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# Implementation of the Analytical Hierarchy Process (AHP) with AI-Assisted Validation for Waste Processing Method Selection

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**Abstract**−The increasing volume of municipal solid waste in Sumenep Regency has created significant challenges for local authorities in selecting an effective and sustainable waste treatment method. The selection process requires consideration of multiple criteria, including economic, technical, environmental, social, labor, and material recovery aspects. Therefore, this study aims to determine the most suitable waste processing method by applying the Analytical Hierarchy Process (AHP) as the primary decision-making approach and an AI-assisted validation approach as a comparative evaluation tool. The AHP method was used to calculate the relative importance of criteria and rank three waste treatment alternatives, namely Composting, Sanitary Landfill, and Incineration, based on expert judgments. To strengthen the reliability of the decision-making process, an AI-assisted evaluation using a Large Language Model (LLM) was conducted to assess the same alternatives according to the established criteria and compare the resulting rankings with those obtained from AHP. The results of the AHP analysis indicate that Composting has the highest priority weight of 48.0%, followed by Sanitary Landfill with 33.5% and Incineration with 18.5%. Similarly, the AI-assisted evaluation generated the highest score for Composting (0.9835), followed by Sanitary Landfill (0.6130) and Incineration (0.6025). The consistency between the rankings produced by AHP and the AI-assisted assessment demonstrates the robustness of the selected alternative. The findings suggest that Composting is the most appropriate waste treatment method for Sumenep Regency due to its superior environmental performance, social acceptance, and material recovery potential. Furthermore, the study highlights the potential of AI-assisted evaluation as a supporting validation tool for enhancing multi-criteria decision-making in waste management planning.

**Keywords**: Waste Management; Analytical Hierarchy Process; Multi-Criteria Decision Making; Artificial Intelligence; Composting; Sanitary Landfill

## 1. INTRODUCTION

Municipal solid waste management has become one of the most significant environmental challenges worldwide due to rapid population growth, urbanization, and economic development[1]. The increasing generation of waste places substantial pressure on existing waste management systems and may lead to environmental pollution, public health issues, and resource depletion if not managed properly[2]. Consequently, selecting an appropriate waste treatment method is essential to ensure sustainable waste management while balancing environmental, social, technical, and economic considerations[3].

Indonesia faces similar challenges in managing municipal solid waste[4]. The continuous increase in waste generation has created difficulties for local governments in providing effective collection, treatment, and disposal systems[5]. Various waste treatment methods, including composting, sanitary landfill, and incineration, have been implemented in different regions[6]. However, each method possesses distinct advantages and limitations in terms of environmental impact, operational feasibility, economic cost, social acceptance, labor requirements, and material recovery potential[7]. Therefore, selecting the most appropriate waste treatment method requires a comprehensive evaluation that considers multiple criteria simultaneously[8].

Several decision-support approaches have been developed to address complex environmental and infrastructure planning problems[9]. Among these approaches, the Analytical Hierarchy Process (AHP) has been widely applied in waste management studies due to its ability to structure decision problems hierarchically and incorporate expert judgment through pairwise comparisons[10]. Previous studies have demonstrated the effectiveness of AHP in evaluating waste management alternatives, landfill site selection, recycling strategies, and integrated waste management systems. The method enables decision-makers to determine the relative importance of evaluation criteria and generate prioritized alternatives based on quantitative weighting results.[11]

Despite the widespread application of AHP in waste management decision-making, most previous studies rely primarily on expert-based assessments[12]. Recent developments in artificial intelligence have introduced new opportunities to support decision-making processes through comparative evaluation and validation of decision outcomes[13]. However, studies examining the consistency between AHP-based rankings and AI-assisted assessments remain limited, particularly in the context of municipal waste management in Indonesia [14]. Furthermore, research specifically addressing waste treatment method selection in Sumenep Regency is still scarce, despite the increasing need for sustainable waste management strategies in the region.

Sumenep Regency, located in the eastern part of Madura Island, has experienced a steady increase in municipal waste generation over the past several years. Data from the Sumenep Regency Environmental Service indicate that daily waste generation increased from approximately 20–21 tons in 2018 to 33.32 tons in 2023. This growth reflects the increasing burden on existing waste management systems and underscores the need for effective waste treatment solutions. Since each waste treatment alternative possesses different environmental, technical, social, and economic

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characteristics, a systematic decision-making approach is required to identify the most suitable method for local conditions.

To address this research gap, this study aims to determine the most appropriate waste treatment method for Sumenep Regency using the Analytical Hierarchy Process (AHP). Three waste treatment alternatives, namely Composting, Sanitary Landfill, and Incineration, are evaluated based on economic, technical, environmental, social, labor, and material recovery criteria[15]. In addition, an AI-assisted evaluation based on a Large Language Model (LLM) is employed as a comparative assessment tool to examine the consistency of the ranking results generated by AHP[16]. The findings of this study are expected to provide decision support for local governments in selecting sustainable waste treatment methods and contribute to the development of integrated approaches combining multi-criteria decision-making and AI-assisted validation in waste management planning[17].

From the above problems, there is a need for infrastructure improvement, including the expansion of landfill capacity and the development of more advanced waste treatment facilities[18]. In addition, education and awareness programs are essential to encourage public participation in 3R (Reduce, Reuse, Recycle) practices, particularly at the household level [19]. Through the implementation of sustainable waste management strategies and appropriate waste treatment technologies, Sumenep Regency has the opportunity to reduce environmental impacts and improve the effectiveness of its waste management system.

To support the selection of an appropriate waste treatment method, this study employs the Analytical Hierarchy Process (AHP), a widely used multi-criteria decision-making method that enables decision makers to evaluate alternatives based on pairwise comparisons of relevant criteria[20]. The method produces priority rankings that reflect the relative importance of each criterion and alternative. In addition to AHP, this study utilizes an AI-assisted evaluation based on a Large Language Model (LLM) as a comparative assessment tool[21]. The AI-assisted evaluation is used to assess the same waste treatment alternatives according to the established criteria and compare the resulting rankings with those obtained from AHP[22]. This approach aims to examine the consistency of decision outcomes and explore the potential of AI as a supporting validation tool in waste management decision-making[23].

## 2. RESEARCH METHODOLOGY

This study employs the Analytical Hierarchy Process (AHP) as the primary decision-making method to evaluate alternative waste treatment methods in Sumenep Regency. The analysis considers multiple criteria, including economic, technical, environmental, social, labor, and material recovery aspects. In addition, an AI-assisted comparative assessment was conducted to examine the consistency of the rankings obtained from the AHP analysis[24]. Unlike the AHP method, which relies on expert judgment through pairwise comparisons, the AI-assisted assessment was used as a supporting evaluation tool to provide an additional perspective on the prioritization of waste treatment alternatives[25]. The overall research procedure consists of problem identification, determination of criteria and alternatives, expert judgment collection, AHP analysis, AI-assisted comparative assessment, and comparison of the final results[26].

### 2.1 Analytic Hierarchy Process (AHP) Method

The Analytic Hierarchy Process (AHP) method is a decision-making technique that helps determine priorities among various options based on certain criteria[27]. AHP is useful for complex situations, where various criteria need to be considered quantitatively and qualitatively, Steps to Use AHP:

a. Defining Problems and Objectives
   1. Determine the main purpose of the analysis. Example: "Choosing the best method for waste management."
   2. Identify alternatives (decision options). Examples: Sanitary Landfill, Incineration, Composting.
   3. Determine the evaluation criteria. Examples: Economic, Environmental Impact, Technical, Material Recovery, etc.

b. Create a Decision Hierarchy, AHP organizes problems in a hierarchical form with three levels:
   1. Level 1 (Purpose): The final goal of the analysis.
   2. Level 2 (Criteria): Factors that influence decision making.
   3. Level 3 (Alternatives): Options or alternatives assessed based on criteria.

c. Creating a Pairwise Comparison Matrix

   Each criterion and alternative were compared pairwise to determine their relative weights within the Analytical Hierarchy Process (AHP). The comparison was conducted using Saaty's fundamental scale, which ranges from 1 to 9 and represents different levels of importance between two elements. The interpretation of the pairwise comparison scale used in this study is presented in Table 1

**Table 1.** Pairwise Comparison Matrix

| Score | Definition |
|---|---|
| 1 | Equally important |
| 3 | A little more important |
| 5 | More important |
| 7 | Much more important |

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| Score | Definition |
|---|---|
| 9 | Absolutely more important |
| 2, 4, 6, 8 | Values between two scales |

The Analytic Hierarchy Process (AHP) method is a decision-making technique that helps determine priorities among various options based on certain criteria. AHP is useful for complex situations, where various criteria need to be considered quantitatively and qualitatively, Steps to Use AHP:

d. Calculating Criteria Weight
   1. Matrix normalization: Add up the values of each column, then divide each value in that column by the column total.
   2. Calculate weights: Take the average of each row of the normalization matrix.

e. Calculating the Weight of Alternatives Against Criteria
   1. Repeat the same steps as above, but this time to compare the alternatives (Sanitary Landfill, Incineration, Composting) based on each criteria.

f. Calculating the Final Score
   Combine the criteria weights and alternative weights to obtain the final score for each alternative:

$$\text{Final Score} = \sum(\text{Criteria Weight x Alternative Weight in Criteria}) \tag{1}$$

g. Calculating the Final Score
   Ensure the calculation results are consistent by calculating the consistency index (CI) and consistency ratio (CR) :

$$CI = \frac{\lambda max - n}{\mathrm{n}-1} \tag{2}$$

$$CR = \frac{CI}{\mathrm{RI}} \tag{3}$$

Where :
$\lambda max$: The largest eigenvalue of the matrix.
n: Number of criteria.
RI: Random index for n, value can be taken from table (example: for n=3, RI=0.58).
If CR<0.1, then the results are considered consistent.

### 2.2 *AI-Assisted Comparative Assessment*

The AI-assisted assessment was conducted using the same alternatives and evaluation criteria applied in the AHP analysis, namely economic, technical, environmental, social, labor, and material recovery aspects. Based on the information provided, the AI system evaluated the alternatives and generated comparative scores and rankings. The resulting rankings were subsequently compared with the AHP results to examine the consistency of the decision outcomes.

The use of AI-assisted evaluation in this study serves as a complementary validation approach that supports multi-criteria decision-making by providing an independent assessment of the alternatives. This comparison enables a more comprehensive interpretation of the results and helps identify whether the prioritization generated by AHP remains consistent when evaluated from an AI-assisted perspective. The AI-assisted comparative assessment was conducted through the following stages:

a. Identification of Alternatives and Criteria
   The waste treatment alternatives evaluated in this study consisted of Composting, Sanitary Landfill, and Incineration. The assessment criteria included economic, technical, environmental, social, labor, and material recovery aspects, consistent with those used in the AHP analysis.

b. Preparation of Assessment Information
   Information regarding each alternative and evaluation criterion was compiled from literature reviews, expert judgments, and data used in the AHP evaluation process. This information served as the basis for the AI-assisted assessment.

c. AI-Assisted Evaluation
   Large Language Model (LLM)-based AI tool was employed to evaluate the waste treatment alternatives according to the established criteria. The AI system analyzed the strengths and limitations of each alternative and generated comparative assessment scores.

d. Generation of Alternative Rankings
   Based on the evaluation results, the AI-assisted assessment produced rankings for each waste treatment alternative. The rankings reflected the relative suitability of each alternative according to the specified criteria.

e. Comparison with AHP Results
   The rankings obtained from the AI-assisted assessment were compared with the results generated by the AHP method. This comparison was performed to examine the consistency of alternative prioritization between the two approaches.

f. Interpretation of Results
   The similarities and differences between the AHP and AI-assisted rankings were analyzed to provide a comprehensive evaluation of the most suitable waste treatment method for Sumenep Regency.

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# 3. RESULTS AND DISCUSSION

This section presents the results of the Analytical Hierarchy Process (AHP) analysis and the AI-assisted comparative assessment conducted to evaluate waste treatment alternatives in Sumenep Regency. The results are discussed by examining the relative importance of criteria, the ranking of alternatives, and the consistency between the AHP and AI-assisted evaluations. Furthermore, the findings are compared with previous studies to identify similarities, differences, and their implications for waste management decision-making.

## 3.1 Identification of Criteria and Sub-Criteria

The criteria and sub-criteria used in this study were determined based on the main objectives of the analysis, findings from previous studies, expert consultations, and considerations of local needs and conditions. These criteria were selected to ensure that the evaluation process comprehensively addresses the economic, technical, environmental, social, labor, and material recovery aspects of waste treatment alternatives.

The proposed evaluation criteria and their corresponding sub-criteria used in the decision-making process are presented in Table 2.

**Tabel 2.** List of Selection Evaluation Criteria

| Criteria | Sub Criteria to be Considered |
|---|---|
| Economical | Capital Costs: initial/installation costs of construction |
| | Operating Costs: operating costs support processing |
| | Income: proceeds from waste processing |
| | Cost burden per resident (contribution) |
| Technical | Reliability |
| | Eligibility |
| | Potential for future development |
| | Adaptation to local conditions |
| Environmental Impact | Global impact: global warming |
| | Regional Impact |
| | 1) Environmental Health |
| | 2) Surface water contamination |
| | 3) Air emissions and wastewater discharges |
| | Local Impact |
| | 1) Environmental Health |
| | 2) Surface water contamination |
| | 3) Air emissions and wastewater discharges |
| Social Impact | Acceptance of the Surrounding Community |
| | Eviction of community land |
| Labor | Local workforce to be absorbed |
| Resources saved | Recyclable products |
| (Material Revovery) | Energy requirements (energy produced) |
| | Market potential |
| | Extent of Land Use |

The Table 2 above provides details of the criteria and sub-criteria considered in decision making, particularly in the context of evaluating waste treatment systems or projects involving multidimensional impacts. The following is an interpretation of the table:

a. Economical
   This criterion highlights the cost and revenue aspects associated with project implementation. The sub-criteria provide the following details:
   1. Capital Costs: Focuses on the initial investment required for the construction or installation of the system.
   2. Operating Costs: Costs required to run the system on an ongoing basis.
   3. Revenue: Revenue that can be generated from waste processing (such as the sale of recycled products).
   4. Cost Burden Per Population: Costs charged to the community (e.g. monthly fees).

b. Technical
   These criteria assess the feasibility and technical capability of the project by considering the following:
   1. Reliability: The degree of reliability of a technology or system.
   2. Applicability: Ability to be applied in a given context.
   3. Future Development Potential: Possibility for expansion or adaptation of technology.
   4. Adaptation to Local Conditions: The ability of a system to adapt to geographic, social, or cultural conditions.

c. Environmental Impact
   These criteria address the project's impacts on the environment at various scales:
   1. Global Impact: Assess contributions to global issues such as global warming.

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2. Regional Impacts: Includes environmental health, surface water contamination, and air and wastewater emissions at the regional level.
3. Local Impact: Similar to regional impact, but more focused on effects in local areas.

d. Social Impact
These criteria measure public acceptance of the project and its effects on the community:
1. Community Acceptance: Level of support or objection from local communities.
2. Eviction of Community Land: Possible social consequences of land acquisition.

e. Workforce
These criteria evaluate the project's contribution to job creation:
1. Local Labor Absorption: Focus on direct economic benefits to local communities.

f. Material Recovery (Recycled Resources)
These criteria assess the project's ability to conserve resources and maximize the benefits of recycled materials:
1. Recyclable Products: Types and volumes of materials that can be recycled.
2. Energy Needs (Energy Generated): Energy efficiency and earning potential.
3. Market Potential: Marketing possibilities for recycled products.
4. Extent of Land Use: Efficient use of land for project operations.

### 3.2 Creating a Hierarchical Structure

AHP requires a clear hierarchical structure, consisting of:

a. Level 1: Primary objective (e.g. selecting the best waste treatment system).
b. Level 2: Main criteria (e.g., economic, technical, environmental impact, etc.).
c. Level 3: Sub-criteria for each criterion.

The hierarchical structure developed for this study serves as the foundation for the AHP analysis. Figure 1 presents the hierarchical model used to evaluate waste treatment alternatives in Sumenep Regency based on multiple decision criteria and sub-criteria.

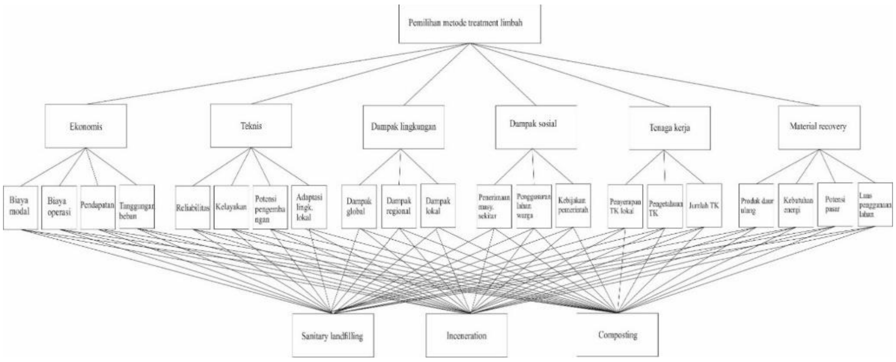


**Figure 1.** Waste Selection Model

As illustrated in Figure 1, the hierarchy consists of four levels: the overall objective at the top level, the evaluation criteria at the second level, the corresponding sub-criteria at the third level, and the waste treatment alternatives at the final level. This structure provides a systematic framework for assessing the relative importance of decision elements and determining the most suitable waste treatment method.

### 3.3 Creating a Hierarchical Structure

After the data is collected:

a. Weights are calculated: Using the eigenvector or normalization method to determine the relative weight of each criterion/sub-criteria.
b. Consistency tested: Calculate the Consistency Ratio (CR) to ensure that the assessment is not contradictory. $CR \leq 0.1$ is considered consistent.

The pairwise comparison data obtained from expert assessments were analyzed using Expert Choice software, which is widely used to support decision-making based on the Analytical Hierarchy Process (AHP). The resulting weights of the main evaluation criteria and the inconsistency ratio are presented in Table 3.

**Table 3.** Weights for all criteria

| Criteria | Weight | Inconsistency |
|---|---|---|
| Economical | 0.034 | 0.08 |
| Technical | 0.091 | |
| Environmental impact | 0.441 | |
| Social impact | 0.263 | |
| Labor | 0.1 | |

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| Criteria | Weight | Inconsistency |
|---|---|---|
| Material recovery | 0.072 | |

As shown in Table 3, the Environmental Impact criterion has the highest priority weight (0.441), indicating that environmental considerations are the most influential factor in selecting an appropriate waste treatment method. This finding suggests that minimizing environmental impacts is the primary concern in the decision-making process.

The Social Impact criterion ranks second with a weight of 0.263, demonstrating the importance of community acceptance and social consequences associated with waste treatment alternatives. Labor and Technical criteria have weights of 0.100 and 0.091, respectively, indicating a moderate level of influence on the overall decision. Material Recovery receives a weight of 0.072, suggesting that resource recovery potential is considered but is not a dominant factor. Meanwhile, the Economic criterion has the lowest weight (0.034), indicating that cost-related aspects are less influential than environmental and social considerations in determining the most suitable waste treatment method.

Furthermore, the inconsistency ratio obtained from the pairwise comparison matrix is 0.08, which is below the acceptable threshold of 0.10. This result confirms that the judgments provided by the experts are sufficiently consistent and can be considered reliable for subsequent analysis.

The inconsistency column shows the level of consistency in the assessment of the comparison of criteria. In AHP, the ideal inconsistency value is below 0.1 (10%), indicating that the comparison between criteria is quite consistent. From the overall results, the decision taken based on this table will emphasize environmental impacts as the main priority, followed by social impacts. Since the Economic criterion contributes to the overall decision-making process, further analysis was conducted to determine the relative importance of its sub-criteria. The weights of the economic sub-criteria obtained from the AHP analysis are presented in Table 4.

**Table 4.** Weights for economic sub-criteria

| Economic sub-criteria | Weight | Inconsistency |
|---|---|---|
| Cost of capital | 0.103 | 0.02 |
| Operating costs | 0.119 | |
| Income | 0.297 | |
| Liability burden | 0.481 | |

As shown in Table 4, Liability Burden has the highest priority weight (0.481), indicating that the financial burden borne by residents is the most influential economic factor in selecting a waste treatment method. This suggests that affordability and cost-sharing considerations are prioritized over other economic aspects. Income ranks second with a weight of 0.297, highlighting the importance of potential revenue generated from waste treatment activities. Operating Cost and Capital Cost have relatively lower weights of 0.119 and 0.103, respectively, indicating that operational expenditures and initial investment costs are considered less influential in the economic evaluation.

Furthermore, the inconsistency ratio obtained for the economic sub-criteria is 0.02, which is well below the acceptable threshold of 0.10. This result indicates that the pairwise comparison judgments provided by the experts are consistent and reliable for subsequent analysis. The weights of the technical sub-criteria obtained from the AHP analysis are presented in Table 5.

**Table 5.** Weights for technical sub-criteria

| Technical Sub Criteria | Weight | Inconsistency |
|---|---|---|
| Reliability | 0.481 | 0.09 |
| Eligibility | 0.149 | |
| Development potential | 0.09 | |
| Adaptation to local conditions | 0.28 | |

As shown in Table 6, Reliability has the highest priority weight (0.481), indicating that the ability of a waste treatment system to operate consistently and effectively is the most important technical consideration in the decision-making process. Adaptation to Local Conditions ranks second with a weight of 0.280, suggesting that the suitability of the technology to local environmental, social, and operational conditions is also a significant factor. Eligibility has a weight of 0.149, reflecting its moderate influence on the technical evaluation. Meanwhile, Development Potential receives the lowest weight (0.090), indicating that future expansion opportunities are considered less important than system reliability and local adaptability. Furthermore, the inconsistency ratio obtained for the technical sub-criteria is 0.09, which remains below the acceptable threshold of 0.10. This result confirms that the expert judgments used in the pairwise comparison process are sufficiently consistent and reliable for further analysis. The weights of the environmental impact sub-criteria obtained from the AHP analysis are presented in Table 6.

**Table 6.** Weights for environmental impact sub-criteria

| Environmental Impact Sub Criteria | Weight | Inconsistency |
|---|---|---|
| Global impact | 0.122 | 0.02 |
| Regional impact | 0.32 | |
| Local impact | 0.558 | |

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As shown in Table 6, Local Impact has the highest priority weight (0.558), indicating that environmental effects directly experienced by the surrounding community are the most important consideration in the evaluation process. These impacts include environmental health conditions, surface and groundwater contamination, and local air emissions resulting from waste treatment activities.Regional Impact ranks second with a weight of 0.320, reflecting the importance of environmental effects that extend beyond the immediate project area, such as the spread of air and water pollution across neighboring regions. Meanwhile, Global Impact has the lowest weight (0.122), suggesting that broader environmental issues, including greenhouse gas emissions and climate change, are considered less influential than local and regional environmental concerns in the decision-making process.

Furthermore, the inconsistency ratio obtained for the environmental impact sub-criteria is 0.02, which is significantly below the acceptable threshold of 0.10. This result indicates that the pairwise comparison judgments provided by the experts are highly consistent and reliable for further analysis. The weights of the social impact sub-criteria obtained from the AHP analysis are presented in Table 7.

**Table 7.** Weights for social impact sub-criteria

| Social Impact Sub Criteria | Weight | Inconsistency |
|---|---|---|
| Acceptance of the surrounding community | 0.709 | 0.05 |
| Eviction of residents' land | 0.113 | |
| government policy | 0.179 | |

As shown in Table 7, Acceptance of the Surrounding Community has the highest priority weight (0.709), indicating that community acceptance is the most influential social factor in the selection of waste treatment methods. This finding suggests that public support and the willingness of local communities to accept a waste management facility are critical considerations in the decision-making process.

Government Policy ranks second with a weight of 0.179, highlighting the importance of regulatory support and policy alignment in facilitating the implementation of waste treatment alternatives. Although government intervention plays a significant role, its influence is considerably lower than that of community acceptance.

Meanwhile, Eviction of Residents' Land has the lowest weight (0.113), indicating that land acquisition and relocation issues are considered less influential than community acceptance and government policy. Nevertheless, this factor remains important because land-use conflicts may affect project implementation and public perception.

Furthermore, the inconsistency ratio obtained for the social impact sub-criteria is 0.05, which is below the acceptable threshold of 0.10. This result confirms that the pairwise comparison judgments provided by the experts are sufficiently consistent and reliable for further analysis. The weights of the labor sub-criteria obtained from the AHP analysis are presented in Table 8.

**Table 8.** Weights for sub-labor

| Sub Criteria for Workforce | Weight | Inconsistency |
|---|---|---|
| Absorption of local labor | 0.637 | 0.04 |
| Workforce knowledge | 0.105 | |
| Number of workers | 0.258 | |

As shown in Table 9, Absorption of Local Labor has the highest priority weight (0.637), indicating that the ability of a waste treatment system to create employment opportunities for local residents is the most important labor-related consideration in the decision-making process. This finding reflects the significance of promoting local economic development and community welfare through job creation. The Number of Workers ranks second with a weight of 0.258, suggesting that the labor requirements of a waste treatment system are also considered an important factor. Alternatives that can provide adequate employment opportunities are generally viewed more favorably from a labor perspective. Meanwhile, Workforce Knowledge has the lowest weight (0.105), indicating that the level of worker expertise and qualifications is considered less influential than local labor absorption and workforce demand. Although workforce competency remains important for operational effectiveness, it is not the primary labor consideration in this evaluation.

Furthermore, the inconsistency ratio obtained for the labor sub-criteria is 0.04, which is below the acceptable threshold of 0.10. This result confirms that the pairwise comparison judgments provided by the experts are sufficiently consistent and reliable for further analysis. The weights of the material recovery sub-criteria obtained from the AHP analysis are presented in Table 9.

**Table 9.** Weights for material recovery sub-criteria

| Material Recovery Sub Criteria | Weight | Inconsistency |
|---|---|---|
| Recycled products | 0.065 | 0.07 |
| Energy needs | 0.533 | |
| Market potential | 0.162 | |
| Area of land use | 0.24 | |

As shown in Table 9, Energy Needs has the highest priority weight (0.533), indicating that energy efficiency and energy recovery potential are the most important considerations within the material recovery criterion. This finding suggests that waste treatment alternatives capable of producing useful energy or minimizing energy consumption are highly preferred. Land Use Area ranks second with a weight of 0.240, demonstrating that the amount of land required for material recovery activities is also a significant consideration. This reflects the importance of efficient land utilization, particularly in areas where land availability may be limited. Market Potential has a weight of 0.162, indicating that the ability of recovered materials or by-products to be accepted and sold in the market contributes to the evaluation process, although its influence is less substantial than energy-related considerations. Meanwhile, Recycled Products receives the lowest weight (0.065), suggesting that the type and quantity of recyclable products generated are considered less influential than the other material recovery sub-criteria.

Furthermore, the inconsistency ratio obtained for the material recovery sub-criteria is 0.07, which is below the acceptable threshold of 0.10. This result indicates that the pairwise comparison judgments provided by the experts are sufficiently consistent and reliable for further analysis.

**Table 10.** Overall Weighted Results

| Method | Overall weight |
|---|---|
| Sanitary landfill | 0.385 |
| Incineration | 0.185 |
| Composting | 0.48 |

The overall weight shows the priority level of each waste processing method based on the criteria and sub-criteria that have been analyzed previously. The greater the weight, the higher the priority of the method in decision making. From Composting, a weight of (0.48) was obtained where the Composting Method has the highest weight, indicating that this method is the best choice based on the evaluation criteria. Where this method has the following advantages: 1. Lower environmental impact compared to other methods; 2. Potential to produce useful products (compost) from organic waste and 3. Suitability to local conditions, especially if the waste being processed is mostly organic. From Sanitary Landfill, a weight of (0.385) was obtained where the Sanitary Landfill Method is in second place, indicating that this method is still an important choice, but not as good as composting. Where this method has the disadvantage of having a higher cost or greater environmental impact than composting and More suitable for inorganic waste that cannot be processed biologically. Then from Incineration, a weight of (0.185) was obtained where the Incineration Method has the lowest weight, indicating that this method is the last choice. Where this method has weaknesses is the high environmental impact, such as emissions of hazardous gases, more expensive operational costs and is less suitable for local conditions or dominant types of waste.

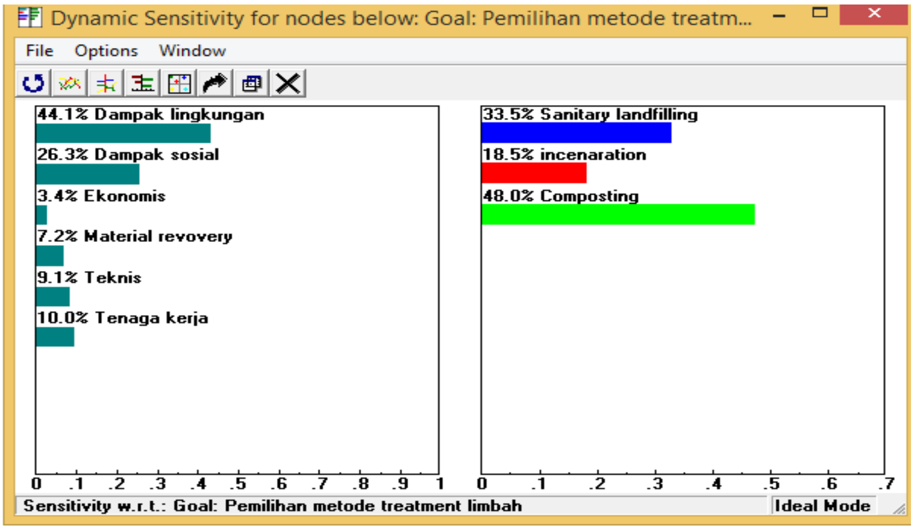


**Figure 2.** Expert Choice Processing Results

The image above was obtained from the Expert Choice Software where the results showed that Composting had the highest percentage of 48%, then the Sanitary Landfill method was in second place with a percentage value of 33.5% and the last was the Incineration Method with a percentage value of 18.5%.

Composting method is recommended as the best waste management approach based on overall weight. Sanitary Landfill can be used as an alternative, while Incineration is only considered if other methods are not possible.

### 3.4 *Using the Driven AI method with the Weighted Sum Model (WSM) approach*

To complement the results obtained from the Analytical Hierarchy Process (AHP), an AI-assisted comparative assessment was conducted using the Weighted Sum Model (WSM).[28] The WSM is a multi-criteria decision-making technique that calculates the overall performance of each alternative by combining criterion weights and alternative scores. In this study, the weights derived from the AHP analysis were utilized as inputs for the WSM evaluation.

The AI-assisted assessment was performed using a Large Language Model (LLM)-based AI tool to evaluate the waste treatment alternatives according to the established criteria and sub-criteria. The purpose of this assessment was not to replace the AHP method but to provide an additional comparative perspective and examine the consistency of the ranking results. The final scores generated through the WSM approach were then compared with the AHP rankings to support a more comprehensive evaluation of waste treatment alternatives in Sumenep Regency.

The procedure for conducting the AI-assisted comparative assessment using the WSM approach is described in the following steps.

a. Determine Weight and Criteria
   Criteria weight for each method:
   1. Sanitary Landfill: 0.385
   2. Incineration: 0.185
   3. Composting: 0.48
   
   Criteria used in the analysis:
   1. Economic (C1): Implementation and operational costs.
   2. Technical (C2): Ease of implementing technology.
   3. Environmental Impact (C3): Air, land and water pollution.
   4. Social Impact (C4): Community acceptance and socio-economic impact.
   5. Labor (C5): Number of workers required.
   6. Material Recovery (C6): Potential to recycle or utilize materials.
b. Initial Matrix (Scores for Each Method)
   Scores are assigned to each method against the criteria on a scale of 0–1 (filled in based on data or waste management policy assumptions):

**Table 11.** Initial Matrix

| Method | Economic (C1) | Technical (C2) | Environmental Impact (C3) | Social Impact (C4) | Labor (C5) | Material Recovery (C6) |
|---|---|---|---|---|---|---|
| Sanitary Landfill | 0.8 | 0.7 | 0.4 | 0.6 | 0.3 | 0.3 |
| Incineration | 0.6 | 0.9 | 0.5 | 0.4 | 0.2 | 0.4 |
| Composting | 0.9 | 0.8 | 0.8 | 0.9 | 0.7 | 0.9 |

   This table provides a score (on a scale, possibly 0–1) for each waste management method based on various criteria. Higher scores indicate better performance in a particular criterion. Where Sanitary Landfill Shows the highest score on the Economic criterion (C1), but tends to be lower on other criteria, especially Labor (C5) and Material Recovery (C6). Incineration Has an advantage in Technical (C2) but has low scores on almost all social and environmental criteria, such as Social Impact (C4) and Labor (C5). Then Composting Scores the highest on almost all criteria, especially Environmental Impact (C3), Social Impact (C4), and Material Recovery (C6), making it the most holistic and ideal method, Interpretation Per Criteria :
   1. Economic (C1):
      a) Composting (0.9) scored the highest, indicating that this method is considered the most cost efficient.
      b) Sanitary Landfill (0.8) is also economical but slightly more expensive than composting.
      c) Incineration (0.6) is the least economical, probably due to the high costs of technology and operation.
   2. Technical (C2):
      a) Incineration (0.9) is technically superior, perhaps because this method has high reliability and efficiency in reducing waste volume.
      b) Composting (0.8) is also technically good, but slightly below incineration.
      c) Sanitary Landfill (0.7) has quite good technical performance, but is less than the other two methods.
   3. Environmental Impact (C3):
      a) Composting (0.8) has the highest score, reflecting the lowest environmental impact.
      b) Incineration (0.5) and Sanitary Landfill (0.4) have low scores, indicating more significant environmental impacts.
   4. Social Impact (C4):
      a) Composting (0.9) has the highest score, indicating that this method is most accepted by the community.
      b) Sanitary Landfill (0.6) is in the middle position, perhaps due to negative influences such as odor or bad perception.
      c) Incineration (0.4) has the lowest score, perhaps due to emissions or other social impacts.
   5. Labor (C5):
      a) Composting (0.7) excels in terms of absorbing local labor.
      b) Sanitary Landfill (0.3) and Incineration (0.2) have low scores, perhaps because these methods depend more on machines or technology than human power.
   6. Material Recovery (C6):
      a) Composting (0.9) has the highest score, indicating the best potential for recycling or reusing materials.
      b) Incineration (0.4) is in the middle position.
      c) Sanitary Landfill (0.3) has the lowest potential in terms of material recovery.
c. Matrix Normalization
   Normalization is done to equalize the scale with the formula [29]:

$$rij = \frac{x_{ij}}{\max(x_{ij})} \tag{4}$$

   Where:

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Ri : Normalized score

**Table 12.** Matrix Normalization Table

| Method | Economic (C1) | Technical (C2) | Environmental Impact (C3) | Social Impact (C4) | Labor (C5) | Material Recovery (C6) |
|---|---|---|---|---|---|---|
| Sanitary Landfill | 0.89 | 0.78 | 0.5 | 0.67 | 0.43 | 0.33 |
| Incineration | 0.67 | 1.00 | 0.63 | 0.44 | 0.29 | 0.44 |
| Composting | 1.00 | 0.89 | 1.00 | 1.00 | 1.00 | 1.00 |

1. Economic (C1):
   How cost efficient is this method?
   a) Composting (1.00): This method is the most economical, indicating that the construction, operational and management costs are more efficient than other methods.
   b) Sanitary Landfill (0.89): Quite economical, but slightly more expensive than composting.
   c) Incineration (0.67): Least economical, probably due to high technology costs and large operating costs.
2. Technical (C2):
   Technical reliability and ease of implementation.
   a) Incineration (1.00): Technically superior, perhaps due to its highly reliable modern technology for rapidly reducing waste volumes.
   b) Composting (0.89): Simple but effective technology, slightly below incineration.
   c) Sanitary Landfill (0.78): Still quite good technically, but less than the other two methods.
3. Environmental Impact (C3):
   How low the environmental impact of the method is.
   a) Composting (1.00): Most environmentally friendly, because it produces useful products (compost) andminimizes pollution.
   b) Incineration (0.63): The impact is moderate, probably due to the gas emissions produced.
   c) Sanitary Landfill (0.50): Has the greatest impact on the environment, such as soil and water pollution and methane gas emissions.
4. Social Impact (C4):
   Social acceptance and other social influences.
   a) Composting (1.00): Most accepted by the community, because it does not involve conflicts such as strong odors or land clearing.
   b) Sanitary Landfill (0.67): Relatively more acceptable than incineration but still has social issues such as odor or negative stigma.
   c) Incineration (0.44): Least accepted, perhaps due to air emissions or negative perceptions of combustion technology.
5. Labor (C5):
   How much labor can be absorbed by this method.
   a) Composting (1.00): Absorbs the most labor, especially from local communities, due to the human resource-intensive nature of the method.
   b) Sanitary Landfill (0.43): Absorbs less labor than composting.
   c) Incineration (0.29): Least labor intensive, possibly due to the use of high automation technology.
6. Material Recovery (C6):
   The ability of a method to produce products that can be recycled or reused.
   a. Composting (1.00): Very good at producing valuable products (compost) for agriculture and the environment.
   b. Incineration (0.44): Has the potential to utilize energy from burning waste, but the recycling results are lower than composting.
   c. Sanitary Landfill (0.33): Lowest in material recovery, because most of the waste is simply buried.

d. Final Score Calculation

The score is calculated using the Weighted Sum Model (WSM) method:

$$V_i = \sum_{j=1}^{n} w_j x r_{ij} \quad (5)$$

Where:
Wj : Criteria weight
Ri : Normalized score
Criteria Weights for Each DimensionFor each criterion, the following weights are assumed:

1. Economic (C1): 0.2
2. Technical (C2): 0.15
3. Environmental Impact (C3): 0.25
4. Social Impact (C4): 0.15
5. Labor (C5): 0.1
6. Material Recovery (C6): 0.15

Score Calculation:

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1. Sanitary Landfill:
   V1=(0.2x0.89) + (0.15x0.78) + (0.25x0.5) + (0.15x0.67) + (0.1x0.43) + (0.15x0.33)= 0.178 + 0.117 + 0.125 + 0.1005 + 0.043 + 0.0495 = 0.613
2. Incineration:
   V2=(0.2x0.67) + (0.15x1.00) + (0.25x0.63) + (0.15x0.44) + (0.1x0.29) + (0.15x0.44)= 0.134 + 0.15 + 0.1575 + 0.066 + 0.029 + 0.066 = 0.6025
3. Composting:
   V3 = (0.2x1.00) + (0.15x0.89) + (0.25x1.00) + (0.15x1.00) + (0.1x1.00) + (0.15x1.00)= 0.2 + 0.1335 + 0.25 + 0.15 + 0.1 + 0.15 = 0.9835

**Tabel 13.** Final result

| Method | Final Score (V) |
|---|---|
| Sanitary Landfill | 0.613 |
| Incineration | 0.6025 |
| Composting | 0.9835 |

From the table above, it can be concluded that the Composting Method with a total final score of (0.9835) obtained the highest score, indicating that composting is the most optimal method for waste processing based on the evaluated criteria. Where the main advantages of this method include the smallest environmental impact, high social acceptance and cost efficiency and the best material recovery potential so that it is recommended as the main method, especially in areas with a lot of organic waste and a focus on environmental sustainability.

Then the Sanitary Landfill Method with a total final score of (0.613) is in second place, indicating that sanitary landfill is still a fairly good option, but is less superior than composting, where this method is considered because the cost is more affordable than incineration and the technical capabilities are quite reliable. However, there are major weaknesses in the greater environmental impact and low material recovery potential.

Meanwhile, the Incineration Method with a total final score of (0.6025) obtained the lowest score, which shows that this method is the last choice with the main reasons for the low score including high costs for operations or technology and greater environmental impacts (gas emissions and residues), but this method is suitable for use if there are land limitations or urgent needs to reduce waste volume quickly.

## 4. CONCLUSION

From the results of the study using the AHP Method, it was found that Composting had the highest percentage of 48%, then the Sanitary Landfill method was in second place with a percentage value of 33.5% and the last was the Incineration Method with a percentage value of 18.5%. From the results of the study using the Driven AI Method, it was found that Composting had the highest score (0.9835), indicating that this method is superior in various aspects, especially in terms of environmental, social and material recovery impacts, Sanitary Landfill is in second place (0.613), suitable for situations with adequate land but less than optimal environmentally and Incineration has the lowest score (0.6025), mainly due to its high costs and impact on the environment. Composting method is the best overall choice, fulfilling almost all criteria very well and Recommended for primary implementation in waste management. While the Sanitary Landfill method as the second alternative which is suitable as a supporting method for waste that cannot be processed through composting and incineration is the last option which can be used only in special conditions such as land limitations or fast management needs.

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