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Environmentally Friendly Strategies for Recycling Agricultural Waste to Produce Renewable Energy: A Case Study of Durian Fruit

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ABSTRACT

The increasing need for harvests, resources, and facilities is associated with significant biowaste production from agricultural processes. Although the waste is nutrient-rich, it may become refinement lands for ailment-triggering bacteria when not managed correctly. The waste can be transformed into raw materials for valuable crops or sources of environmentally friendly energy. Therefore, this study examined agricultural waste management strategies as Indonesia's sustainable renewable energy source. SWOT and TOPSIS methods were used to identify the optimal approach for advancing renewable energy in Riau Province, while multiple respondents participated in identifying critical criteria and evaluating each option. The results showed that based on SWOT analysis, the Strength–Opportunity (SO) factor favored using agricultural waste for renewable energy in Indonesia. Furthermore, TOPSIS analysis indicated that Alternative A2 (Bioethanol) had the most significant distance among the alternatives, with a weight of 0.825. Future studies are needed to provide more accurate results and improve the current understanding regarding the evolution of renewable energy in Indonesia. Additionally, in-depth investigations should prioritize increased consumer awareness of renewable consumption, higher producer productivity, and strengthened policies.

1. Introduction

Waste production generated from the growing industrialization of the agriculture sector is associated with significant environmental threats. According to a previous report, agriculture produces 5 million metric tonnes of plant matter annually [1]. A significant portion of the waste released by the agro-based nutrition sector is rich in nutrients but may act as breeding grounds for microorganisms that cause illness when not adequately managed or cleaned. However, the waste can be used as renewable energy sources or raw materials to produce value-added products [2].

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Indonesia is an agronomic country cultivating many crops, including fruits, grains, tubers, cassava, potato varieties, maize, soybeans, and sugar beets. For example, the tropical seasonal durian, also called the "king of fruits," is prized for its distinct flavor and aroma. This plant, native to the Malay Peninsula, is extensively grown in tropical areas, including Indonesia, Thailand, Malaysia, and the Philippines [3]. According to a previous study, only about 15 to 30 percent of the durian fruit is edible, and the remaining fraction is often considered biomass waste [4]. Durian peel and seed constitute another subset of biomass waste, with other names for peel being rind, skin, husk, and shell. Other forms of biomass waste are wood, tree trunks, or sticks, in addition to fruits. Currently, Indonesia produces more than 880,000 tonnes of durian annually, and depending on the type, only 10–30% of the fruit is nutritious, with the remaining portion consisting of the skin (50–60%) and seeds (10–20%), often thrown away as waste [5]. Durian skin waste is categorized as organic waste, which can potentially reduce environmental quality [6]. Organic waste generation and suboptimal treatment contribute significantly to environmental concerns that lead to economic challenges due to the high expenses associated with disposal, transportation, and collection [7].

Globally, one of the most significant concerns is energy depletion, which raises issues regarding greenhouse gas (GHG) emissions and environmental deterioration [3]. Government funding for studies into creating renewable energy sources is essential to prevent the depletion of natural energy supplies. Biomass energy accounts for approximately 10 to 14% of the global energy supply, equivalent to 51 exajoules (EJ). It is considered one of the most significant renewable energy sources worldwide [3].

The National Action Plan, as stated in President Declaration No. 61 of 2011, is to reduce GHG emissions by 26% and achieve carbon neutrality by 2030 in Indonesia [8]. Resource use, development programs, and strategic management are necessary at the provincial and countrywide levels to accomplish sustainable development. In addition, evaluation is needed to ensure that the strategies and policies adopted support sustainable development. It is crucial to evaluate a nation's or district's development and track improvement toward attaining sustainability objectives [9]. This condition underlines the need for appropriate strategic planning as an initial stage in reaching the right decisions. One method suitable for planning strategies towards renewable energy problems is SWOT analysis. The SWOT method can assess the expansion of renewable energy for electricity generation in Indonesia, and it is necessary to conduct an internal study of the microenvironment. This analysis focused primarily on the pertinent strengths, weaknesses, opportunities, and threats (SWOT) [10,11], which various entities commonly use in strategic planning. A SWOT analysis provides insights into the strengths and weaknesses of the current energy system. It offers comprehensive information on the potential exploitable opportunities and obstacles capable of hindering the achievement of an objective. Furthermore, the SWOT analysis suggests actionable solutions that can be advocated in the roadmap [12].

The SWOT analysis was established for assessing and strategizing in business and marketing. Recently, it has been implemented in various study domains, such as the energy sector [13], specifically in renewable energy. Jordan used the technology to examine the present condition of renewable energy, while Nigeria used the method for nuclear exploration. Kamran *et al.,* [14] used the SWOT method to assess Pakistan's sustainable development of renewable energy. In Ghana, it was used to access the national plan for advancing nuclear energy [15]. Moreover, Chen *et al.,* [16] used the SWOT analysis to promote the adoption of renewable energy in Japan, South Korea, and Taiwan. SWOT analysis cannot independently determine a decision-making strategy, underscoring the need for additional methods to ensure that decisions are consistent with user needs. Therefore, applying a multi-criteria decision-making method can complement SWOT analysis.

Multi-criteria decision-making (MCDM) is the predominant method used to evaluate the sustainability of a country or region in the energy industry. Problems with multiple objectives can be resolved using the MCDM method. Several solutions can be applied for energy management and preparation pronouncements based on the slanted average, outranking, significant apprehension situation, fuzzy impressions, and integrations [17,18]. MCDM has experienced significant developments since the early 1960s, including state-of-the-art methods and powerful algorithms (computer tools) [19]. Additionally, a study was conducted on synergistic strategies for sustainable hospital site selection in Saudi Arabia using the Spherical Fuzzy MCDM method [20]. The objective was to develop a model for selecting a PhD supervisor from various options available at the academic institution. A hybrid MCDM framework was used to select supervisors based on the criteria preferred by students in an interval-valued intuitive fuzzy (IVIF) scenario. The Analytical Hierarchy Process (AHP) was used to determine the relative importance of the criteria. In contrast, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was used to rank supervisors based on the assigned weights of the criteria [21].

Another study also used the MCDM method to identify the crucial components for sports, politics, journalism or media, and technical empowerment of women in India. The AHP and Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) were used to identify the most effective criteria for empowerment [22]. Additionally, Momena *et al.,* [23] demonstrated the application of generalized double doubt hexagonal fuzzy numbers (GDHHχFN) in diagnosing symptoms and using MCDM to assess disease potential. The symptoms include fever, body pains, weariness, chills, shortness of breath (SOB), nausea, vomiting, and diarrhea.

The decision-making process in renewable energy is highly challenging and complicated. Various studies have recently utilized MCDM for planning and prioritization due to the field's diverse and often conflicting criteria. This method proposes different possibilities, including energy, technology, and scenarios essential for decision-makers. Several investigations have evaluated alternative energy alternatives at the regional or national level using MCDM [24,25]. For example, the method was applied to estimate the best energy scenario [26,27]. Moreover, Alshamrani *et al.,* [28] utilized a hybrid decision-making model with various criteria to determine the most significant choices for achieving renewable energy sustainability. A novel hybrid MCDM model was introduced, utilizing the Fuzzy Analytic Hierarchy Process (FAHP) and the Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS). This model aimed to assess and rank the development of five low-emission energy technologies in Poland. In addition, in order to achieve various sustainable development policy goals, a series of criteria and sub-criteria are established [29]. Another study assessed the performance of each nation belonging to the Organisation for Economic Cooperation and Development (OECD) using Data Envelopment Analysis (DEA) weights in combination with a modified TOPSIS that incorporates the concept of the aspiration level referred to as modified TOPSIS-AL [30].

This study used the hybrid SWOT-TOPSIS method to integrate qualitative and quantitative features of the current energy transition scenario. The novelty was expanded further by utilizing the results to assess Indonesia's plans for renewable energy scenarios. Therefore, this study analyzed agricultural waste management strategies as Indonesia's sustainable renewable energy source.

2. Methodology

This study aimed to determine the appropriate strategy for recycling agricultural waste as renewable energy using SWOT and TOPSIS methods. Strategies for recycling agricultural waste as a sustainable energy source were identified and analyzed using SWOT. The TOPSIS method was applied to determine the best option based on the results. A review of relevant literature, interviews with various individuals, field observations, and expert surveys were used to collect the necessary data. For the SWOT method, data regarding internal and external factors were collected through an open questionnaire distributed to academics, non-governmental organizations, renewable energy observers, and legislators, and then the results were arranged in a table form. Meanwhile, the TOPSIS method was used to determine alternative renewable energy strategies through a pairwise comparison questionnaire. The questionnaire was distributed to professionals, considering the depth of experience, time availability, and level of knowledge in renewable energy.

2.1 SWOT Analysis

In the first phase of the study, using agricultural waste as renewable energy was analyzed and discussed in terms of strengths, weaknesses, opportunities, and threats through SWOT analysis. This method is frequently utilized in natural resource management and the commercial world to assist with strategy, policy, and decision-making. It has been used in several waste management-related investigations, including Aich and Ghosh [31], Nyakudya *et al.,* [32], Mejjad *et al.,* [33], Alam and Wulandari [34], Pulansari *et al.,* [35] and Wikurendra *et al.,* [36]. Every project, program, development strategy, and management plan has advantages, disadvantages, possibilities, and risks. A project coordinator handles potential issues skillfully by considering SWOT (strengths, weaknesses, opportunities, and threats). In this context, threats can be turned into opportunities, and weaknesses can be balanced against strengths. The analysis applies to various concepts, groups, individuals, items, initiatives, programs, or projects [37]. The external and internal components critical to accomplishing the goal include:

a. Internal factors: The management of strengths and limitations.
b. External factors: The chances and dangers that come from the outside world.

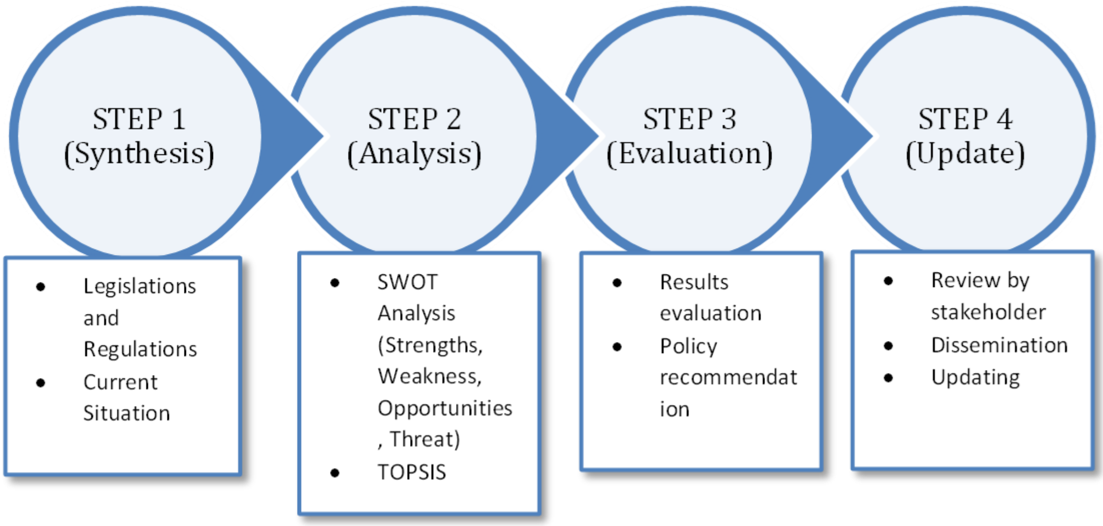

Fig. 1. Methodology for utilizing agricultural waste as renewable energy

SWOT analysis defines strengths as the innate capacity to succeed and develop, while weaknesses are the innate limitations that impede development and survival. Opportunities are favorable conditions for development, while threats refer to external difficulties with the potential to limit innate strengths, worsen weaknesses, and prevent opportunities [38]. The four primary steps in the study method are as follows (Figure 1):

a. Examining pertinent laws, rules, and publications.
b. Using an activity worksheet, the baseline survey identified pertinent elements of the internal and external factors. Table 1 provides a SWOT analysis activity worksheet. Seven internal and six external components were identified, as shown in Table 1.
c. A results-based assessment of the advantages, disadvantages, opportunities, and dangers.
d. Making policy recommendations based on the SWOT analysis using the TOPSIS method.

Table 1
SWOT analysis activity worksheet

Factors	Questions
Strength	• Employees with skills in the field of agriculture waste management in renewable energy • Training on how to recycle agriculture waste into renewable energy • Government policy support • Adequate area for agriculture waste management into renewable energy • The province has quite good cooperation and relationships with fellow waste industry stakeholders • Abundant agricultural waste • The workforce in environmental institutions is sufficient • Agriculture waste management technology for renewable energy is available and accessible to obtain
Weakness	• Potential for developing agriculture waste management technology into renewable energy in the Riau Province environment • Lack of funding for procurement of agriculture waste management technology into renewable energy • The performance of agriculture waste recycling in the Riau Province environment is still low. • Adequate equipment and materials for processing agriculture waste into renewable energy • The process of recycling agricultural waste into products that have economic value • The results of agriculture waste recycling produce products/results that can benefit the people of Riau Province.
Opportunities	• Support from other institutions for HR training (e.g., universities and the Environmental Service) • Support from the Department of Hygiene and Environment for the development of waste management • The technology currently available can still be developed • Support from banking institutions regarding capital in agriculture waste management technology into renewable energy • Technology for processing agriculture waste into renewable energy is increasingly popular • Independent technical service in integrated waste management (Waste Bank) • Understanding of Climate Change
Threats	• Increased operational costs for agriculture waste management • Climate change affecting agriculture waste management

Factors	Questions
	• Potential risks of landfill closure • There is an impact of poor agriculture waste management on public health • Decreased environmental quality due to agriculture waste management

2.2 TOPSIS Analysis

In the first phase of this study, using SWOT analysis, the use of agricultural waste as renewable energy was analyzed and discussed in terms of strengths, weaknesses, opportunities, and threats. The following stage entailed using the TOPSIS method to determine the optimal choice for advancing renewable energy sourced from agricultural waste after identifying constraints hindering the expansion.

TOPSIS method, introduced by Hwang and Yoon [39], is a simple and practical technique for grading. Typically, the method identifies decisions that yield a positive and negative ideal solution. The best approach improves the benefit criterion while optimizing and minimizing the expense condition. TOPSIS ranks alternatives and utilizes attribute information without needing individual attribute preferences [18]. This strategy requires using mathematical characteristic rates with matching elements and a consistent rise or reduction.

In the first phase, the method started by normalizing the decision matrix after initial establishment. The second phase entailed constructing a weighted normalized decision matrix, while the third phase was achieved by selecting between beneficial and harmful optimal options. Meanwhile, planning for each specific situation was carried out in the fourth phase. The closeness indicator was computed in the fourth phase, arranging the options list in descending order. The following steps can be used to illustrate the TOPSIS procedure:

a. Create a decision matrix.
   A decision structure of a matrix was derived from Eq. (1) as follows:

$$A=\begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ . \\ . \\ . \\ A_m \end{array}\begin{pmatrix} C_1 & C_2 & C_n \\ X_{11} & X_{12} & X_{1n} \\ X_{21} & X_{22} & X_{2n} \\ X_{31} & X_{32} & X_{3n} \\ . & . & . \\ . & . & . \\ . & . & . \\ X_{m1} & X_{m2} & X_{mn} \end{pmatrix} \tag{1}$$

   Where Ai expresses alternative i, i = 1,…., m, C_i denotes the choice criteria, and Xkj represents the set of performance ratings of each alternative supplier against the selection criteria, k = 1,…,m and j = 1,…, n

b. Make an ordered choice matrix, defined as rkj.
   The normalized value (rkj) was computed using Eq. (2) as follows:

$$r_{kj}\ (x) = \frac{X_{kj}}{\sqrt{\sum_{k=1}^{n} X_{kj}^2}}\ , k = 1, \dots n, j = 1, \dots , m \tag{2}$$

c. Weight and normalize the created matrix.
   The normalized and weighted matrices were calculated using Eq. (3) as follows:

$V_{kj}\ (x) = \ w_j\ x\ r_{kj}(x),\ k = 1, \dots m;\ j = 1, \dots, n$ (3)

Where w_j is the weight from the j-th criteria, while r_{kj} is the normalized rate.

d. Determine the ideal positive (A+) and negative score (A-)

The initial phase entailed identifying the benefit and cost criteria from the provided list. The benefit category pertained to the criteria with the highest Vkj value, indicating positive and superior outcomes. Conversely, the cost category was applicable when the most negligible V_{kj} value demonstrated good and superior outcomes.

The ideal positive (A+) and negative (A-) scores were calculated using Eqs. (4) and (5) as follows:

$A+ = \{V1+(x), V2+(x), \dots, Vj+(x), \dots, Vm+(x)$ (4)

$= \{(\max kvkj\ (x) \mid j \in J1), (\min kvkj \mid j \in J2) \mid k = 1, \dots, n\}$

$A- = \{V1-(x), V2-(x), \dots, Vj-(x), \dots, Vm-(x)$ (5)

$= \{(\min kvkj\ (x) \mid j \in J1), (\max kvkj \mid j \in J2) \mid k = 1, \dots, n\}$

Where *J1* is the criterion of benefit, and *J2* is the criterion of cost.

e. Compute the distance between all possible options from the ideal positive (A+) and negative point (A-)

The separator value determined by the Euclidean distance in Eqs. 6 and 7 was used to calculate the distance between the ideal positive (A+) and negative point (A-) between the alternative criteria.

$$D_k^* = \sqrt{\sum_{j=1}^{m} \left[v_{kj}(x) - v_j^+\ (x)\right]^2}, k\ \ 1, \dots, n \quad (6)$$

$$D_k^- = \sqrt{\sum_{j=1}^{m} \left[v_{kj}(x) - v_j^-\ (x)\right]^2}, k = 1, \dots, n \quad (7)$$

f. Estimate the comparative closeness of individual alternativesto the ideal solution and grade.

The respective nearness of the possible Ai to the ideal positive point (A+) was calculated using Eq. (8) as follows:

$$C_k^* = \frac{D_k^-}{(D_k^* + D_k^-)},\quad k = 1, \dots, n \quad (8)$$

where the index value of C_k^* is between 0 and 1. Alternatives with the most significant index value tend to perform well.

3. Results

Interviews with experts, stakeholders, and scholars in the field yielded diverse insights on agricultural waste as a clean energy foundation in Indonesia. Various internal and external factors, such as strengths, weaknesses, opportunities, and threats, were reflected when formulating a plan. Table 1 shows the progression of different internal and external factors, and then a survey was developed to investigate significant sub-factors with the potential to serve as new renewable energy sources. The questionnaire was circulated to experts, and responses from the critical respondents were organized in SWOT Analysis, as shown in Table 2 and Table 3.

Table 2
Internal Factors Analysis

No	Factors	Weight	Rating	Score
Internal Factors				
1	Employees with skills in the field of agriculture waste management in renewable energy	0,068	3	0,21
2	Training on how to recycle agriculture waste into renewable energy	0,073	3	0,25
3	Government policy support	0,079	3	0,26
4	Adequate area for agriculture waste management into renewable energy	0,079	3	0,27
5	The province has quite good cooperation and relationships with fellow waste industry stakeholders	0,074	3	0,25
6	Abundant agricultural waste	0,080	4	0,29
7	The workforce in environmental institutions is sufficient	0,076	3	0,25
8	Agriculture waste management technology for renewable energy is available and accessible	0,071	4	0,26
	Total Strength			2,038
9	Potential for developing agriculture waste management technology into renewable energy in the Riau Province environment	0,072	4	0,26
10	Lack of funding for procurement of agriculture waste management technology into renewable energy	0,055	3	0,16
11	The performance of waste recycling in the Riau Province environment is still low	0,062	3	0,21
12	Adequate equipment and materials for processing agriculture waste into renewable energy	0,060	3	0,21
13	The process of recycling agricultural waste into products that have economic value	0,075	4	0,26
14	The results of agriculture waste recycled produce products/results that can benefit the people of Riau Province	0,077	4	0,29
	Total Weakness			1,386

Table 3
External Factors Analysis

No	Factors	Weight	Rating	Score
	External Factors			
1	Support from other institutions for HR training (e.g., universities and the Environmental Service)	0,09	3,72	0,33
2	Support from the Department of Hygiene and Environment for the development of waste management	0,09	3,56	0,32
3	The technology currently available can still be developed	0,08	0,28	0,02
4	Support from banking institutions regarding capital in agriculture waste management technology into renewable energy	0,07	3,22	0,22
5	Technology for processing agriculture waste into renewable energy is increasingly popular	0,08	3,33	0,26
6	Independent technical service in integrated waste management (Waste Bank)	0,09	3,28	0,29
7	Understanding of Climate Change	0,09	3,56	0,32
	Total Opportunity			1,76
8	Increased operational costs for agriculture waste management	0,08	3,17	0,26
9	Climate change affecting agriculture waste management	0,08	3,11	0,25
10	Potential risks of landfill closure	0,08	3,11	0,24
11	There is an impact of poor agriculture waste management on public health	0,09	3,50	0,33
12	Decreased environmental quality due to waste management	0,08	3,28	0,27
	Total Threat			1,35

Based on the results, internal and external factors were analyzed on the potential of durian peel as renewable energy. The weight values of the strength (S), weakness (W), opportunity (O), and threat (T) factors are shown in Table 4 as follows:

Table 4
SWOT Strategy Weight Value

No	Strategy	Weight
1	Strength (S)	2,038
2	Weakness (W)	1,386
3	Opportunity (O)	1,76
4	Threat (T)	1,35

By utilizing both internal (strengths and weaknesses) and external factors (opportunity and threats), an alternative approach was developed for recycling durian peel as agricultural waste. This waste can be transformed into renewable energy suitable in Riau Province. The formulation of SO, ST, WO, and WT strategies was obtained from internal and external factors arranged into the IFAS and EFAS SWOT Matrix.

A SWOT matrix was created to optimize strengths and opportunities while avoiding weaknesses and threats. The strategy priorities were prepared from the combination of the highest weight values to the combination of the lowest acquired from the consequences of the respondent's form. The outcomes of these scheming are presented in Table 5.

Table 5
SWOT Strategy Value Weight Calculation

No	Strategy	Value Weight
1	Strength – Opportunity (SO)	2,038 + 1,76 = 3,798
2	Strength – Threat (ST)	2,038 + 1,35= 3,388
3	Weakness – Opportunity (WO)	1,386 + 1,76= 3,146
4	Weakness – Threat (WT)	1,386 + 1,35= 2,736

Based on the provided data in Table 5, the Strength-Opportunity (SO) strategy had the maximum weight of the SWOT strategy value, reaching 3,798, while Weakness-Opportunity had the smallest value of 2,736. The quadrant position was determined through factors on the X and Y axes, as shown in Figure 2. SWOT analysis results placed the Riau Provincial Government within quadrant 1 in developing the potential of durian skin waste for renewable energy using recycled agricultural waste. The Provincial Government can utilize the strengths to maximize existing opportunities.

Decision criteria serve as guiding principles, goals, standards, requirements, and circumstances used by a group or organization to reduce the number of options or arrive at a decision. These components enable teams to select an action plan from various possibilities, thereby enhancing the norm for uniformity, justice, and standard of collective decisions. Alternatives are assessed based on these criteria, which are governed by the type and caliber, depending on the job. Table 6 summarises the options and qualifications based on the experts' responses to the questionnaire.

Table 6
Criteria for agriculture waste as renewable energy

Criteria	Status	Weight (%)
Environment	Benefit	30
Economy	Cost	10
Social	Benefit	10
Technology	Cost	35
Policy	Benefit	15

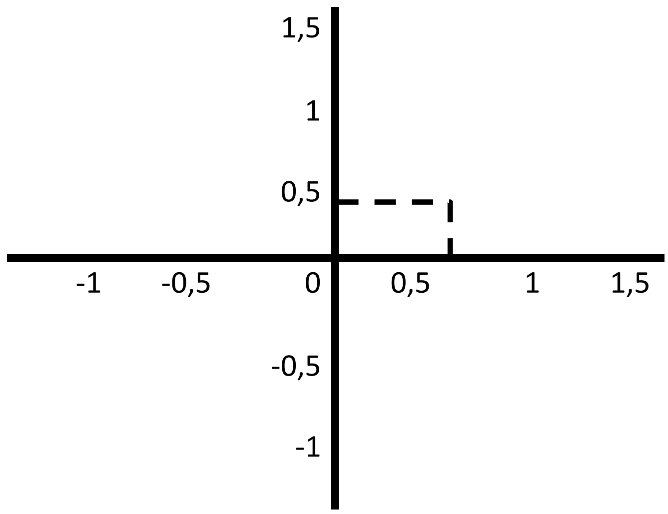

Fig. 2. SWOT Analysis Diagram

The results showed that seven criteria of different weights were considered when making wood pellets, each with two states, namely Benefit and Cost. The advantage derived from producing wood pellets is the benefit, while expenses represent risks or losses that potentially occur when renewable energy development fails.

Alternatives refer to potential ways, options, and approaches to accomplish an objective. The government and stakeholders (environment, economy, social, technology, and policy) typically select these alternatives, providing information on the skills, background, and funding needed to develop wood pellets. Respondents were allocated a score based on evaluations of the options, and for each criterion, the alternative pairwise was compared using the Saaty scale [40]. Table 7 provides specifics on the outcomes of pairwise assessments for every single alternate on each criterion. For example, when asked to compare the environment with the economy, the responder selected a mean value of seven, suggesting the significance of one over the other in the highest possible order.

Table 7
Results from contrasting options according to all criteria

Alternative	Description	Criteria				
		Env	Eco	Soc	Tech	Pol
		C1	C2	C3	C4	C5
A1	Biogas	7	7	8	8	7
A2	Bioethanol	9	9	9	9	8
A3	Wood pellet	8	9	8	8	8
A4	Bricket	8	8	9	8	9
A5	Maggot BSF	8	8	7	8	9

Eq. (1) was used to apply a normalization process to every matrix. In a Multi-criteria Decision-Making (MCDM) scenario, decision-makers commonly define criteria to address various aspects across many domains concerning possibilities and interests [18]. Consequently, regardless of the units used, presentation beliefs can fulfill the criteria for government incentives. All the data were standardized into a similar scale so that the MCDM method could function effectively with this information. This process is called "normalization". The results are shown in Table 8.

Table 8
The normalized matrix for each criterion depending on the options

X1	X2	X3	X4	X5
17,94435844	18,4119526	18,411953	18,35755975	18,41195264

Table 9
Normalized Performance Rating

Alternative	Description	C1	C2	C3	C4	C5
Normalized		R1	R2	R3	R4	R5
A1	Biogas	0,3901	0,3802	0,4345	0,4358	0,3802
A2	Bioethanol	0,5016	0,4888	0,4888	0,4903	0,4345
A3	Wood pellet	0,4458	0,4888	0,4345	0,4358	0,4345
A4	Bricket	0,4458	0,4345	0,4888	0,4358	0,4888
A5	Maggot BSF	0,4458	0,4345	0,3802	0,4358	0,4888

The normalized performance rating (rij) calculation relies on the following considerations. In MCDM situations, decision-makers commonly define criteria to consider different variables across many sectors about options and preferences. Consequently, meeting the criteria for government incentives becomes feasible using accomplishment measures in different quantities. Moreover, to achieve effective results for the MCDM method, it is essential to standardize all data to a uniform unit of measurement. This process is called "normalization," Table 9 shows the complete outcomes of the computations. The weighing results were supplied by the stakeholder in charge of producing renewable energy, as shown in Table 10. Additionally, Eq. (2) was used to ascertain the adjusted weight ranking.

Table 10
Criteria weighting

Alternatives	C1	C2	C3	C4	C5
Weight (W)	10	35	15	30	10

The computation of weighted normalization for each option on every criterion was detailed, utilizing Tables 9 and 10 as references. Eq. (3) computations were also utilized to obtain positive and negative optimal resolutions. The survey responses were analyzed, and the results for several criteria are presented in Table 10, which shows alternate attributes. After analyzing the questionnaires containing a section on the advantages of the criteria and associated costs or distortions, it was discovered that each criterion possessed a distinct status. Eq. (4) computes the proximity across each option and the positive and negative ideal results. The outcomes are presented in Table 11.

Table 11
Computed results of the normalized weight rating

Alternative	Description	C1	C2	C3	C4	C5
Weighted criteria		Y1	Y2	Y3	Y4	X5
A1	Biogas	3,9009	13,3066	6,5175	13,0736	3,8019
A2	Bioethanol	5,0155	17,1085	7,3322	14,7078	4,3450
A3	Wood pellet	4,4582	17,1085	6,5175	13,0736	4,3450
A4	Bricket	4,4582	15,2075	7,3322	13,0736	4,8881
A5	Maggot BSF	4,4582	15,2075	5,7028	13,0736	4,8881

Table 12
Alternatives requirement parameters

Alternatives	C1	C2	C3	C4	C5
Parameters	Benefit	Cost	Benefit	Cost	Benefit

Table 13
Highest and lower limit values for all criteria

POSITIVE	A+	NEGATIVE	A-
Y1+	5,0155	Y1-	3,9009
Y2+	17,1085	Y2-	13,3066
Y3+	7,3322	Y3-	5,7028
Y4+	14,7078	Y4-	13,0736
Y5+	4,8881	Y5-	3,8019

Table 14
Maximum and minimum scores for all criteria

A+	5,0155	17,1085	7,3322	14,7078	4,8881
A-	3,9009	13,3066	5,7028	13,0736	3,8019

The positive and negative ideal solutions are also found using calculations based on formula 3. Based on the responses to the given questionnaire, Table 12 presents the findings of alternate attributes for each criterion. Tables 13 and 14 present the computed results of alternative inclinations for both positive and negative distances. Based on the computed results, option A2 (Bioethanol) had the highest preference value of 17.1085, while A5 (Maggot BSF) had the lowest at approximately 3.8019. Table 13 was subsequently altered to Table 14 to present the utmost and most minor amounts for each predetermined circumstance. The preference value for each criterion was determined using Eq. (5), while the computation outcomes are presented in Tables 15 and 16.

Table 15
The disparity between the quantity of each option and the sum of the positive and negative ideal solution matrix was calculated

Alternative Distance	Positive (+)	Negative (-)	D+ + D-
A1	4,4852	0,8147	5,2999
A2	0,7370	4,5254	5,2623
A3	2,0465	3,8582	5,9046
A4	2,5680	2,3437	4,9117
A5	9,2496	1,6846	10,9342

Table 16
Preference value

No	Description	Alternative	V	Ranking
1	Biogas	A1	0,154	Not eligible
2	Bioethanol	A2	0,860	Best Alternative 1
3	Wood pellet	A3	0,653	Best Alternative 2
4	Bricket	A4	0,477	Best Alternative 3
5	Maggot BSF	A5	0,154	Not eligible

The distance between each option was computed using the results of the preference value computation as a basis. Therefore, with a weight of 0,884, Alternative A2 (Bioethanol) had the greatest significant distance according to the computed statistics. Based on these predictions, Bioethanol was considered the optimal option for utilizing agricultural waste as an environmentally friendly power source in Riau Province, Indonesia.

4. Discussion

Numerous abundant and potentially sustainable renewable energy sources are available in Riau Province and almost all regions in Indonesia. Renewable energy can meet the high demand by utilizing recycled agricultural waste, specifically for less privileged families. Furthermore, this source presents an opportunity for sustainable and controlled transition from a coal-dependent energy system to a more carbon-free one. Coal has dominated the energy sector of Riau Province for decades, limiting the development of renewable energy options.

This study used SWOT and TOPSIS analysis to assess the potential of various renewable energy sources. Several important policy implications were identified based on the methods used to create a path toward a sustainable energy system transition. Authorities should prioritize programs that promote renewable energy sources based on several acceptable policies derived from the analysis. The results showed that the Indonesian government could overcome the persistent energy problems by using the widely abundant agricultural waste as a renewable energy source. Stakeholders can challenge dangerous presumptions and identify harmful blind spots regarding the performance of an organization with the aid of SWOT and TOPSIS analyses. When used thoughtfully and cooperatively, these methods can provide fresh perspectives and create the ideal action plan for any circumstance.

Environmental changes related to agriculture affect both agricultural output and the natural environment. A sustainable agricultural system is crucial for preserving a harmonious equilibrium between productivity and ecosystems. A sustainable agriculture technique enhances accessibility, availability, application, and steadiness among all sustainability elements to improve produce quality while protecting the environment and promoting community harmony.

Sustainable agriculture uses agricultural waste for various purposes, including fertilizer, protecting crops with organic matter, creating healthy soil and carbon-storing biochar, and controlling irrigation water quality. These practices are in line with the fundamental tenets of agricultural sustainability, which include 1) increasing resource efficiency, 2) participating in activities aimed at preserving natural assets, 3) safeguarding the means of subsistence in agriculture, 4) enhancing the ability of both persons and ecosystems to withstand and recover from disturbances; 5) promoting accountable governance structures [41].

As the circular bio-economy becomes more widely recognized, along with the demand for reusing and recycling waste, new agricultural waste management approaches are being developed. In addition, inappropriate agricultural waste management has been rising globally due to industrialization and urbanization. Approximately 25% of the calories produced globally are lost or squandered [42,43]. Agriculture waste contains significant levels of fat, protein, and carbohydrates. Due to the high moisture content, these materials can be used in chemical hydrolysis, aerobic composting, or anaerobic digestion (AD) [44].

The primary goal of an agricultural waste management system is to effectively and sustainably manage the environmental repercussions. An all-round agricultural recycling system facilitates the generation of electricity from waste and the appropriate disposal of residue. Therefore, selecting the best waste treatment technology on the market that satisfies all requirements is crucial. Each system for transforming waste into electricity has benefits and drawbacks [45].

The technical and financial feasibility and a detailed comprehension of processes, chemical and physical properties, capital, mode of operation, and maintenance expenses are prerequisites for adopting a novel Waste to Energy (WtE) technology. The primary steps in the architectural evolution of the technology include proposing capacity, selecting collection areas, and designing logistics. Demonstrating and modeling are crucial for optimizing each process and guaranteeing the effective and efficient functioning of the WtE transformation. Furthermore, examining various parameters, including gathering destinations, themes, disposal expenditures, machinery, employment, transfer facility destinations, facilities for processing, waste dumps, waste flow shipment, and recovering proportion, can lead to substantial cost savings and optimization of the steps.

Indonesia is well-positioned to generate and distribute agricultural waste globally due to its large size and strategic location. A recent study showed that the country can generate approximately 756.1 million gigajoules of energy annually, with 141.5 million gigajoules originating from agricultural residues [46]. Based on the calculations, the potential energy in 2010 was predicted to be approximately 470 million GJ/year, higher than the 2007 potential of 441 GJ/year.

Despite the tremendous potential for biomass energy from agricultural waste, only a tiny amount is currently utilized. In 2015, only approximately 5% of the energy mix in the country was non-renewable. The National Energy Board also reported that low biomass energy is used in electricity production. For example, the current capacity is 1,716 MW, representing 5% of the total capacity of 32,654 MW. The vast ecosystems in Indonesia, spanning 94.1 million hectares, have the potential to provide renewable energy. However, only a portion of woodland timber is utilized to produce bioenergy wood pellets manufactured solely from premium wood, allowing for uninterrupted production as an environmentally friendly form of energy [47].

This study analyzed the framework for utilizing agricultural waste to assess the Riau Provincial government's capacity to achieve sustainable development. The results outlined the resources available to achieve the objectives based on SWOT and TOPSIS analysis. Using agricultural waste as a renewable energy source aligns with the Sustainable Development Goals (SDGs), established by the United Nations and unanimously endorsed by all participating nations in 2015. The objective is to achieve worldwide wealth along with environmental responsibility by 2030.

The seventh goal (SDG 7) out of 14 is to achieve accessible and environmentally friendly energy. Power usage has grown significantly over the past decade, underscoring the need to develop environmentally friendly and cleaner energy options. Furthermore, achieving SDG 7 requires significant progress in decarburisation and sustainable industry [48]. Numerous countries have embraced the SDGs to achieve the goals of renewable energy legislation. For instance, India is a significant player in the renewable energy market compared to other prominent countries [49] due to the successful policy implications [50]. Furthermore, there has been a recent surge in global attention towards the SDGs, focusing on investigations and legislative consequences. The worldwide objectives of Sustainable Development Goal 7 to be achieved by 2030 are as follows:

a. Guarantee universal access to sustainable, dependable, and cost-effective energy supplies.
b. Dramatically increase the volume of energy derived from renewable sources in the worldwide energy portfolio.
c. Enhance national and international cooperation to promote funding for eco-friendly energy facilities and equipment and support the adoption of environmentally sustainable energy innovations, including alternative energy and conservation.
d. Cooperate with the assistance program aimed at upgrading technology and creating infrastructure to offer cutting-edge energy services that are environmentally friendly to all

developing nations, particularly those with minimal development, small Islands, and without mainland.

The analysis showed that the government could develop the potential of durian skin waste for renewable energy, utilizing current strengths to maximize existing opportunities. Furthermore, a skilled workforce in agricultural waste management can be a driving factor in immediately increasing the use of new and renewable energy. Implementing this strategy would lead to utilizing considerable human resources across various sectors, including manufacturing, services, and agriculture, stimulating economic growth. Increased worker wages would lead to a rise in demand for goods and services. Therefore, businesses should expand and hire more employees to create a positive feedback loop that drives growth. A larger workforce also translates to higher tax revenues for the government, facilitating the allocation of more funds to health services, education, and infrastructure, as well as all areas that can improve the economic environment and attract new businesses and investors.

Prioritizing regulatory reform is crucial, including mandating companies to utilize waste recycling as renewable energy in specific amounts. It is also important to advocate the progress of domestic biomass waste-based renewable energy development, promote the study and development of technology, and build the necessary grid infrastructure to facilitate the incorporation of renewable energy sources. However, potential challenges, such as initial costs, must be considered when applying these concepts. Switching to renewable energy requires enormous initial costs, which may cause financial stress. Addressing the problem of dependence on fossil fuels is very important, given the Indonesian economy's heavy reliance on them. Resistance from vested individuals may also pose obstacles to any transformation effort. Additionally, future studies should prioritize examining the limitations of technology. For example, certain renewable technologies may not be suitable for every location or purpose, and complications regarding grid integration may arise.

Public acceptance is essential in successfully implementing renewable energy programs in Indonesia. Additionally, public acceptance may require increasing awareness among the general public regarding the benefits of using renewable energy sources and addressing potential concerns regarding noise pollution, aesthetics, or environmental impacts. Sociocultural aspects must also be considered by recognizing and addressing any possible cultural or religious sensitivities related to the use of renewable energy. Ignoring social issues can create community resistance and hinder implementation initiatives, while effective community participation promotes the development of targeted and efficient legislation.

Although previous investigations on sustainability and renewable energy in Indonesia are perceptive, this study provides the possibility of further comprehensive exploration. Further investigation could examine the interplay between the complex sensitivity of renewable energy sources with other criteria, providing context for scaling up models to include components such as policy instruments, infrastructure improvements, and financial dynamics. Examining the potential uncertainty in decision-making relationships within the renewable energy sector based on biomass waste can provide valuable insights. In addition, decision-making models that explore criteria and sub-criteria for developing renewable energy based on biomass waste offer a more proactive perspective. A more comprehensive study on this decision-making strategy will offer a deeper understanding of how renewable energy impacts sustainable development for Indonesia and worldwide.

4. Conclusions

In conclusion, this study offered insights into a plan for recycling agricultural waste as an eco-friendly energy source. SWOT and TOPSIS were used to identify critical variables and develop a strategy by analyzing strengths, weaknesses, opportunities, and threats. The Strength-Opportunity (SO) strategy had the highest SWOT value, 3.798, while the Weakness-Opportunity strategy had the lowest value of 2.736. SWOT analysis results also showed that the Riau-Indonesia Provincial Government could develop the potential for recycling durian skin waste into new, renewable energy. Furthermore, the optimal type of renewable energy source was Bioethanol, with a weight of 0.860, followed by wood pellets and briquettes with weights of 0.653 and 0.477, respectively, based on the TOPSIS method.

Further study is needed to provide more accurate results and improve the current understanding of the evolution of renewable energy in Indonesia. Increased attention should be given to raising consumer awareness of renewable consumption, elevating producer productivity, and strengthening policies, specifically those related to the implementation of renewable energy utilization. Furthermore, the economic relationships between the continued expansion of agricultural waste recycling utilization and exogenous variables such as oil price fluctuations must be accurately delineated. Examining how industry executives perceive consumer adoption behavior regarding renewable energy technology is also essential. This exploration will draw attention to the differences between how people make decisions and the expectations of the local governments. There is currently limited study on how businesses and society perceive renewable energy technologies, with existing reports primarily focused on political and financial constraints rather than decision-making processes.

Author Contributions

Conceptualization, D.R.; methodology, D.R.; software, D.R.; validation, D.R.; formal analysis, D.R. and D.A.; investigation, D.R., D.A. and R.M.; resources, D.R. and D.A.; data curation, D.R.; writing—original draft preparation, D.R., D.A. and R.M.; writing—review and editing, D.R., D.A. and R.M.; visualization, D.R.; supervision, D.A.; project administration, D.A. All authors have read and agreed to the published version of the manuscript.

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Data included in article/supp. Material/referenced in the article.

Conflicts of Interest

The authors declare that any known competing financial interests or personal relationships could have influenced none of the work reported in this study.

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