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Determination of critical factors and the best alternatives for developing biodiesel from Maggot BSF

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Abstract
This paper explores the approach for producing biodiesel from Maggot Black Soldier Fly (BSF) as a sustainable, renewable energy source in Indonesia. The SWOT and VIKOR techniques determine the most effective strategy for promoting renewable energy in Indonesia. The paper included numerous respondents to ascertain the criteria and assess each option. Environmental consciousness is an important strong component in biodiesel development, with a value of 1.52. A significant drawback in biodiesel production is the elevated investment costs, quantified at 1.48. A notable opportunity in biodiesel development is its potential as an environmentally sustainable energy alternative, scoring 1.32, while a considerable threat is inadequate financial assistance, scoring 1.24. Moreover, applying the VIKOR approach reveals that alternative 6 (Enhancing collaboration among stakeholders) is the most critical option, as expert evaluations indicate, with a value of 0.048. The outcomes of this study require enhancement since additional research is necessary to yield more precise findings that will augment our comprehension of the evolution of renewable energy in Indonesia. Future studies should focus on the ramifications of producing biodiesel from BSF maggots, particularly in terms of energy security and energy autonomy in Indonesia.

Keywords:
Biodiesel;
Black Soldier Fly (BSF);
Renewable Energy;
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INTRODUCTION

Climate change is seen as a significant problem for the sustainable evolution of human society, with anthropogenic greenhouse gas (GHG) emissions, primarily from the use of natural gas, identified as the principal cause of the observed climatic alterations to date [1, 2, 3]. The combustion of natural gas leads to various anthropogenic activities, including transportation, coal-based energy production, and large-scale businesses. It can pollute the climate by emitting greenhouse gases, notably nitrogen oxides and ammonia. Elevated levels of nitrogen oxides in the atmosphere may result in environmental problems due to acid rain and smog formation. Consequently, using biodiesel as a substitute for oil and gas is considered environmentally sustainable because biodiesel can be derived from renewable biomass sources.

To mitigate the issue, most nations globally are implementing strategies to regulate or diminish their carbon emissions [4]. In this environment, the transition of energy from petroleum and coal to alternative energy sources is a primary choice for the world, with bioenergy anticipated to assume a significant position within the renewables sector. For example, the United States Environmental Protection Agency states that biodiesel can decrease greenhouse gas emissions by 86%. The increasing global consumption of biodiesel, around 429.9 thousand barrels daily, has necessitated the investigation of sustainable feedstocks for biodiesel production [5]. The production of biofuels from agricultural produce, categorized as the initial feedstock, may result in a shortage of food supply. Lignocellulosic biomass was recently studied to create the subsequent generations of biodiesel. Nonetheless, a sophisticated apparatus is required for the operational procedure, resulting in substantial investment expenses [6]. Despite exploring third-generation biofuels as a substitute for lignocellulosic biomass in biodiesel production from microalgae and cyanobacteria, a prohibitively high harvesting cost remains unavoidable. Despite the high lipid content of these microorganisms, exceeding 75% in microalgae, substantial time and considerable energy are required for processing significant quantities of microalgal feedstock [7]. Lipids derived from insect larvae have emerged as a viable source for biodiesel production, addressing existing challenges. These larvae are considered a cost-effective feedstock, easily cultivated, and capable of converting biological recyclables into plant matter through a biological transformation [8][9].

Insect larvae can consume organic substances such as food scraps, agricultural waste, animal waste, and sludge, thereby bio-converting these materials into valuable larval plant matter for subsequent applications [10][11]. Insect-derived lipids, mainly as fat, represent a substantial portion of plant matter explored for sustainable biofuel production [12, 13, 14].

Lipids are retained in the larval body for use throughout the non-feeding stage of their lifespan [15]. Among many types of insects, including the flesh fly, superworm, mealworm beetle, housefly, latrine blowfly, soldier fly, and ants, Hermetia illucens larvae, commonly known as black soldier fly larvae (BSFL), are often selected for the production of biodiesel. This preference is due to their ability to valorize diverse organic wastes, their high lipid content (approximately 50%), the non-pest status of the adults, their adaptability to various environmental conditions, including temperatures and pH levels, and humidity, and the reduced labor requirements for mass rearing [16, 17, 18, 19]. The fatty acid profile of BSFL lipid primarily consists of C12:0 (38.43 wt%), C16:1 (15.71 wt%), and C14:0 (12.33 wt%), which are essential components for the production of biodiesel.

Furthermore, the elevated levels of C12:0 in fatty acid methyl esters (FAMEs) of biodiesel may influence the modest density and viscosity kinematic, as well as the high oxidation stability of the resulting biodiesel [20][21]. In addition, the Fatty Acid Methyl Esters (FAMEs) obtained from the lipid extraction of black soldier fly larvae (BSFL) predominantly consisted of C12:0, with proportions of 76.1%, 58.3%, and 48.1% when fed individually on fruit debris, sewage effluent, and palm decanter, respectively [22][23].

Diverse insect species, such as flesh flies, superworms, mealworm beetles, houseflies, blowflies, and black soldier flies, have been utilized in biodiesel production [23][24]. Black soldier fly larvae are recognized for being able to decompose a range of biological waste products, such as leftovers from meals, industrial by-products, cow dung, and human excrement, while generating high-fat content biomass [25]. Previous studies revealed that 11–42% of lipids were detected in BSFL [26][27]. The development of biodiesel from different kinds of insects has been studied previously [22, 28, 29]. This situation emphasizes the need for effective strategic planning as a first step in making the right decisions. A relevant tool for strategizing solutions to the challenges of renewable energy based on BSF Maggot is the SWOT analysis. SWOT analysis can evaluate biodiesel development that requires an internal examination of the microenvironment [30][31]. This analysis focuses on the relevant strengths, weaknesses, opportunities, and threats (SWOT) commonly used by various entities in strategic planning. SWOT analysis provides insight into the strengths and weaknesses of the existing energy system. This analysis provides a comprehensive insight into potential opportunities and obstacles that can be exploited to hinder the achievement of a goal. SWOT analysis provides actionable answers that can be promoted in the plan [32][33].

Formulating strategies to utilize renewable energy sources is crucial for environmental sustainability [34][35]. To tackle the challenges associated with the energy-economy-environment nexus and fulfill Sustainable Development Goals, various nations and institutions have implemented strategic plans to diversify their energy mix and integrate renewable energy sources with other energy types. Most countries globally are actively advancing renewable energy initiatives, supportive policies, and established targets [36]. Decision-makers face challenges in selecting a specific renewable energy source due to the need to evaluate the advantages and disadvantages of each option. Consequently, choosing renewable energy sources is a nation's strategic and critical decision-making process, influenced by multiple factors [37][38]. Decision-makers should evaluate qualitative and quantitative factors alongside environmental considerations to ensure renewable energy sources' safe, sustainable, and efficient use [39]. Various multi-criteria decision-making (MCDM) methods have been established to address complex decisions when selecting the most appropriate renewable energy sources (RES) for a specific country. MCDM methods are models grounded in operations research that tackle decision-making issues involving multiple competing objectives. Conflicting criteria, incommensurable units, and challenges in the design and selection of alternatives are significant aspects of these methods, which accommodate both quantitative and qualitative criteria [37].

Replacing petroleum products with biodiesel is increasingly economically feasible and is an essential step towards the growth of a sustainable economic system. Consequently, the expansion and advancement of the biodiesel market require formulating and implementing a well-coordinated strategy for producing diverse biodiesels in Indonesia and establishing effective and transparent laws that will outline the main pathways for fostering the biodiesel sector. This study aims to develop a strategy for developing biodiesel based on Maggot BSF oil as one of the alternative sustainable renewable energy sources.

METHOD

This study attempts to identify the optimal way to develop BSF Maggots into renewable biodiesel energy by utilizing SWOT and VIKOR methodologies. SWOT analysis identifies and evaluates strategies to develop BSF Maggots as a sustainable biodiesel energy source. The VIKOR approach determines the optimal options based on the results. Data were collected through a review of related literature, interviews with various individuals, field observations, and expert surveys. Data on internal and external aspects for the SWOT analysis were collected through an open-ended questionnaire distributed to academics, non-governmental groups, biodiesel renewable energy analysts, and legislators and then compiled in a tabular format. Simultaneously, the VIKOR approach was applied to identify strategies for biodiesel renewable energy through a paired comparison questionnaire. The questionnaire was distributed to experts, considering their experience, availability, and expertise in renewable energy. Furthermore, to facilitate understanding, this article presents a research methodology as illustrated in Figure 1.

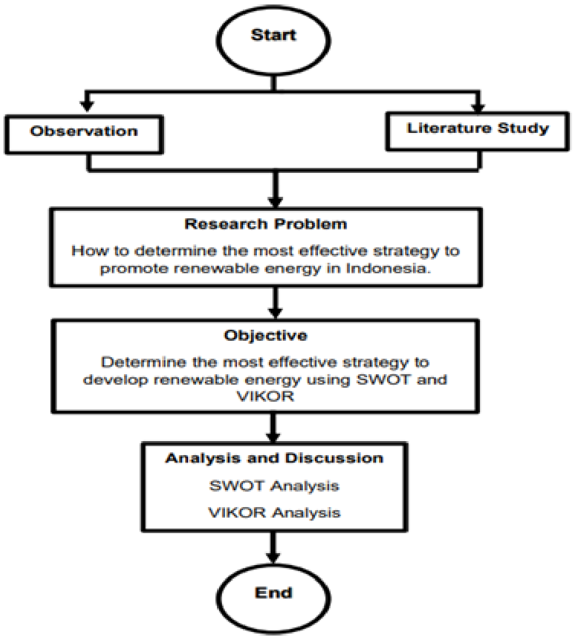

Figure 1. Research methodology Flowchart

SWOT analysis is a strategic technique designed to evaluate an organization's strengths and weaknesses, as well as external opportunities and threats. It was embraced by public administration in the 1980s for regional development and municipal planning [40][31]. When confronted with a circumstance and making a decision, we should evaluate the positive and negative aspects and the advantages and disadvantages of the alternative. A SWOT analysis can assist in identifying the existing situation and facilitate a more comprehensive evaluation before making a decision. Bioenergy production on marginal land might be seen as an initiative or project, subject to SWOT analysis. Numerous instances of effective use of SWOT analysis exist in bioenergy sustainable development and industrial planning strategy (Table 1).

However, biodiesel production has different characteristics when facing various internal and external conditions. A SWOT analysis is conducted to evaluate the possibilities and risks in the global external environment, as well as the strengths and weaknesses of the project.

The next steps of the analysis are as follows [31]:

a. Determining the internal production parameters for bioenergy in compliance with the predetermined development goals. This encompasses advantageous or disadvantageous factors such as land accessibility, technological appropriateness, and economic viability.

Table 1. The application of the SWOT method in bioenergy

No.	SWOT Application	References
1	Analyze the renewable energy industry and identify the factors that influence FDI to attract new investments,	[41]
2	Assessing the potential of potato-based bioethanol in India	[42]
3	Renewable energy transition assessment	[43]
4	Literature review and anonymous survey on renewable energy in Mazowieckie Voivodeship (Poland)	[44]
5	Identify the barriers and drivers for developing a local supply chain for forest residues in an Italian alpine valley by gathering and analyzing the perspectives of all regional actors involved.	[32]
6	SWOT to participatory decision making.	[45]
7	Addressing the challenge: transforming intermediate bioenergy carriers into a catalyst for a climate-neutral Europe	[46]
8	A preliminary evaluation of large-scale solar technology in Malaysia through an integrated SWOT (Strengths, Weaknesses, Opportunities, and Threats) and PESTLE (Political, Economic, Social, Technical, Legal, and Environmental) analysis, combined with the analytic hierarchy process (AHP) methodology.	[47]
9	Assessment of renewable energy's current status and future strategies for enhanced utilization.	[48]
10	Elucidate the advancements in renewable energy over the previous decade and the obstacles confronting the Togolese government.	[49]

b. Identification of external elements that may affect the outcome of BSF Maggot-based bioenergy.
c. Detailing the intrinsic factors that have been identified. Evaluating aspects may increase or decrease the project's competitiveness relative to competing options. Characterization of the external elements indicated-evaluation of issues that may pose dangers or opportunities for the project's progress.
d. Improvement of internal elements, such as selecting suitable Maggot BSF for cultivation, strengthens the project, in addition to external factors that may provide opportunities for it—proposed measures to highlight the project's strengths and effectively exploit the identified prospects.
e. Analysis of internal variables that weaken the project and external factors that may harm its progress. Proposed actions to address project deficiencies and mitigate identified hazards.

The factors to be analyzed in the SWOT method are shown in Table 2. These factors are input from expert respondents with biodiesel renewable energy capabilities. The expert respondents include academics, energy resources, environmental services, and BSF Maggot cultivators.

The VIKOR approach, established by Opricovic in 1990, was used to rank the development of Maggot BSF-based biodiesel. Different fuel cell technologies have specific performance values, as shown by a review study by Akinyele et al. (2020). The performance values R_{ij} of the options related to specific criteria were analyzed to determine the minimum (R_{ij})min and maximum (R_{ij})max values in the decision matrix.

a. Pairwise comparisons of each criterion

$$w_i = \frac{1}{n}\sum_j a_{ij} \tag{1}$$

b. The maximum and minimum values were used in normalizing and linearizing the score set for each Maggot BSF-based biodiesel development factor according to the equation:

$$R_{ij} = \left(\frac{X_j^+ - X_{ij}}{X_j^+ - X_j^-}\right) \tag{2}$$

Where R_{ij} and X_{ij} (i= 1,2,3,…m and j= 1,2,3,…n) are the elements of the decision-making matrix (alternative i to criterion j), and X_j^+ is the best factor of criterion j. X_j is the worst factor of criterion j.

Table 2. Internal and external factors for the development of BSF Maggots as biodiesel

Internal Factor	External Factors
Strength Factor	**Opportunity Factors**
The production process is simple and easy	Wide open market demand for biodiesel use
Strategic production location	BSF maggots are easy to cultivate
Good product quality because it complies with SNI standards	Becoming an environmentally friendly energy solution
Available Workforce	Increasing added value
Environmentally conscious	Creating multiplier effects
Easy to apply technology.	Alternative energy transition
Weakness Factors	**Threat Factors**
Production technology is not yet available for mass production	Changes in strategy and policy
People still rely on fossil fuels.	High potential for conflict of interest
High investment costs	Weak coordination between stakeholders
Lack of pro-renewable energy policies	Weak financial support

c. Determine the values of S and R using the following equation:

$$S_i = \sum_{j=1}^{n} w_j \left(\frac{x_j^+ - x_{ij}}{x_j^+ - x_j^-}\right) \quad (3)$$

And,

$$R_i = Max\ j \left[W_j = \left(\frac{x_j^+ - x_{ij}}{x_j^+ - x_j^-}\right)\right] \quad (4)$$

Where W_j is the weight of each criterion, j

d. Determine the index value with the equation:

$$Qi = \left[\frac{S_i - S^+}{S^+ - S^-}\right] v + \left[\frac{R_i - R^+}{R^+ - R^-}\right] (1 - v) \quad (5)$$

Where:
S = min S_w
S^+ = max S_i and
R^- = min R_i
R^+ = max R_i and
v = 0.5

The ranking result is the result of sorting S, R, and Q. The best alternative solution based on the minimum Q value becomes the best ranking with the following conditions:

$$Q(A^{(2)}) - Q(A^{(1)}) \geq DQ \quad (6)$$

Where:
$A^{(2)}$ = alternative with second order in Q ranking and
$A^{(1)}$ = alternative with the best order in Q ranking
DQ = 1- (m-1) where *m* is the number of alternatives
Alternative $A^{(1)}$ must be ranked best on S and/or R.

Table 3 provides information on several previous studies related to the application of multi-criteria decision-making methods in bioenergy.

Table 3. Application of MCDM in bioenergy

No	MCDM application	Reference
1	Assessing RER alternatives is a multi-criteria decision-making (MCDM) challenge that can be addressed using adaptable tools to navigate complex scenarios and aid decision-makers (DMs) in analyzing the issue.	[50]
2	Evaluation of a renewable energy development objective based on economic, technological, social and environmental factors	[38]
3	Prioritise alternatives, including solar photovoltaic (PV), concentrated solar power (CSP), wind energy, hydropower, and biofuels appropriate for sustainable electrification in Benin.	[37]
4	Analyzed agricultural waste management strategies as a sustainable renewable energy source for Indonesia. The SWOT and TOPSIS methodologies were employed to determine the most effective strategy for promoting renewable energy in Riau Province, with numerous respondents contributing to identifying essential criteria and assessing each alternative.	[31]
5	Prioritization of renewable energy resources using intuitionistic fuzzy AHP and VIKOR methods	[51]
6	Evaluate seven distinct material alternatives based on sixteen factors: corrosion resistance, mechanical qualities, cost, and adverse environmental impact.	[52]
7	The examination and evaluation of renewable energy technologies have garnered heightened interest in the political arenas of various nations and the scientific literature. The	[53]
8	Hybrid multi-criteria decision-making methodology for selecting suitable biomass resources for biofuel production	[54]
9	Examine and prioritize Iran's primary renewable energy sources: biomass, geothermal, hydropower, solar photovoltaic, and wind.	[55]
10	Examine and prioritize Iran's primary renewable energy sources: biomass, geothermal, hydropower, solar photovoltaic, and wind.	[56]

The results of discussions with respondents related to the criteria and alternatives as in Table 4.

Table 4. Criteria and alternatives for developing BSF Maggots as biodiesel

Criteria	Code	Alternative	Code
The production process is simple and easy	CRT_1	Improvement of environment ally friendly technologies	ALT_1
Strategic production location	CRT_2	Government incentives	ALT_2
Product quality complies with SNI standards.	CRT_3	Capital investment	ALT_3
Environmentall y aware	CRT_4	Regulatory support	ALT_4
High investment costs	CRT_5	Increasing public understandin g of renewable energy	ALT_5
Lack of pro-renewable energy policies	CRT_6	Increased collaboration between stakeholders	ALT_6
Energy transition alternatives	CRT_7		
Changes in strategy and policy	CRT_8		

High potential for conflict of interest	CRT_9
Low coordination between stakeholders	CRT_10
Lack of financial support	CRT11

RESULTS AND DISCUSSION

Discussions with experts, stakeholders, and academics in the field resulted in various perspectives on the strategy of developing BSF Maggot as a raw material for biodiesel production in Indonesia. Various internal and external aspects, including strengths, weaknesses, opportunities, and threats, were considered in formulating the plan. Questionnaires were distributed to experts, and responses from key respondents were compiled into a SWOT Analysis, as illustrated in Table 5.

Table 5 provides information related to the results of expert assessments related to strengths, weaknesses, opportunities, and threats. Furthermore, based on the table, it is obtained that the strength value has the highest total of around 3.29, and the lowest total value is the threat of around 2.58. The factor strength with the highest value is environmental awareness, around 1.52, and the highest weakness is the high investment cost, with a score of around 1.32. Meanwhile, the opportunity and threat factors with the highest values are the factors of being an environmentally friendly energy solution and weak financial support, with scores of around 1.32 and 1.24, respectively.

The regulatory system plays a pivotal role in promoting renewable energy technologies by shaping the energy framework and enhancing market competitiveness [41]. In addition, India's extensive potato farming provides a readily available and sustainable feedstock for bioethanol production, supported by growing demand for renewable fuels and a robust agricultural sector [42].

In addition, according to the SWOT analysis findings, the main strengths of the biofuel market in Ukraine include biomass energy generation potential, availability of wood and agro-industrial waste, large amounts of waste and crops, and high costs of conventional energy sources [57].

Based on the results of each researcher's study, it can be seen that the strength factors possessed by each country are different. This difference shows that the strength factors in bioenergy development will have a perspective that is adjusted to the conditions of each country.

Table 5. SWOT assessment of respondents

Internal Factor			
Strength Factor	**Weight**	**Rating**	**Score**
The production process is simple and easy	0.08	2	0.16
Strategic production location	0.12	2	0.24
Good product quality because it complies with SNI standards	0.11	4	0.44
Available Workforce	0.13	3	0.39
Environmentally conscious	0.38	4	1.52
Easy to apply technology.	0.18	3	0.54
Total	1		3.29
Weakness Factor	**Weight**	**Rating**	**Score**
Production technology is not yet available for mass production	0.23	3	0.69
People still rely on fossil fuels	0.9	1	0.19
High investment costs	0.37	4	1.48
Lack of pro-renewable energy policies	0.21	3	0.63
Total	1		2.99
External Factors			
Opportunity Factors	**Weight**	**Rating**	**Score**
Wide open market demand for biodiesel use	0.09	1	0.09
BSF maggots are easy to cultivate	0.12	2	0.24
Becoming an environmentally friendly energy solution	0.33	4	1.32
Increasing added value	0.21	3	0.63
Creating multiplier effects	0.13	4	0.52
Alternative energy transition	0.12	3	0.36
Total	1		3.16
Threat Factors	**Weight**	**Rating**	**Score**
Changes in strategy and policy	0.26	1	0.26
High potential for conflict of interest	0.22	3	0.66
Weak coordination between stakeholders	0.21	2	0.42
Weak financial support	0.31	4	1.24
Total	1		2.58

Furthermore, based on the results of the SWOT analysis, it is continued with an analysis of determining alternatives that will be a priority in biodiesel development. Based on the results of the assessment carried out by key respondents, the paired comparison values are obtained, which are shown in Table 6. The paired comparison assessment uses (1).

Moreover, normalization was carried out on the results of the pairwise comparisons shown in Table 7. Furthermore, respondents were also asked to provide an assessment of the alternatives for each criterion. The results are shown in Table 8.

Then, perform normalization calculations on alternative values for each criterion using (2). The results of these calculations are summarized in Tables 9 and 10.

Table 6. Paired comparison results

Criteria	CRT_1	CRT_2	CRT_3	CRT_4	CRT_5	CRT_6	CRT_7	CRT_8	CRT_9	CRT_10	CRT_11
CRT_1	1.000	2.646	0.416	0.416	0.416	0.379	0.416	0.416	0.416	2.159	1.823
CRT_2	0.378	1.000	0.402	0.402	0.520	0.379	0.402	0.546	0.546	0.546	0.546
CRT_3	2.401	2.489	1.000	2.159	2.159	2.159	0.454	2.159	0.454	2.088	0.494
CRT_4	2.401	2.489	0.463	1.000	0.402	0.454	0.454	0.477	2.019	0.402	0.379
CRT_5	2.401	1.924	0.463	2.489	1.000	1.540	2.019	1.918	2.197	2.197	0.379
CRT_6	2.642	2.642	0.463	2.204	0.649	1.000	2.273	2.197	2.474	2.392	2.474
CRT_7	2.401	2.489	2.204	2.204	0.495	0.440	1.000	0.494	0.494	0.494	0.494
CRT_8	2.401	1.830	0.463	2.096	0.521	0.455	2.023	1.000	2.474	2.392	0.416
CRT_9	2.401	1.830	2.204	0.495	0.455	0.404	2.023	0.404	1.000	0.494	0.416
CRT_10	0.463	1.830	0.479	2.489	0.455	0.418	2.023	0.418	2.023	1.000	0.416
CRT11	0.549	1.830	2.023	2.642	2.642	0.404	2.023	2.401	2.401	2.401	1.000
Total	19.440	22.998	10.581	18.597	9.715	8.032	15.109	12.433	16.499	16.567	8.838

Table 7. Normalization assessment of pairwise comparisons

Criteria	CRT_1	CRT_2	CRT_3	CRT_4	CRT_5	CRT_6	CRT_7	CRT_8	CRT_9	CRT_10	CRT_11	TOTAL	
CRT_1	0.05	0.11	0.04	0.02	0.04	0.05	0.03	0.03	0.02	0.13	0.21	0.74	0.068
CRT_2	0.01	0.04	0.04	0.02	0.05	0.05	0.03	0.04	0.03	0.03	0.06	0.42	0.038
CRT_3	0.12	0.10	0.09	0.11	0.22	0.27	0.03	0.17	0.03	0.12	0.06	1.35	0.123
CRT_4	0.12	0.10	0.04	0.05	0.04	0.06	0.03	0.04	0.12	0.02	0.04	0.68	0.063
CRT_5	0.12	0.04	0.13	0.10	0.19	0.13	0.15	0.13	0.13	0.04	0.04	1.23	0.113
CRT_6	0.13	0.11	0.04	0.11	0.07	0.12	0.15	0.18	0.15	0.14	0.28	1.51	0.137
CRT_7	0.12	0.11	0.21	0.11	0.05	0.05	0.07	0.04	0.03	0.03	0.06	0.89	0.081
CRT_8	0.12	0.08	0.04	0.11	0.05	0.06	0.13	0.08	0.15	0.14	0.05	1.03	0.094
CRT_9	0.12	0.08	0.21	0.03	0.05	0.05	0.13	0.03	0.06	0.03	0.05	0.84	0.077
CRT_10	0.02	0.08	0.04	0.13	0.05	0.05	0.13	0.03	0.12	0.06	0.04	0.78	0.071
CRT11	0.02	0.08	0.19	0.14	0.27	0.05	0.13	0.19	0.15	0.14	0.11	1.49	0.136

Table 8. Assessment of alternatives for each criterion

ALT	CRT_1	CRT_2	CRT_3	CRT_4	CRT_5	CRT_6	CRT_7	CRT_8	CRT_9	CRT_10	CRT_11
ALT_1	90	90	90	90	90	90	90	90	90	90	90
ALT_2	60	70	80	60	70	80	80	80	70	60	70
ALT_3	75	80	80	80	80	80	80	80	70	70	80
ALT_4	75	80	80	80	80	80	80	80	70	80	80
ALT_5	80	70	70	70	70	70	80	60	70	70	70
ALT_6	75	70	70	70	70	80	80	70	70	70	70

Table 9. Normalization of alternative values

Alternative	CRT_1	CRT_2	CRT_3	CRT_4	CRT_5	CRT_6	CRT_7	CRT_8	CRT_9	CRT_10	CRT_11
ALT_1	90	90	90	90	90	90	90	90	90	90	90
ALT_2	60	70	80	60	70	80	80	80	70	60	70
ALT_3	75	80	80	80	80	80	80	80	70	70	80
ALT_4	75	80	80	80	80	80	80	80	70	80	80
ALT_5	80	70	70	70	70	70	80	60	70	70	70
ALT_6	75	70	70	70	70	80	80	70	70	70	70

Table 10. Normalization of alternative values

ALT	CRT_1	CRT_2	CRT_3	CRT_4	CRT_5	CRT_6	CRT_7	CRT_8	CRT_9	CRT_10	CRT_11
ALT_1	0	0	0.123	0.000	0	0	0	0	0	0	0
ALT_2	0.067	0.038	0.122	0.062	0.113	0.137	0.080	0.093	0.076	0.071	0.136
ALT_3	0.019	0.061	0.062	0.037	0.068	0.080	0.093	0.076	0.071	0.091	0.5
ALT_4	0.061	0.031	0.225	0.045	0.040	0.093	0.076	0.213	0.136	0.333	0
ALT_5	0.020	0.112	0.274	0.053	0.093	0.153	0.071	0.272	1	0	0
ALT_6	0056	0.137	0	0.062	0.076	0.071	0.136	0	0	0	0

Next, calculate each alternative's S and R values using (3) and (4). The results of these calculations are shown in Table 11.

Based on Table 11, the largest and smallest values in S and R can be seen. The most significant value in S is alternative 5 with a score of 2.053, and the smallest score is alternative 1 with a score of 0.123.

Meanwhile, the most significant value in R is alternative five (Alt_5), and the smallest is alternative 1.

Furthermore, from these results, the VIKOR index value is calculated using (5) and (6), the results of which are summarized in Table 12. Based on the calculation results in Table 12, provide information about the alternative ranking value.

Table 11. S and R Values

Alternative	Score S	Score R
ALT_1	0.123	0.123
ALT_2	1	0.137
ALT_3	1.162	0.5
ALT_4	1.257	0.333
ALT_5	2.053	1
ALT_6	0.540	0.137

Table 12. The alternative ranking values

Alternative	Score S
ALT_1	1
ALT_2	0.160
ALT_3	0.406
ALT_4	0.334
ALT_5	0.908
ALT_6	0.048

Furthermore, the best alternative from the results is alternative 6 (Increasing collaboration between stakeholders) with a value of around 0.048, where this value is the smallest value of all existing alternatives.

Based on the calculation results displayed in Table 12, provide information about the alternative ranking value. Furthermore, the best alternative from the results is alternative 6 (Increasing collaboration between stakeholders) with a value of around 0.048, where this value is the smallest value of all existing alternatives.

DISCUSSION

In this study, we combine two methods in determining the biodiesel development strategy by applying the SWOT method and the VIKOR method. In the SWOT method, the selected expert respondents make an assessment related to strengths, weaknesses, opportunities, and threats. Based on the assessment results, it can be seen that the total value of the most significant strength is 3.29, and the total value of threats is 2.58. In addition, the opportunity and weakness values each have a score of around 3.16 and 2.99.

The significant strength factor in biodiesel development is Environmental consciousness, which has a value of 1.52. The significant weakness factor in biodiesel development is high investment costs, which have a value of 1.48. In addition, the significant opportunity factor in biodiesel development is becoming an environmentally friendly energy solution, with a score of 1.32, and the significant threat factor is Weak financial support, with a score of 1.24.

Furthermore, based on the selection of priority alternatives by applying the VIKOR method, it can be seen that alternative 6 (Increased collaboration between stakeholders) is the most significant choice based on expert assessments. Increased collaboration between stakeholders will contribute to reducing high investment costs, which are one of the weaknesses, for example, working with financial institutions to obtain soft loans that do not burden biodiesel producers. In addition, soft loans will also reduce the threat of financial support. Mutually beneficial cooperation between stakeholders has the potential to provide positive value to the development of biodiesel in Indonesia.

The strategy for developing biodiesel production using BSF Maggots will make a significant contribution to achieving sustainable development goals (SDGs) in Indonesia. Several targets in the SDGs that are directly related to the biodiesel development strategy include Goal 7 and Goal 13. Furthermore, through the development of biodiesel using BSF Maggots, it can provide access to contemporary, cost-effective, and sustainable energy sources [58], addressing energy poverty in marginalized areas [59]. In addition, biodiesel development also has the potential to reduce greenhouse gas emissions, which are important in the transition to a low-carbon economy [60]. Through the development of biodiesel using Maggots, it can reduce environmental damage associated with the extraction and consumption of fossil fuels. Based on the analysis using the SWOT and VIKOR methods related to the strategy for developing biodiesel using BSF Maggots, it will also encourage job creation in production, maintenance, and research [61]. Thus, increasing regional economic resilience can be realized [62]. Furthermore, the renewable energy development strategy can be carried out by creating a decentralized system to improve energy security in a disaster-prone area [63].

The approach to developing biodiesel as a renewable energy source has significant consequences for the environment, society, economy, and government policy [64][65]. From an environmental perspective, there are several positive impacts, such as reduced greenhouse gas emissions, where biodiesel generally produces lower levels of carbon dioxide, sulfur dioxide, and particles compared to fossil fuels, thus contributing to climate change mitigation [66][67]. Furthermore, reduced air pollution as biodiesel combustion produces fewer harmful pollutants, such as unburned hydrocarbons and carbon monoxide. In addition, studies conducted by Neupane underline that biodiesel is non-toxic and biodegradable, reducing the potential for environmental pollution in the event of a spill [67]. Meanwhile, several studies have shown resource efficiency by using agricultural by-products and waste oil, thereby reducing the environmental consequences of waste disposal [68, 69, 70, 71].

On the other hand, there are potential disadvantages, for example, changes in land use, where the production of plant-based biodiesel can result in deforestation, habitat destruction, and reduced biodiversity if the raw materials are obtained through unsustainable methods [61] [72]. Furthermore, several studies have reported water and soil pollution caused by the increased use of fertilizers and pesticides for crop cultivation to produce biodiesel, and this can have adverse effects on aquatic ecosystems and reduce soil integrity [73, 74, 64]. In addition to energy input, particular biodiesel production exhibits significant energy requirements, potentially negating environmental benefits [75, 76, 77].

The biodiesel development strategy also has social implications. Various previous studies provide information that the social implications of biodiesel development have the potential to reduce dependence on imported fossil fuels [78][79]. Thus, reducing this dependence will encourage energy independence and stability in a country [80][81]. Furthermore, biodiesel development has the potential to create jobs, increase community income, and change the local economy [82][83]. In addition, the diversion of food crops such as soybeans and corn to produce biodiesel has the potential to worsen food insecurity by increasing prices and reducing the availability of food reserves [84][85]. Socially, biodiesel development can also improve air quality by reducing emissions and resulting in better public health [86, 87, 88].

Economically, biodiesel development will have implications for energy portfolio diversification and stimulate the growth of green industries [89][90]. Furthermore, the biodiesel supply chain from agriculture to production and distribution can create jobs [91]. In addition, the demand for biodiesel feedstock can increase commodity prices that benefit farmers, but potentially burden consumers [92]. Studies show that raw material price volatility and competition with fossil fuels can drive risks for biodiesel producers from an economic perspective [93][94]. In addition, the biodiesel sector can attract investment in research, infrastructure, and technology development [95].

The development of biodiesel based on BSF Maggots also has implications for government policy. The government must provide subsidies and tax incentives to encourage biodiesel production and consumption [96]. In addition, policies such as blending mandates, carbon pricing, and emission regulations will encourage people to make an energy transition to biodiesel [97]. Furthermore, the government should balance biodiesel production with sustainable land use and allocate natural resources to minimize environmental damage [98][99]. In addition, biodiesel development will impact trade policy, considering that countries can conduct transactions to buy and sell BSF Maggot raw materials or biodiesel products [90]. The study by van Tol et al. confirms that investment in advanced biodiesel technology is one of the key areas in the efficiency and sustainability of renewable energy programs [100].

CONCLUSION

This article aims to develop a strategy for developing BSF Maggot oil-based biodiesel as a sustainable, renewable alternative energy source. The hybrid SWOT and VIKOR methods are applied to identify significant factors and develop a strategy for developing BSF Maggot oil-based biodiesel in Indonesia for renewable energy. This method involves the analysis of strengths, weaknesses, opportunities, and threats. Environmental awareness is a critical component in biodiesel development, with a value of 1.52. A significant weakness in biodiesel production is the high investment cost, quantified at 1.48. A significant opportunity in biodiesel development is its potential as an environmentally friendly, sustainable energy alternative, with a score of 1.32, while a significant threat is inadequate financial assistance, with a score of 1.24. In addition, applying the VIKOR approach reveals that alternative 6 (Enhancing collaboration among stakeholders) is the most important option, as indicated by expert evaluation with a value of 0.048. Based on the results of this research, future research can be improved to complete our understanding of the potential of BSF Maggots as one of the sources of raw materials for making biodiesel in Indonesia. Some suggestions that can be used as a basis for future research should build a sustainable biodiesel development model, where this model considers the production capacity of Maggot oil, which will be the raw material for biodiesel. In addition, the built model also considers uncertainty factors, especially those related to the implications of developing biodiesel based on BSF Maggots in Indonesia.

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