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Research Article

Advancing Indonesia's Net Zero Goals Through Sustainable Biomass Supplier Selection: Insights from Multi-Criteria Decision Analysis

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Abstract: Indonesia has experienced a significant increase in greenhouse gas (GHG) emissions over the past two decades, primarily driven by rising fossil fuel consumption for electricity generation. In response, the state-owned electricity company PT PLN (Persero) has committed to achieving Net Zero Emissions (NZE) by 2060, with biomass co-firing in coal-fired steam power plants (PLTUs) serving as a key transitional strategy. A 2018 study revealed that Indonesia's biomass potential stands at 857 GJ per year, while a 2021 study from the PJB Technology Unit estimated that Java alone possesses a biomass potential of 9.2 GW, mainly derived from agricultural products. Despite this potential, a significant challenge lies in selecting reliable and sustainable biomass suppliers, particularly for sawdust, a readily available agricultural byproduct. Although various decision-making models have been proposed for supplier evaluation in renewable energy contexts, there remains a lack of structured, stakeholder-informed approaches tailored to Indonesia's biomass co-firing initiatives. This study aims to identify and rank the criteria used in choosing sawdust biomass suppliers through the Analytical Hierarchy Process method. Data was gathered through literature reviews, stakeholder interviews, and surveys to assess the criteria. The study identified nine criteria with the following weights: Quality (0.250); Sustainability (0.219); Location (0.159); Price (0.136); Warranty Period (0.063); Delivery Time (0.051); Social (0.044); Flexibility (0.0384); and Service (0.0382). By systematically evaluating supplier selection factors using AHP, this study offers a decision-making framework to guide PT PLN and other stakeholders in designing more robust and sustainable biomass procurement strategies. The findings contribute to the growing knowledge on renewable energy supply chain optimization and support Indonesia's long-term decarbonization goals.

Keywords: Analytical Hierarchy Process; Biomass; Co-Firing; Supplier Selection

1. Introduction

As the Publications Office of the European Union reported, Indonesia's greenhouse gas emissions have steadily risen over the last twenty years, averaging an annual increase of 3.46%. By 2022, the country's carbon dioxide emissions hit 24 gigatons, representing 2.3% of global greenhouse gas emissions (European Commission, 2023). The significant contributors to these emissions are associated with the energy and fuel sectors. PT PLN (Persero) has initiated a range of programs, among which is the significant co-

firing of biomass in power plants. Studies conclude that Indonesia possesses enormous biomass potential, primarily from agricultural waste such as tree trunks [1]. Research on the biomass energy potential originating from agricultural and plantation wastes indicated that, in 2018, crop residue potential recorded a 40% increase, resulting in a yearly total of 857 GJ, from the 661 GJ figure in 2010 [2].

Moreover, research by the Technology Unit of PJB has revealed that Java has biomass energy potential of 9.2 GW from agricultural residues like husk rice, corn, sugarcane, and cassava, plantations like oil palm, coconut, and wood, and animal and municipal waste [3]. By 2025, the biomass demand anticipated for co-firing at PT PLN (Persero) is projected to increase significantly, reaching approximately 10 million tons. The company must select an appropriate biomass supplier to fulfill this target. An optimal supplier can also improve production cost efficiency, ensure timely delivery, enhance customer satisfaction, and augment profits (Doan, 2020). The table below, labeled as Table 1, delineates various methodologies previously employed in research about supplier selection.

Table 1. Previous Research on Supplier Selection

No	Title	Methods	Results	Reference
1	*Solar Panel Supplier Selection for the Photovoltaic System Design by Using Fuzzy Multi-Criteria Decision-Making (MCDM) Approaches*	• *Fuzzy Analytical Hierarchy Process* (FAHP) • *Data Envelopment Analysis* (DEA)	Financial: 0.1365 Technical: 0.6250 Environment: 0.2385 Social: 0.08	[4]
2	*Spherical Fuzzy Multicriteria Decision-Making Model for Wind Turbine Supplier Selection in a Renewable Energy Project*	Spherical Fuzzy MCDM (*Multi-Criteria Decision Making)*	Manufacture: 0.21124 Environment: 0.24331 Technical: 0.20351 Financial: 0.34194	[5]
3	*Addressing the supplier selection problem by using the analytical hierarchy process*	*Analytical Hierarchy Process* (AHP)	Financial: 0.053 Quality: 0.409 Delivery: 0.300 Flexibility: 0.135 Communication: 0.103	[6]
4	*Multi-Criteria Decision Making For Determining A Simple Model of Supplier Selection*	*Analytical Hierarchy Process* (AHP)	Criteria are selected based on the Pareto 80/20 principle, according to which the 20% most essential criteria influence 80% of supplier selection decisions.	[7]
5	*Supplier Selection Modeling and Analysis in the Metal Casting Industry Using the Analytical Hierarchy Process*	*Analytical Hierarchy Process* (AHP)	Quality: 0.63 Price: 0.26 Delivery: 0.10	[8]

6	*Ceramic Supplier Selection using the Analytical Hierarchy Process Method*	*Analytical Hierarchy Process* (AHP)	Quality: 0.456 Financial: 0.158 Delivery: 0.252 Flexibility: 0.058 Service: 0.073		[9]
7	*Supplier Selection and Evaluation in the Dairy Industry Using the Analytical Hierarchy Process*	*Analytical Hierarchy Process* (AHP)	Location: 0.084 Quality: 0.499 Quantity: 0.289 Social: 0.126		[10]
8	*Selection of Organic Fertilizer Supplier Using Analytical Hierarchy Process (AHP) Method In PT Jmn Kabupaten Bandung*	*Analytical Hierarchy Process* (AHP)	Delivery: 0.204 Price: 0.147 Warranty Period: 0.085 Quality: 0.473 Service: 0.091		[11]

Table 1 outlines various approaches for selecting suppliers, including FAHP, DEA, Spherical Fuzzy MCDM, and AHP. The AHP method is widely adopted across different industries due to its simplicity and ease of understanding. Its effectiveness in addressing complex challenges has also been demonstrated in practical applications. Although existing studies highlight AHP's use in the industrial sector, it has not yet been applied in the renewable energy field, particularly in biomass. This research focuses on selecting biomass suppliers to achieve corporate goals related to the energy mix and reducing PLTU emissions.

2. METHODS

2.1. Analytical Hierarchy Process

The initial stage of the AHP method involves creating a hierarchical tree, which is illustrated in Figure 1 below.

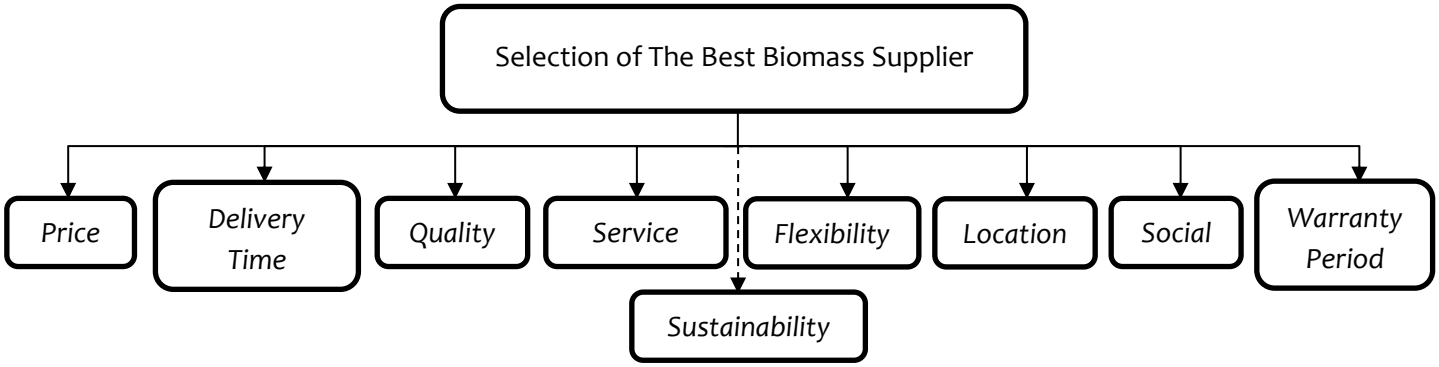

Figure 1. Hierarchy Tree

The criteria for this study were derived from two data collection methods: literature reviews and expert interviews. Nine criteria were identified through these methods, and they are outlined in Table 2 below.

Table 2. Identification Criteria

Criteria	Description	Reference
Price	The costs involved in the procurement process, including raw materials, taxes, handling, and more	Directorate Regulation on Co-Firing Implementation Guidelines at PT PJB [12]
		(Manik, 2023) [6]
		(Harwati, 2017) [7]
		(Firdantara et al., 2024) [8]
		(Rahmiati et al., 2021) [9]
		(Anwar et ak., 2021) [11]
		(Desmukh and Vasudevan, 2014) [13]
		(Lia Hananto et al., 2021) [14]
Delivery Time	Delivery should be timely, as per the agreement.	(Manik, 2023) [6]
		(Harwati, 2017) [7]
		(Firdantara et al., 2024) [8]
		(Rahmiati et al., 2021) [9]
		(Anwar et ak., 2021) [11]
		(Ridhawati et al., 2017) [15]
		Directorate Regulation on Co-Firing Implementation Guidelines at PT PJB [12]
Quality	The capability to satisfy quality specifications and requirements, including moisture content, product dimensions, and biomass calorific value.	(Manik, 2023) [6]
		(Harwati, 2017) [7]
		(Firdantara et al., 2024) [8]
		(Rahmiati et al., 2021) [9]
		(Kubde et al.) [10]
		(Anwar et ak., 2021) [11]
		(Desmukh and Vasudevan, 2014) [13]
		(Ridhawati et al., 2017) [15]
Service	Supplier responsiveness and friendliness in coordinating and delivering complete documents.	(Manik, 2023) [6]
		(Harwati, 2017) [7]
		(Rahmiati et al., 2021) [9]
		(Anwar et ak., 2021) [11]
		(Desmukh and Vasudevan, 2014) [13]
Flexibility	Capability to modify orders according to customer requirements	(Manik, 2023) [6]
		(Rahmiati et al., 2021) [9]
Location	Supplier distance from PLN Nusantara Power units	(Kubde et al.) [10]
Social	The supplier's business ecosystem relies on past	(Kubde et al.) [10]

	performance, environmental influence, and engagement with the local community.	Expert Interview
Warranty Period	Time granted by the supplier within a particular period to claim product conditions	(Anwar et ak., 2021) [11]
Sustainability	The biomass provided to the PLN Nusantara Power unit is guaranteed to be both sustainable and legally sourced (not from illegal logging, etc.).	Expert Interview

Table 2 indicates that the literature studies recognized eight criteria: price, delivery time, quality, service, flexibility, location, social value, and warranty period. Furthermore, sustainability, an additional criterion, was obtained through expert interviews. The subsequent step involves surveying eight respondents by distributing questionnaires to evaluate each criterion in a pairwise manner.

2.2. Consistency Test

First, calculate the consistency index (CI) using the following formula to calculate the consistency level.

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

Description:
λ max = Largest eigenvalue of the comparison matrix
n = number of criteria elements

Then, calculate the Consistency Ratio (CR) using the following formula.

$$CR = \frac{CI}{RI} \tag{2}$$

Description:
RI = Random Consistency Index

The RI value signifies a Random Index of Consistency constant, which varies depending on the number of criteria elements involved. Below, Table 3 presents the RI values for diverse matrix sizes based on the count of criteria.

Table 3. Random Consistency Index Constant Value [16]

n (Number of Criteria)	RI (*Random Consistency Index)*
1	0
2	0
3	0,58
4	0,9
5	1,12
6	1,24
7	1,32
8	1,41
9	1,45

If the consistency ratio (CR) exceeds 0.1, the comparison is regarded as inconsistent, thereby necessitating a reassessment. Upon confirming the consistency of the comparison matrix values, the subsequent step involves calculating the criteria weights, thereby assigning each criterion a weight that reflects its relative importance.

3. RESULT AND DISCUSSION

3.1. Consistency Test Result

The results of the CI calculation using formula (1) produce the following calculation.

$$CI = \frac{9{,}631 - 9}{9 - 1}$$

$$CI = 0{,}07888$$

Next, the CR calculation using formula (2) produces the following values.

$$CR = \frac{0{,}07888}{1{,}45}$$
$$CR = 0{,}0544 = 5{,}44\%$$

Based on these calculations, it is known that the CR value < 0.1, which indicates that the survey questionnaire results from respondents are relatively consistent.

3.2. Criteria Weight

Data processing for weight calculations with pairwise comparison produces values that can be seen in Table 4.

Table 4. Criteria Weight

Rank	Criteria	Description	Weights
1	Quality	Capability to fulfill requirements and specifications, including moisture content, product dimensions, and biomass calorific value.	25,04%
2	Sustainability	The biomass sourced for the PLN Nusantara Power unit is guaranteed to be sustainable and legally	21,98%

		obtained, thereby excluding any contributions from illegal logging or similar activities.	
3	Location	Distance of the supplier from PLN Nusantara Power units	15,92%
4	Price	The amount of costs required for the procurement process, starting from raw materials, taxes, handling, and others	13,56%
5	Warranty Period	Time allowance in a specific period given by the supplier to claim product conditions	6,30%
6	Delivery Time	Punctuality of delivery as per the agreement	5,10%
7	Social	A supplier's business ecosystem shaped by past performance, environmental considerations, and community engagement.	4,44%
8	Flexibility	Ability to adapt by adding or reducing orders depending on consumer needs	3,84%
9	Service	The promptness and cordiality of the supplier in arranging and delivering comprehensive documentation	3,82%

The findings from the Analytical Hierarchy Process (AHP) reveal that the primary factors in choosing sawdust biomass suppliers for PT PLN's co-firing program are Quality (25.04%), Sustainability (21.98%), and Location (15.92%). These findings underscore the substantial technical and strategic emphasis stakeholders place on the effectiveness and sustainability of the biomass supply. The focus on quality illustrates the essential need to maintain operational efficiency in power plants, as moisture content, calorific value, and dimensional consistency directly affect combustion efficiency and emissions. This implies that PLN's procurement strategies are significantly influenced by the compatibility of biomass materials with the existing coal infrastructure.

As far as the quality parameters are concerned, the current tender document prescribes that the information on the quality of biomass is obtained from a certification letter from the supplier. The letter establishes the nature and quality of the biomass, for example, the Gross Calorific Value (GCV) on an as-received basis (Ar), and must not be older than three months. We recommend these improvements by adding a clause where the vendors should be willing to provide product samples in agreed-upon quantities to guarantee that product quality is in accordance with the certification requirements. The action would reduce the risk of contracting vendors whose product quality is below the standards of PT PLN Energi Primer Indonesia.

Sustainability being the second most important criterion indicates increasing recognition of the importance of responsible sourcing for the environment.This encompasses aspects like compliance with legal forestry practices, the renewability of biomass sources, and the traceability of supply chains. The nearly equal emphasis on sustainability and quality further suggests a harmony between technical performance and ethical procurement practices, reflecting PT PLN's dedication to national and international sustainability standards. This relevance is underscored by global concerns regarding land-use changes and the deforestation risks linked to biomass harvesting.

Regarding the sustainability criteria, the prior tender documents required vendors to submit a Letter of Origin for Biomass Raw Materials. This document was utilized to verify that the product or raw material originated from the specified source. We propose an improvement by introducing a requirement for legal certification documents, which an accredited third-party certification body

must issue. This measure will ensure that the biomass products comply with legal and sustainability standards, thereby facilitating the objective of biomass co-firing as a pivotal step towards achieving Net Zero Emissions. Examples of legal certifications include SVLK (Timber Legality Verification System), FSC (Forest Stewardship Council), ISCC (International Sustainability & Carbon Certification), and PEFC (Programme for the Endorsement of Forest Certification), among others.

The significance of location (15.92%) as the third criterion emphasizes biomass procurement's logistical efficiency and cost-effectiveness. Reduced distances between suppliers and PLN's power generation units are expected to lower transportation costs, greenhouse gas (GHG) emissions, and delivery uncertainties. This geographical aspect is vital in Indonesia, where the island layout and varying infrastructure create logistical hurdles. Additionally, it underscores the strategic benefit of establishing local biomass supply chains, which can bolster rural economies while decreasing the carbon footprint of fuel transport.

Furthermore, it is recommended that biomass procurement processes be digitalized. This initiative would facilitate prompt access to information about the availability of biomass suppliers, encompassing details such as type, quality, and proximity to the units managed by PT PLN (Persero). In addition to offering real-time visibility, this digitalization will also provide pertinent information regarding the current status of biomass in transit, thereby enabling more precise estimates of delivery times.

An intriguing aspect of this study is the price criterion's ranking at 13.56%, placing it in fourth position. Typically, this criterion carries more significance in procurement processes. Nonetheless, it occupies the fourth spot in the biomass procurement process at PT PLN (Persero). This indicates that the company emphasizes biomass quality, aiming to enhance the efficiency of power generation units, secure a reliable electricity supply, and preserve the sustainability of the biomass co-firing program to reach Net Zero Emissions.

Other criteria with weights below 10% comprise the warranty period (6.30%), delivery time (5.10%), social criteria (4.44%), flexibility (3.84%), and service (3.82%). These five criteria are regarded as secondary priorities for the company. Interviews conducted with biomass procurement stakeholders indicated that the warranty period criterion is generally addressed through penalties for non-compliance with the agreement. Concerning delivery time, the location criterion (ranked third) contributes to mitigating potential delays, as suppliers are mandated to be situated within 50 km of the relevant units, thereby ensuring that transportation routes are sufficiently adequate to minimize delays.

With regard to social criteria, selected suppliers are evaluated based on the Supplier List maintained by PT PLN Energi Primer Indonesia, which is compiled from recommendations provided by consultants engaged by PT PLN. This list serves to fulfill the supply requirements of contracts valued at less than IDR 500,000,000 (Five Hundred Million Rupiah), thereby obviating the necessity for an open tender process. The criterion of flexibility is deemed less pertinent for supplier selection, as PT PLN (Persero) convenes a monthly Biomass Coordination Meeting with suppliers to delineate biomass requirements for the forthcoming period. Most suppliers are capable of meeting contractual obligations due to the anticipated lead time being generally aligned with actual delivery times. The criterion assigned the lowest priority is service, as it is considered to have a minimal effect on the technical facets of the field and is primarily an administrative issue.

Following the rankings presented by the Analytic Hierarchy Process (AHP), PT PLN (Persero) should establish a procurement policy that prioritizes quality assurance, sustainability, and local purchasing as the top three criteria from the analysis. Given that biomass quality is at the

heart of the power plant efficiency, the procurement contracts should include detailed technical specifications, periodic quality monitoring, and incentive mechanisms for promoting dependable supply practices. Additionally, strict enforcement of supplier pre-qualification processes, along with investment in capacity-development programs, will enhance adherence to these standards.

Sustainability has achieved virtual equality with quality, and suppliers are now required to prove the legality and renewability of their biomass supplies.

This can be done by using sustainability certifications, implementing ESG scoring systems, and giving priority to orders from suppliers conducting business in an environmentally and socially responsible manner. In order to increase supply chain transparency and lower the environmental footprint, PLN needs to encourage local sourcing practices by giving more points to suppliers who are closer to power plants, creating regional biomass hubs, and collaborating with local cooperatives or SMEs. While pricing continues to be a key factor, studies point to a shift in the direction of value-based procurement that balances cost-effectiveness with reliability, sustainability, and long-term risk management. This can include multi-year pricing agreements with flexible terms and total ownership cost calculations. Additionally, risks related to timely delivery and supply quality can be reduced through the adoption of service-level agreements (SLAs), warranty provisions, and electronic performance monitoring. While the reduced emphasis on elements such as social influence, flexibility, and service is feasible, their significance is not diminished. PLN can maximize the value of its relationships with suppliers by strengthening open communication, evaluating community engagement, and providing flexible contractual arrangements that evolve with the organization's needs. Collectively, these approaches create a unified procurement strategy that is in alignment with Indonesia's renewable energy ambitions and PT PLN's vision for Net Zero Emissions.

The project concentrates on assessing the requirements for an open tendering process concerning the purchase of biomass in PT PLN Energi Primer, as demonstrated in the following Table 5.

Table 5. Evaluating Requirements for Open Tender Procurement of Biomass at PT PLN Energi Primer

No.	Before	After
1	Having a document or certificate that details the type and quality of the biomass fuel, including the Gross Calorific Value (GCV) on an as-received basis (Ar), obtained within the last three months.	It's essential to have a document or certificate that specifies the biomass fuel's type and quality, including the Gross Calorific Value (GCV) based on the most recent three months, alongside a commitment to send product samples in the agreed quantities.
2	A Letter of Origin for Biomass Raw Materials must be submitted.	It is required to submit a Biomass Legality Certificate, like FSC/PEFC/SVLK/ISCC, along with a Letter of Origin for Biomass Raw Materials.
3	Not in yet	Ready to adhere to all digitalization processes for biomass procurement at PT PLN Energi Primer Indonesia.

4. CONCLUSIONS

Based on the description provided, it can be concluded that the main criterion for selecting biomass suppliers for PT PLN Nusantara Power is quality, which carries a weight of 25.04%. The quality of biomass is crucial for several reasons, including its role in achieving the Net Plant Heat Rate performance target and its influence on boiler performance. The next significant criterion is sustainability, assigned a weight of 21.98%. This sustainability criterion is innovative in supplier selection, as it was not identified in earlier literature. However, it emerged from expert interviews. Sustainability is now recognized as a vital factor in biomass procurement, particularly for co-firing applications.

We recommend enhancements for the biomass procurement requirements in the open tender at PT PLN Energi Primer. These improvements include a mandate for the shipment of biomass samples in agreed quantities, the introduction of biomass legality certificates, and a requirement for suppliers to comply with all ongoing digitalization processes developed by PT PLN Energi Primer Indonesia.

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