritize. The results are obtained subjectively, and if necessary, it is necessary to repeat them early to improve decisions. The principle of pairwise comparison in this method takes a lot of time until the consistency index is fulfilled.

Meanwhile, the advantage of this method is that it can make unstructured problems into a model that is easy to understand. Fuzzy AHP can be used on independent system elements and does not require a linear relationship. This method can consider the robustness of the sensitivity analysis output in decision making and can produce more consistent results than other methods. Also, the

AHP method has advantages in the decision-making process that accommodates quantitative and qualitative attributes [27]. This method will form a hierarchy to clarify complex problems into systematic hierarchical forms [23]. The step of the fuzzy AHP method is below [28].

a. Develop a hierarchy structure.
b. Calculate the value of each member of the pairwise comparison matrix.
 The matrix is determined based on the respondents' answers converted to a Triangular Fuzzy Number (TFN) in *l,m,u.* TFN is the fuzzy set used for measurements related to human subjective judgments using linguistic language.
c. Calculate the value of the average member of the pairwise comparison matrix using a geometric mean according to the average value of the expert's assessment.

$$\tilde{g}_i = \left[\prod_{j=1}^{n}(a_{ij})\right]^{1/n}, i = 1,2,\ldots n \quad (1)$$

 Following the combined approach, the average fuzzy number ($\widetilde{M}$) = ($l$, $m$, $u$) is converted into a crisp number.

$$P(\widetilde{M}) = \frac{(l+4m+u)}{6} \quad (2)$$

d. Determine the matrix of A, W, AR, B, and C.
 The matrix of A is the average matrix of pairwise comparisons converted into crisp numbers.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (3)$$

 The matrix of W is a normalized matrix generated by adding up the columns of A matrix and then dividing each element of A matrix.

$$W = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1n} \\ w_{21} & w_{22} & \cdots & w_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_{n1} & w_{n2} & \cdots & w_{nn} \end{bmatrix} \quad (4)$$

 It is then calculating the average of W matrix for AR matrix. AR matrix is the resulting average of the normalized matrix. Calculate B matrix by multiplying the columns of the A matrix with the rows of the AR matrix. Each row of B matrix is added up and used as an element of C matrix.

$$AR = \begin{bmatrix} ar_{11} \\ ar_{21} \\ \vdots \\ ar_{n1} \end{bmatrix} = \begin{bmatrix} \frac{\sum_{i=1}^{n} w_{1i}}{n} \\ \frac{\sum_{i=1}^{n} w_{2i}}{n} \\ \vdots \\ \frac{\sum_{i=1}^{n} w_{ni}}{n} \end{bmatrix} \quad (5)$$

$$C = \begin{bmatrix} c_{11} \\ c_{21} \\ \vdots \\ c_{n1} \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{n} b_{1i} \\ \sum_{i=1}^{n} b_{2i} \\ \vdots \\ \sum_{i=1}^{n} b_{ni} \end{bmatrix} \quad (6)$$

e. Calculating the maximum eigenvalues.

$$\lambda_{max} = \frac{\sum_{i=1}^{n} \frac{c_{i1}}{ar_{i1}}}{n} \quad (7)$$

f. Determination of CI and CR
 The consistency index (CI) indicates the consistency of judgment in all pairwise comparisons. Consistency Ratio (CR) is an expression of transitivity in the ordo of the RI is random index consistency. The RI value can be seen in Table 1.

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (8)$$

$$CR = \frac{CI}{RI} \quad (9)$$

**Table 1.** RI value with matrix ordo

| **Matrix Ordo** | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| RI | 0.00 | 0.00 | 0.58 | 0.90 |
| **Matrix Ordo** | **5** | **6** | **7** | **8** |
| RI | 1.12 | 1.24 | 1.32 | 1.41 |
| **Matrix Ordo** | **9** | **10** | **11** | **12** |
| RI | 1.45 | 1.48 | 1.49 | 1.51 |

After the CR value is generated and if the CR value is 10%, proceed to the steps for determining the weight of the criteria adapted from the "Chang" method. The following are the steps of the "Chang" method [29].

a) Determination of fuzzy synthesis.
b) Determination of vector values.
c) Determination of ordinate values.
d) Normalization of the weight vector.
e) Calculate the weight of all sub-criteria by multiplication the weight of the sub-criteria with the main criteria.

### 2.2. Fuzzy technique for order preference by similarity to ideal solution (TOPSIS)

A method that integrates TOPSIS with fuzzy logic. This method is based on the concept


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that the resulting alternative has the closest alternative distance to the positive ideal solution and the farthest alternative distance from the negative ideal solution**.** The method of TOPSIS has a limitation; there is no determination of the weights of the criteria priority, which helps increase the validity of the weight values of the criteria calculation [25]. While the advantage of this method is its simple concept, so it is very popular and used in many areas of decision making [30]. In addition, this method takes into account the distance to the positive ideal solution and the distance to the negative ideal solution simultaneously to produce an optimal solution [27]. The following is the calculation sequence for the TOPSIS fuzzy method [31].

a. Create a triangular fuzzy value matrix.
   It is determined by changing the questionnaire results to the TFN TOPSIS number.
b. Calculate the geometric mean.
   Calculate the geometric mean value as in the second stage of the fuzzy AHP method.
c. Create a normalized decision matrix.

$$p_{ij} = \frac{\tilde{x}_{ij}}{\sqrt{\sum_{i=1}^{m}\left(s(\tilde{x}_{ij},0)\right)^2}} \quad (10)$$

with,

$$s(\tilde{x}_{ij},0) = \frac{x_{ij}^{l}+2x_{ij}^{m}+x_{ij}^{u}}{4} \quad (11)$$

d. Create a weighted normalized matrix.

$$v_{ij} = W_{ij} \times p_{ij} \quad (12)$$

e. Determination of the value of the ideal solution.

$$A^{+} = \{v_1^{+}, v_2^{+}, \dots, v_n^{+}\}$$
$$A^{-} = \{v_1^{-}, v_2^{-}, \dots, v_n^{-}\} \quad (13)$$

f. Determine the alternative distance options.
   The alternative distance with the positive ideal solution.

$$D_i^{+} = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^{+}\right)^2} \quad (14)$$

The alternative distance with the negative ideal solution.

$$D_i^{-} = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^{-})^2} \quad (15)$$

g. Determination of green supplier priorities.

$$Vi = \frac{D_i^{-}}{D_i^{-}+D_i^{+}} \quad (16)$$

The value of *V*i or preference value is the final result determining the alternative priority, with the first-order value being the highest preference value.

## 3. RESULTS AND DISCUSSION

### 3.1 Determine the criteria and sub-criteria

This research uses five criteria with the following sub-criteria, while for green suppliers, there are 10. The first thing to do is describe the hierarchy structure to facilitate the resolution of existing problems, as seen in Fig. 1. Level 1 contains the objectives of the decisions taken, level 2 consists of criteria, level 3 consists of sub-criteria, and level 4 consists of alternatives.

Determining the criteria and sub-criteria for green supplier selection has three stages. The first stage is conducting a literature study to determine the criteria and sub-criteria used in green supplier selection. The second stage is to conduct interviews with the manager of procurement. The procurement manager was chosen as the resource person because he understands the company's business strategy and operating strategy and understands the supplier selection process. This stage is helpful to find out how the condition of the company and how the criteria and sub-criteria for supplier selection before this research is carried out. The third stage is to make adjustments between the criteria and sub-criteria contained in the literature used with the company's current condition. Based on Qazvini et al. [32]. this research uses the sub-criteria of qualification rate and quality management rate. Based on Zhang et al. [13], this research uses the sub-criteria of reject rate, on-time delivery rate, lead time, transport-tation cost, payment flexibility, service rate, and green image. Based on Gustina et al. [21], this research uses the sub-criteria of order fulfilment rate and product price. Based on Payam et al. [16], this research uses the sub-criteria of the environmental management system and environ-mental certification. These criteria and sub-criteria will be included in the research questionnaire, which will involve three expert respondents.

### 3.2 Determine of final weights using the AHP method

AHP fuzzy data processing begins by comparing all existing criteria and sub-criteria. The comparison is converted from the numerical value of the questionnaire to the triangular fuzzy number value. The next calculation looks for the value of the mean member of the pairwise comparison matrix between criteria using the geometric mean equation in Table 2. The same is done for each sub-criteria.

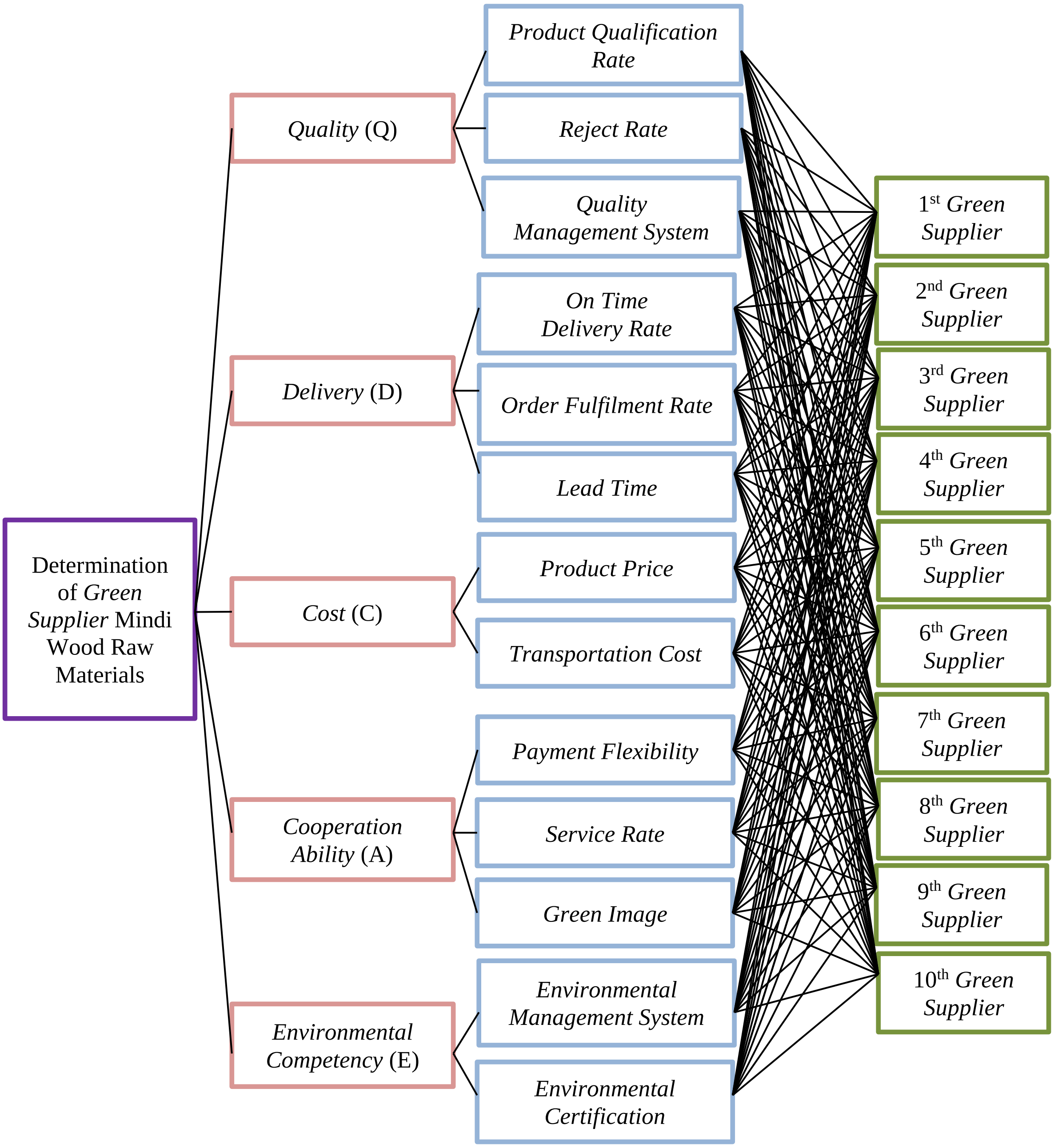


**Fig. 1.** Hierarchical Structure

**Table 2.** Average Pairwise Comparison Matrix between Criteria

| **Main Criteria** | ***Quality*** | | | ***Delivery*** | | | ***Cost*** | | | ***Cooperation Ability*** | | | ***Environmental Competency*** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quality | 1.00 | 1.00 | 1.00 | 1.00 | 1.15 | 1.26 | 1.44 | 1.96 | 2.47 | 1.26 | 1.78 | 2.29 | 1.00 | 1.15 | 1.26 |
| Delivery | 0.79 | 0.87 | 1.00 | 1.00 | 1.00 | 1.00 | 1.44 | 1.96 | 2.47 | 1.26 | 1.78 | 2.29 | 1.00 | 1.00 | 1.00 |
| Cost | 0.41 | 0.51 | 0.69 | 0.41 | 0.51 | 0.69 | 1.00 | 1.00 | 1.00 | 1.00 | 1.55 | 2.08 | 0.40 | 0.51 | 0.69 |
| Cooperation Ability | 0.44 | 0.56 | 0.79 | 0.35 | 0.42 | 0.55 | 0.48 | 0.64 | 1.00 | 1.00 | 1.00 | 1.00 | 0.44 | 0.56 | 0.79 |
| Environmental Competency | 0.79 | 0.87 | 1.00 | 1.00 | 1.00 | 1.00 | 1.44 | 1.96 | 2.47 | 1.26 | 1.78 | 2.29 | 1.00 | 1.00 | 1.00 |


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Then calculate the maximum eigenvalue, which helps calculate the consistency test. Below is the calculation of the consistency ratio.

a) Consistency Ratio of Main Criteria.

$$CR = \frac{CI}{IR} = \frac{0.006}{1.12} = 0.005$$

b) Consistency Ratio of Quality (Q)

$$CR = \frac{CI}{IR} = \frac{0.014}{0.58} = 0.024$$

c) Consistency Ratio Delivery (D)

$$CR = \frac{CI}{IR} = \frac{0.007}{0.58} = 0.011$$

d) Consistency Ratio of Cost (C)

$$CR = \frac{CI}{IR} = \frac{0}{0} = 0$$

e) Consistency Ratio of Cooperation Ability (A)

$$CR = \frac{CI}{IR} = \frac{0}{0.58} = 0$$

f) Consistency Ratio of Environmental Competency (E)

$$CR = \frac{CI}{IR} = \frac{0}{0} = 0$$

Because the consistency ratio between criteria and sub-criteria has a value of $CR \leq 0.1$, the questionnaire results have met the requirements and are declared consistent. The next step is the weighting of the main criteria also sub-criteria. They start with calculating the fuzzy synthesis value. The result of fuzzy synthetic extent is in Table 3.

**Table 3.** Fuzzy synthetic extent value for criteria

| Main Criteria | *l* | *m* | *U* |
|---|---|---|---|
| Quality | 0.172 | 0.255 | 0.366 |
| Delivery | 0.166 | 0.240 | 0.343 |
| Cost | 0.097 | 0.148 | 0.228 |
| Cooperation Ability | 0.082 | 0.116 | 0.183 |
| Environmental Competency | 0.166 | 0.240 | 0.343 |

The same is done for each sub-criteria calculation. The vector value and the ordinate value between the main criteria and sub-criteria are calculated from the fuzzy synthesis value. The vector and shared values help calculate the weight value of the criteria and sub-criteria.

The processing results show that the on-time delivery (D1) sub-criteria has the highest weight, which is 0.149. There is an environmental management system (E1) and environmental certification (E2) with a value of 0.141. In third place, there is a product qualification rate (Q1), a reject rate (Q2) is 0.123, and other sub-criteria in order according to the weight values listed in Table 4. The importance of the weights can be used as a reference in the assessment of green suppliers using the TOPSIS fuzzy method to find out which sub-criteria are priorities in the assessment.

**Table 4.** Final weight for sub-criteria

| Sub-criteria | Final Weight |
|---|---|
| Product Qualification Rate (Q1) | 0.123 |
| Reject Rate (Q2) | 0.123 |
| Quality Management System (Q3) | 0.057 |
| On Time Delivery Rate (D1) | 0.149 |
| Order Fulfilment Rate (D2) | 0.120 |
| Lead Time (D3) | 0.013 |
| Product Price (C1) | 0.053 |
| Transportation Cost (C2) | 0.053 |
| Payment Flexibility (A1) | 0.007 |
| Service Rate (A2) | 0.007 |
| Green Image (A3) | 0.007 |
| Environmental Management System (E1) | 0.141 |
| Environmental Certification (E2) | 0.141 |

The difference seen between the results of previous studies and this research is caused by the industry being studied. Previous research has focused on supplier selection or contactors selection in construction projects, while this research focuses on supplier selection for raw materials for the production process (Mindi wood). Like the research conducted by Payam et al. [16] on construction projects, it can be seen that the sub-criteria of green material design and equipment flexibility have the highest weight. It is different from this research which focuses on the furniture industry; the sub-criteria of on-time delivery, environmental management system, and environmental certification has the highest weight.

The development of science causes an organization to focus not only on the quality and delivery of raw materials but also on the environmental aspect, especially in developing countries such as Indonesia, which currently has abundant forest land. The current government is more focused on how to overcome environmental problems. So, the results of this research that environmental competency criteria have the highest weight can be used to prevent environmental problems through the priority criteria in the best green supplier selection because the best green supplier will implement environmental policies correctly and adequately.

### 3.3 Determine of ideal solution using the TOPSIS method

TOPSIS fuzzy data processing begins by creating a triangular fuzzy value matrix obtained by converting the questionnaire results into a TOPSIS triangular fuzzy number value. Then the geometric mean is calculated. It is used to calculate the normalized decision matrix.

Multiplying the normalized decision matrix by the weight of each sub-criteria generated in the fuzzy AHP method will become a weighted normalized decision matrix. The following determination determines the value of the ideal solution that is useful for calculating alternative distances so that the results are as shown in Table 5.

**Table 5.** Positive ideal solution and negative ideal solution

| Sub-criteria | Ideal Solution ($A^+$) | Ideal Solution ($A^-$) |
|---|---|---|
| Product Qualification Rate (Q1) | 0.047 | 0.027 |
| Reject Rate (Q2) | 0.047 | 0.027 |
| Quality Management System (Q3) | 0.022 | 0.012 |
| On Time Delivery Rate (D1) | 0.055 | 0.034 |
| Order Fulfilment Rate (D2) | 0.044 | 0.027 |
| Lead Time (D3) | 0.005 | 0.004 |
| Product Price (C1) | 0.022 | 0.014 |
| Transportation Cost (C2) | 0.022 | 0.012 |
| Payment Flexibility (A1) | 0.003 | 0.002 |
| Service Rate (A2) | 0.003 | 0.002 |
| Green Image (A3) | 0.003 | 0.002 |
| Environmental Management System (E1) | 0.055 | 0.031 |
| Environmental Certification (E2) | 0.055 | 0.031 |

The results of the alternative distance calculation in the evaluation of the green supplier are shown in Table 6. In determining the priority of green suppliers, it is necessary to calculate the distance to the positive ideal solution. The value of Vi or the preference value obtained is the final valuable result for knowing alternative prefe-rences with the order of preference values starting from the highest preference value in Table 7.

**Table 6.** Alternative distance for green supplier evaluation

| Green Supplier | $d_1^+$ | $d_1^-$ |
|---|---|---|
| 1st Green Supplier | 0.031 | 0.039 |
| 2nd Green Supplier | 0.032 | 0.034 |
| 3rd Green Supplier | 0.036 | 0.032 |
| 4th Green Supplier | 0.039 | 0.017 |
| 5th Green Supplier | 0.029 | 0.030 |
| 6th Green Supplier | 0.036 | 0.024 |
| 7th Green Supplier | 0.028 | 0.029 |
| 8th Green Supplier | 0.013 | 0.047 |
| 9th Green Supplier | 0.025 | 0.036 |
| 10th Green Supplier | 0.015 | 0.048 |

**Table 7.** Vi value and the rank of green supplier

| Green Supplier | Vi | Rank |
|---|---|---|
| 1st Green Supplier | 0.557 | 4 |
| 2nd Green Supplier | 0.511 | 5 |
| 3rd Green Supplier | 0.471 | 8 |
| 4th Green Supplier | 0.305 | 10 |
| 5th Green Supplier | 0.508 | 6 |
| 6th Green Supplier | 0.404 | 9 |
| 7th Green Supplier | 0.504 | 7 |
| 8th Green Supplier | 0.777 | 1 |
| 9th Green Supplier | 0.591 | 3 |
| 10th Green Supplier | 0.762 | 2 |

The Table 7 shows the *Vi* value or preference value and green supplier ranking. The value of *Vi* or the value of an enormous preference is the first rank in order from the highest *Vi* value to the lowest Vi value. The first rank on the processing results is the 8th green supplier with a preference value of 0.777. It is chosen as the best green supplier. The company can prioritize the 8th green supplier in purchasing mindi wood raw materials.

The results obtained have a higher level of truth than in previous studies using the AHP and TOPSIS methods without adding fuzzy logic. Because fuzzy logic has reasoning abilities similar to human reasoning abilities, it can apply the experiences of experts directly without a training process. Thus, the research contributes to applying fuzzy logic in the AHP and TOPSIS methods to analyze the behaviour of variables in the decision-making process.

### 3.4 Sensitivity Analysis

Sensitivity analysis is very important for the decision-maker to understand how changes in a parameter can affect changes in other parameters or results because effectiveness methodology is


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managerially based entirely on the preferences and utility of the decision-maker [33]. Several studies conducted a sensitivity analysis to determine a model sensitivity that has been formed to changes in the weight of a parameter. The research conducted by Durmic et al. [34] formed 12 scenarios where the criteria values were changed, and it was found that the model was sensitive to changes in the criteria. The research conducted by Chatterjee et al. [30] formed 24 scenarios where the criteria values were changed. The model formed was stable because it was the best solution in some situations. The research conducted by Zavadskas et al. [35] in the sensitivity analysis that has been carried out shows that the model formed is stable due to changes in the significance of the criteria by up to 30%, and the results remain the same. The chosen solution remains in the first rank. While in this study using 18 scenarios. The first to the 13th scenario is conducted by increasing each sub-criteria weight by 8% from the first to the last. The 14th scenario is conducted by increasing the important sub-criteria weight, Q1, Q2, D1, D2, E1, and E2, by 4%, and the rest remained. The 15th scenario is conducted by reducing the important sub-criteria weight, which are Q1, Q2, D1, D2, E1, E2, by 4%, and the rest is reduced by 2%. The 16th scenario increases the weight of the lowest sub-criteria, D3, A1, A2, and A3, by 4% and the rest is reduced by 2%. In the 15th scenario, all sub-criteria weights are considered the same. The 18th scenario forms the weight of the sub-criteria Q1, Q2, D1, D2, E1, E2 of 0.16, and the others are considered 0 or not taken into account.

Based on Fig. 2, the 8th green supplier is in the first rank as an acceptable alternative in 15th of the 18 scenarios have been formed. There is no significant change from the first scenario until the 13th scenario, where the 8th green supplier remains in the first position. However, changes occur in the 12th and 13th scenarios: the 10th green supplier is in the first position, and the 8th green supplier is in the second position. It shows that sub-criteria E1 and E2 are the most significant sub-criteria in playing a role in the decision-making process. The rating change also occurs in the 18th scenario, where the 10th green supplier is in the first position. Important sub-criteria are considered to weigh 0.16, and others are not considered to exist or are omitted. At the same time, the 14th scenario until the 17th scenario show that the 8th green supplier remains in the first position. So, it can be seen that the model formed is stable. Because the significant changes are only in 3 scenarios and the others remain the same, the 8th green supplier remains in the first rank and is the most acceptable alternative.

### 3.5 Comparative Analysis

The stability of the results that have been obtained from the applied method has been carried out through comparative analysis using other MCDM methods. The proposed model is compared with other MCDM methods: the fuzzy AHP with fuzzy Promethee method and the fuzzy AHP with fuzzy SAW (Simple Additive Weighting) method. The results obtained indicate that the proposed fuzzy TOPSIS with fuzzy AHP model is perfectly correlated with the fuzzy AHP with fuzzy Promethee and fuzzy AHP with fuzzy SAW models. It shows that the model applied is stable, with the 8th green supplier remaining in the first position and others. The result of the comparative analysis can be seen in Table 8.

**Table 8.** The result of comparative analysis

| Green Supplier | Fuzzy Promthee | Rank | Fuzzy SAW | Rank |
|---|---|---|---|---|
| 1st Green Supplier | 0.01991 | 3 | 0.82133 | 4 |
| 2nd Green Supplier | 0,00606 | 5 | 0.79054 | 6 |
| 3rd Green Supplier | -0.01318 | 8 | 0.78813 | 8 |
| 4th Green Supplier | -0.07076 | 10 | 0.71523 | 10 |
| 5th Green Supplier | 0.00156 | 6 | 0.79127 | 5 |
| 6th Green Supplier | -0.03746 | 9 | 0.73102 | 9 |
| 7th Green Supplier | -0.0118 | 7 | 0.78862 | 7 |
| 8th Green Supplier | 0.02691 | 1 | 0.93034 | 1 |
| 9th Green Supplier | 0.00953 | 4 | 0.82369 | 3 |
| 10th Green Supplier | 0.02447 | 2 | 0.91117 | 2 |

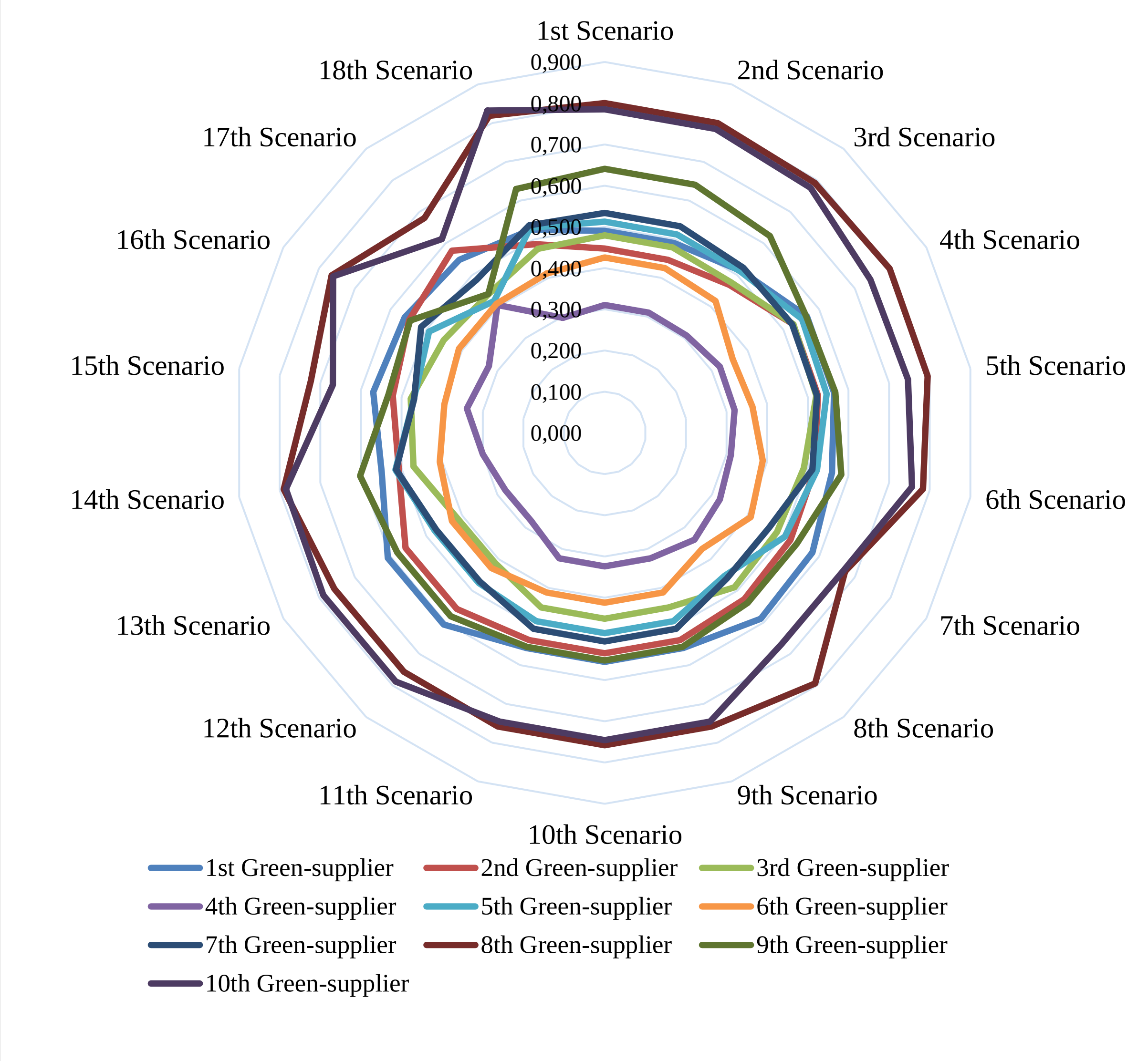


**Fig 2.** The result of sensitivity analysis

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## 4. CONCLUSION

This study focuses on selecting the best green suppliers as input for companies in prioritizing the green suppliers used. The decision-making uses two stages: processing data using fuzzy AHP and then processing data using fuzzy TOPSIS. The 8th green supplier was produced with a *Vi* value of 0.777, which indicates the highest preference value. Then in order from second to tenth rank, there are 10th green supplier (0.762), 9th green supplier (0.591), 1st green supplier (0.557), 2nd green supplier (0.511), 5th green supplier (0.508), green 7th supplier (0.504), 3rd green supplier (0.471), 6th green supplier (0.404), and 4th green supplier (0.305).

This research has advantages in the results obtained having a higher level of truth than in previous studies using the AHP and TOPSIS methods without adding fuzzy logic. Fuzzy logic has reasoning abilities similar to human reasoning abilities to apply the experiences of experts directly without a training process. In addition, this research has a broader scope than previous research, which was limited to universities. By researching the scope of the manufacturing industry, the views of the experts will follow the concept of the research hierarchy because the selected experts are in the division or field that is in accordance with the research topic. So, the results obtained will have a higher level of accuracy.

On the other hand, this research has limitations in using quality, delivery, cost, cooperation ability, and environmental

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competency and uses 13 sub-criteria. Because this is following the company's condition, Green supplier research is not limited to only five criteria. Still, other criteria can be added, for example, chemical waste treatment plants and rework ability for each green supplier.

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