Formosa Journal of Science and Technology (FJST)
Vol. 5, No. 1, 2026: 65-80

Examining Decision Making Practices in Biodiesel Production Processes within Emerging Renewable Energy Industries

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A R T I C L E I N F O

Keywords: Biodiesel Production, Decision-Making Practices, Renewable Energy Industry, Production Process, Sustainability.

Received : 27, November
Revised : 29, December
Accepted: 30, January

A B S T R A C T

The biodiesel industry faces production decision-making challenges driven by technological constraints, regulatory dynamics, and market uncertainty. This qualitative case study examines strategic and operational decision-making in a medium-scale biodiesel plant in Indonesia, focusing on raw material selection, production processes, efficiency, sustainability standards, and risk management. Data were collected through in-depth interviews with six key informants and document analysis, and analyzed thematically. The findings show that biodiesel production decisions are adaptive and multidimensional, influenced by technical, economic, regulatory, sustainability, and market considerations, with professional experience playing a key role under information constraints. The study highlights the importance of an integrated decision-making framework to enhance performance, sustainability, and competitiveness in the biodiesel industry, and provides managerial and policy-relevant insights for the renewable energy sector.

ISSN-E: 2964-6804
DOI: https://doi.org/10.55927/fjst.v5i1.385
https://traformosapublisher.org/index.php/fjst

INTRODUCTION

The global transition to low-carbon energy is driving the increasing role of biodiesel as one of the strategic renewable energy sources, especially in developing countries that are still dependent on fossil fuels. Biodiesel is seen as able to reduce greenhouse gas emissions, increase energy security, and create economic added value from local resources (International Energy Agency, 2023). However, the development of the biodiesel industry globally still faces structural challenges in the form of volatility in raw material prices, limitations in process technology, and long-term energy policy uncertainty (Cherubini et al., 2021). This condition places production decision-making practices as a key factor that determines the sustainability and competitiveness of the biodiesel industry.

In the context of developing countries, the complexity of decision-making in biodiesel production is increasing due to limited industrial infrastructure, dependence on technology imports, and frequently changing regulatory dynamics. Studies show that decisions related to raw material selection, process configuration, and production scale are often made under conditions of incomplete information and high economic pressures (Balat & Ayar, 2020). In Indonesia, as one of the largest producers of palm oil-based biodiesel, these challenges are reinforced by global sustainability demands and domestic policies such as mandatory biodiesel (B30–B35) that affect the industry's decision-making structure (Purwanto et al., 2022). Therefore, an in-depth understanding of how biodiesel production decisions are made is becoming an increasingly relevant issue academically and practically.

Previous literature on biodiesel has generally focused on technical and economic aspects, such as conversion efficiency, life cycle analysis, and production cost feasibility (Aghbashlo et al., 2021; Khoo et al., 2020). Although these studies make important contributions, the approaches used tend to be quantitative and normative, assuming technical rationality as the main basis for decision-making. As a result, the social, organizational, and contextual dimensions of decision-making practices at the industry level are relatively underexplored. This gap shows that the decision-making process in biodiesel production has not yet been fully understood as a complex and multidimensional managerial phenomenon.

Some recent research has begun to recognize the importance of non-technical factors in renewable energy industry decision-making, such as managerial experience, regulatory pressures, and market risk perceptions (Bui et al., 2022; Zhang & Chen, 2023). However, most of these studies still use survey approaches or decision modeling that are less able to capture the dynamics of the decision process in depth. In addition, the context of the biodiesel industry in developing countries is still underrepresented in the international literature, which is dominated by studies in developed countries. This creates a research gap related to an empirical understanding of how biodiesel industry actors in developing countries navigate the complexity of production decisions in real practice.

Based on these gaps, this study aims to analyze and explorate strategic and operational decision-making practices in the biodiesel production process in

the emerging renewable energy industry. This study specifically examines how industrial actors consider technical, economic, regulatory, and sustainability aspects in determining production choices. Using a qualitative approach based on case studies, this study seeks to describe the patterns, mechanisms, and contextual factors that shape biodiesel production decisions. This goal is designed to complement the limitations of the quantitative approach that has dominated biodiesel studies.

Theoretically, this research contributes to the development of the decision-making literature in the renewable energy industry by presenting contextual and actor-centric perspectives. The findings of this study expand the understanding of how production decisions are shaped by the interaction between organizational structure, external pressures, and individual professional judgment, as presented in context-based decision theory and bounded rationality (Gigerenzer & Gaissmaier, 2020). In addition, this study enriches the study of case studies in renewable energy with empirical evidence from developing countries. Thus, this research fills a conceptual gap between decision-making theory and biodiesel industry practice.

Practically, the results of this research are expected to be the basis for biodiesel industry managers in designing a more integrated and adaptive production decision-making framework. The findings of this study are also relevant for policymakers in formulating regulations that are more in line with the operational reality of the biodiesel industry (Yao et al., 2024). In addition, this research provides implications for the development of the human resource capacity of the renewable energy industry through strengthening decision-making competencies. Thus, this research not only contributes to the development of science, but also to the improvement of the sustainability and competitiveness of the biodiesel industry.

THEORETICAL REVIEW

Biodiesel Production within Emerging Renewable Energy Industries

Biodiesel is one of the fastest-growing forms of renewable energy in response to the global energy crisis and carbon emission reduction commitments. Research shows that biodiesel has significant potential in supporting the energy transition, especially in developing countries that have abundant availability of biomass feedstocks (Demirbas, 2021). However, the biodiesel industry in emerging markets regions faces structural challenges in the form of technological limitations, fluctuations in raw material prices, and dependence on government policies (Kumar et al., 2022). This condition makes the biodiesel production process not only a technical activity, but also an arena for complex strategic decision-making.

In the context of the growing renewable energy industry, biodiesel production is often at the crossroads between the demands of economic efficiency and compliance with sustainability standards. The study by Atabani et al. (2021) confirms that biodiesel production decisions are heavily influenced by external factors such as environmental regulations and global energy market dynamics. This suggests that biodiesel production practices cannot be partially

understood, but rather must be analyzed within the framework of a broader industrial system. Therefore, the literature emphasizes the importance of a multidimensional approach in reviewing the biodiesel industry.

Decision-Making Practices in Industrial Production Systems

Decision-making in industrial production systems is a process that involves interaction between actors, information, and organizational contexts. Modern decision-making theory emphasizes that industrial decisions are rarely completely rational, but rather shaped by information limitations, time pressures, and the experience of decision-making actors (Elbanna & Fadol, 2020). In a dynamic industrial environment, decisions are often adaptive and based on continuous learning. This is relevant to the biodiesel industry which operates in conditions of technological and market uncertainty.

Empirical research in the manufacturing sector shows that operational and strategic decisions are influenced by a combination of technical, economic, and institutional considerations (Rialti et al., 2021). The study confirms that the role of managers and engineers is not only as technical implementers, but also as strategic actors in interpreting risks and opportunities. In the context of renewable energy, production decisions often involve trade-offs between short-term efficiency and long-term sustainability. Therefore, decision-making practices are a central aspect in understanding the performance of the biodiesel industry.

Technical and Economic Considerations in Biodiesel Production Decisions

Technical and economic aspects are the dominant factors in biodiesel production decisions, especially related to the selection of raw materials, conversion technology, and production scale. Studies show that variations in the quality of biodiesel feedstocks can significantly affect process efficiency and production costs (Mardhiah et al., 2020). In addition, the selection of production technology is often determined by the availability of capital and the level of technological maturity in each country. This causes differences in biodiesel production practices between developed and developing countries.

From an economic perspective, biodiesel production decisions are greatly influenced by fossil oil prices, government incentives, and operational costs (Sajid et al., 2021). The instability of these factors prompted the biodiesel industry to adopt flexible production strategies. Research also shows that energy efficiency is a major consideration in maintaining the competitiveness of biodiesel in the energy market (Islam et al., 2022). Thus, biodiesel production decisions are the result of a complex interaction between technical parameters and economic calculations.

Regulatory, Sustainability, and Risk Dimensions in Decision Making

Energy regulation and sustainability demands play a crucial role in shaping decision-making practices in the biodiesel industry. Mandatory biodiesel policies, emission standards, and sustainability certification are external factors that must be considered in every production decision (Scarlat et al., 2022). Studies show that regulatory uncertainty can increase investment risks

and affect the operational stability of the biodiesel industry. Therefore, industry actors often integrate policy considerations into their production strategies.

In addition to regulation, market and environmental risk management is also an important dimension in biodiesel decision-making. Research by Fang et al. (2023) shows that the volatility of biodiesel demand and prices encourages companies to rely on professional experience and managerial intuition. Under these conditions, decisions are based not only on quantitative data, but also on the subjective assessment of key actors. This confirms that biodiesel decision-making practices are contextual and highly influenced by external conditions.

Research Gap and Conceptual Positioning of the Study

Although the literature on biodiesel and industrial decision-making has evolved, most research still focuses on technical aspects and quantitative modeling. Such approaches tend to ignore the dynamics of the decision-making process that takes place at the organizational and individual levels (Hansson et al., 2021). In addition, empirical studies that explore the experience of biodiesel industry actors in developing countries are still limited. This gap shows the need for a qualitative approach to understand decision-making practices more deeply.

This study positions itself to fill this gap by exploring the decision-making practices of biodiesel production through qualitative case studies. By emphasizing the perspectives of the actors and the context of the evolving renewable energy industry, this study complements the existing literature and enriches the understanding of the dynamics of biodiesel production decisions. This approach is expected to be able to bridge the gap between technical analysis and managerial realities in the biodiesel industry.

METHODOLOGY

Types and Approaches to Research

This study uses a qualitative approach with an exploratory case study design to examine in depth decision-making practices in the biodiesel production process in the emerging renewable energy industry. The qualitative approach was chosen because the purpose of this study is not to test causal relationships or measure variables statistically, but rather to understand the processes, considerations, and decision dynamics formed by organizational actors in the real context of the biodiesel industry (Creswell & Poth, 2021). The design of the case study allows for a holistic exploration of the phenomenon by considering the linkages between technical, economic, regulatory, and sustainability aspects in a single clearly defined unit of analysis (Yin, 2024).

Research Location and Case Study Context

This research was carried out at a medium-scale biodiesel plant in Indonesia that is actively operating within the framework of the national renewable energy policy. The selection of the location was purposively carried out by considering several criteria, namely: (1) the plant has been operating commercially for at least five years, (2) using raw materials based on domestic resources, (3) being bound by mandatory national biodiesel regulations, and (4)

facing market dynamics and sustainability pressures. These characteristics make the research location relevant as a representation of the biodiesel industry in developing countries. The literature shows that organizational context and the institutional environment have a significant influence on decision-making practices in the renewable energy industry (Köhler et al., 2022).

Population, Research Informants, and Sampling Techniques

The research population includes all organizational actors involved in the decision-making process of biodiesel production in the plants studied. The sampling technique used is non-probability sampling with a purposive sampling strategy, which is the selection of informants based on the criteria of direct involvement, experience, and authority in production decision-making.

This study involved six key informants, which were considered adequate for qualitative case study research because it met the principle of data saturation, which is a condition when the information obtained has been repeated and does not produce a substantive new theme (Guest et al., 2020). The details of the informants are as follows:

One Production Manager

Responsible for the planning, control, and evaluation of the overall biodiesel production process, including decision-making related to production capacity and process efficiency.

One Process Engineer

Plays a role in making technical decisions related to process configuration, technology selection, quality control, and production process adjustment to technical limitations.

One Operations Manager

Responsible for coordinating the daily operations of the plant and taking short-term operational decisions in conditions of raw material supply uncertainty and demand fluctuations.

One Regulatory Compliance and Sustainability Staff

Have a role in ensuring production decisions are aligned with renewable energy regulations, environmental standards, and national and international sustainability requirements.

One Enterprise-Level Strategic Decision Maker

Involved in determining the strategic direction of biodiesel production, including investment decisions, raw material diversification, and response to government policies.

One Senior Production Supervisor

Have hands-on operational experience and act as a liaison between managerial decisions and technical implementation at the field level.

This combination of informants is designed to capture the perspective of decisions from different levels of the organization, thus enabling comprehensive and multidimensional analysis.

Data Collection Techniques and Instruments

Data collection was carried out through semi-structured in-depth interviews and document analysis. Semi-structured interviews are used to delve into the informant's experiences, considerations, and decision-making logic in detail in the context of biodiesel production. The interview guide was compiled based on a conceptual framework of industrial decision-making and energy sustainability developed from the cutting-edge literature (Knaflic & Norton, 2023). Each interview lasts between 60–90 minutes and is recorded with the informant's consent.

The document analysis includes standard operational production procedures, production performance reports, internal policy documents, as well as renewable energy regulations and national biodiesel policies. The combination of interviews and documents allows for triangulation of data to reinforce the validity of findings.

Research Implementation Procedure

The research is carried out through systematic stages, starting from the literature study and the preparation of a conceptual framework, followed by the determination of the location and informants of the research. The data collection stage is carried out after obtaining ethical consent and informed consent from all informants. All interviews are transcribed verbatim to maintain data accuracy. The next stage is data analysis, interpretation of findings, and preparation of research reports. This procedure follows the methodological practice of qualitative research in the study of organization and energy (Saldaña & Omasta, 2024).

Data Analysis Techniques

Data was analyzed using thematic analysis with stages of open coding, code grouping, identification of main themes, and conceptual interpretation of findings. The analysis was carried out iteratively to capture the dynamics of biodiesel production decision-making. NVivo software is used to support data management, improve coding consistency, and maintain analysis transparency (Braun & Clarke, 2021). To improve the clarity of the analytical process, the stages of data analysis are also summarized in a schematic form as presented in Figure 1.

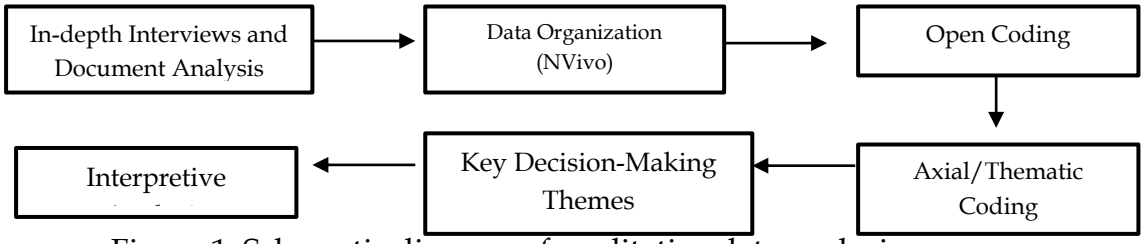

Figure 1. Schematic diagram of qualitative data analysis process

Data Validity and Research Ethics

The validity of the data is maintained through source triangulation, member checking, and the implementation of trail audits. The ethical aspect of research is maintained by ensuring the confidentiality of informant identities, the use of data for academic purposes, and compliance with ethical research principles. This approach is in line with the principle of trustworthiness in contemporary qualitative research (Tracy, 2020).

RESEARCH RESULTS

Adaptivity of Production Decisions in Technical and Operational Limitations

The results of the study show that decision-making in the biodiesel production process is adaptive and situational, especially in responding to technical limitations and daily operational dynamics. Production actors do not rely entirely on standard operating procedures (SOPs), but rather make decision adjustments based on actual conditions in the field, such as variations in raw material quality, equipment performance, and unexpected operational disruptions. This adaptivity serves as the main mechanism to maintain the stability and continuity of the production process in the midst of technological and resource limitations.

Decision flexibility is seen as a practical necessity in plant operations, especially when production conditions do not match the initial planning assumptions: "*We can't always run the process according to the book. When the quality of raw materials changes, decisions must be adjusted immediately so that production continues and does not stop,*" (MP-01, October 12, 2025 interview). This view is reinforced by another informant who explains that technical adaptation is an inherent part of day-to-day decision-making at biodiesel production facilities: "*Technically, there are many adjustments that must be made in the field. Under certain conditions, the process configuration must be changed so that the quality of biodiesel remains to meet the standards,*" (IP-01, interview October 14, 2025). From the operational side, adaptive decisions have also emerged in response to time pressures and raw material supply uncertainty: "*If the supply of raw materials is late or the volume drops, we have to immediately rearrange the schedule and production capacity. Can't wait too long for a decision,*" (MO-01, October 15, 2025 interview).

These findings show that adaptivity is a structural character of biodiesel production decision-making. Decisions develop dynamically and contextually by integrating the technical, operational, and practical considerations of key actors in dealing with the limitations of production systems.

Dominance of Economic Efficiency Considerations in Production Decisions

Cost efficiency and energy use emerged as dominant considerations in almost all biodiesel production decisions. The high cost pressures of production and relatively limited profit margins encourage management to continuously evaluate production options. In this context, technical and operational decisions are geared towards minimizing costs without sacrificing the quality of the final product.

Economic considerations are perceived as the endpoint of almost every production decision: "*Every decision must end in costs. If it is not efficient, the factory*

can suffer losses even though production is still running," (PK-01, interview October 18, 2025). Economic efficiency is also the main basis in determining daily production capacity: "*We always recalculate whether it is better to have full production or downgraded. The decision was very dependent on the cost of energy and the price of raw materials at that time,*" (MP-01, October 12, 2025 interview). At the implementation level, economic decisions are felt directly in technical practices on the ground: "*Sometimes we have to save energy or chemicals. It was a decision from the management, but we immediately felt the implementation in the production process,*" (SP-01, interview October 20, 2025).

These findings show that economic efficiency is integrated across organizational levels and is a key dimension that connects strategic and operational decisions in maintaining the financial sustainability of the biodiesel industry.

Regulatory Pressure as a Limiting Framework and Decision Direction

The results of the study show that renewable energy regulations and national biodiesel policies function as a limiting framework as well as a guide in production decision-making. Decisions not only consider technical and economic feasibility, but must also be aligned with the ever-evolving demands of regulatory compliance.

The risk of non-compliance is seen as a crucial factor in every production decision: "*Every production decision must be seen from the regulatory side. If it is not suitable, the risk is quite large for the company,*" (KR-01, interview October 21, 2025). Changes in government policies also have a direct impact on medium- and long-term decisions: "*Changes in the mandatory biodiesel policy directly affect investment decisions and the determination of production capacity,*" (PK-01, interview October 18, 2025). From a technical perspective, regulations affect operational procedures in the field: "*Environmental standards are getting stricter, so the production process must be adjusted. Sometimes it adds complexity and cost,*" (IP-01, interview October 14, 2025). These findings confirm that regulation serves as a structural factor that shapes the limits, directions, and consequences of biodiesel production decisions.

Integration of Sustainability Demands in Production Decision Practices

Environmental sustainability is emerging as an increasingly integrated consideration in biodiesel production decision-making practices. The sustainability aspect is no longer positioned as an additional element, but rather a core part of the selection of processes, technologies, and production arrangements.

Decision orientation indicates a shift towards a stronger attention to environmental impact: "*Now the decision can not only be about production and cost, but also the impact on the environment,*" (KR-01, interview October 21, 2025). Sustainability demands also affect the management of daily production processes: "*We have to make sure waste and emissions remain up to standard, even if it makes the production process more complex,*" (MO-01, October 15, 2025 interview). At a strategic level, sustainability is seen as a long-term competitive factor: "*If sustainability is neglected, in the future the biodiesel industry can lose market and trust,*"

(PK-01, interview October 18, 2025). These findings suggest that sustainability serves as a normative and strategic dimension that influences technical, operational, and investment decisions.

The Central Role of Professional Experience in Conditions of Uncertainty

In conditions of limited information and market uncertainty, the professional experience of key actors plays a central role in biodiesel production decision-making. Not all decisions can be based entirely on formal data, so intuition and field experience are important sources of consideration.

Experience is seen as crucial in quick decision-making: "*Data is sometimes incomplete, so experience helps to make decisions quickly,*" (MP-01, October 12, 2025 interview). Field experience helps translate managerial decisions into operational practice: "*We already know from experience, under certain conditions, how should it be. It is not always written in the SOP,*" (SP-01, interview October 20, 2025). Continuous learning is also the basis for technical decisions in unexpected situations: "*Many technical decisions are made based on previous experience, especially when faced with unexpected problems,*" (IP-01, interview October 14, 2025).

These findings confirm that biodiesel production decision-making is **adaptive and multidimensional**, influenced by a combination of technical considerations, economic efficiency, regulatory pressures, sustainability demands, and market risks, with professional experience playing an important role in conditions of information limitations.

DISCUSSION

The results show that biodiesel production decision-making is adaptive and multidimensional, influenced by the interaction between technical, economic, regulatory, sustainability, and market risk considerations. These findings are in line with the adaptive decision-making approach in operations management theory, which emphasizes that production decisions in complex systems cannot be fully standardized, but rather must be adapted to the dynamics of the organization's internal and external environment (Bertsimas & Kallus, 2020). In the context of the renewable energy industry, adaptivity is key due to the uncertainty of raw material supply, technological variability, and fluctuations in market demand. Thus, the results of this study reinforce the view that biodiesel production decision-making is not linear, but contextual and situational, as also shown in a study of the global bioenergy industry by Demirbas (2021).

The dominance of technical considerations and economic efficiency in biodiesel production decisions shows the strong economic rationality in industrial operational practices. These findings are in line with the theory of cost-efficiency driven operations, which states that in industries with limited profit margins, energy efficiency and cost are the main parameters in decision-making (Zhang et al., 2023). Previous empirical studies have also shown that decisions related to production capacity, technology selection, and process regulation in the biodiesel industry are greatly influenced by the calculation of energy and raw material costs (Sánchez-Bastardo et al., 2022). Consequently, although biodiesel is promoted as an environmentally friendly energy, its production practices

remain within the framework of strict economic rationality. The results of this study enrich the literature by showing how economic efficiency not only influences strategic decisions, but also permeates the daily operational level.

The findings on the role of regulation as a limiting framework and direction of decisions reinforce the argument in institutional governance theory, which states that public policies shape organizational behavior through incentive and sanction mechanisms (Scarlat et al., 2022). In the biodiesel industry, mandatory regulations, quality standards, and environmental provisions not only limit the space of movement of production actors, but also direct investment decisions and production capacity. International research shows that changes in biofuel policies in various countries directly affect production decisions and industrial sustainability (International Energy Agency, 2023). Thus, the results of this study confirm that biodiesel production decisions cannot be understood in isolation from the context of national and global energy policies.

The integration of sustainability demands in biodiesel production decisions shows a paradigm shift from a mere production orientation to a sustainability-oriented operations approach. These findings are consistent with research emphasizing that environmental sustainability has become a strategic factor in the renewable energy industry, not just a normative obligation (Kumar et al., 2021). Decisions related to waste management, emissions, and clean technology are now considered along with cost and productivity aspects. Consequently, sustainability serves as a source of social legitimacy and long-term competitiveness for the biodiesel industry. The results of this research contribute to the development of science by showing how sustainability is internalized in the practice of production decisions, not just at the level of policy or strategic discourse.

The central role of professional experience in production decision-making reinforces the theory of bounded rationality, which states that the limitations of information encourage actors to rely on heuristics and prior experience (Gigerenzer, 2021). In conditions of market and technical uncertainty, field experience serves as a source of practical knowledge that complements formal data. Previous research has also shown that in high-risk industries, experience-based decisions are often more responsive than decisions that rely entirely on quantitative models (March & Sutton, 2022). These findings provide a broader understanding that professionalism and continuous learning are strategic assets in maintaining the stability of biodiesel production.

The findings suggest that the role of professional experience is more dominant. This difference can be explained by the high operational uncertainty and limitations of data-driven decision support systems at the factory level, as also reported in emerging energy industry studies (Alizada et al., 2024). Another supporting factor is the ever-increasing regulatory complexity and sustainability demands, which encourage production actors to rely on contextual assessments rather than standard procedures alone.

Although it makes a strong conceptual contribution, the study has limitations, especially in the scope of the research location and the relatively limited number of informants, so the generalization of the findings needs to be

done carefully. In addition, this study has not integrated quantitative production data that can strengthen the qualitative analysis. Therefore, follow-up research is recommended to use a mixed methods approach, involving more biodiesel production facilities, as well as combining in-depth interviews with analysis of operational and economic data. This approach is expected to expand understanding of the decision-making mechanism of biodiesel production in the context of the global energy transition.

CONCLUSION AND RECOMMENDATION

This study concludes that decision-making practices in the biodiesel production process in the emerging renewable energy industry are adaptive and multidimensional, and are shaped by the complex interaction between technical considerations, economic efficiency, regulatory pressures, sustainability demands, and market risks. In the context of technological limitations and the uncertainty of the operational environment, the professional experience of key actors plays an important role as a basis for situational and reflective decision-making, complementing the limitations of formal data and standard procedures. These findings confirm that biodiesel production decisions cannot be partially understood, but rather require an integrated decision-making framework between strategic and operational aspects. Thus, this research makes a conceptual contribution to the development of decision-making studies in the renewable energy industry as well as practical implications for management and policymakers in improving the performance, sustainability, and competitiveness of the biodiesel industry.

FURTHER STUDY

Future research is encouraged to develop a more formalized decision-support framework that integrates experiential knowledge with quantitative data analysis, such as multi-criteria decision-making (MCDM), system dynamics, or scenario-based modeling, to reduce subjectivity in biodiesel production decisions. Further studies may also examine how digital technologies, such as real-time monitoring systems and artificial intelligence, can complement managerial experience in improving decision accuracy under uncertainty. In addition, comparative research across different regions, regulatory regimes, or renewable energy subsectors would provide broader insights into how institutional contexts influence adaptive decision-making practices. Such studies would strengthen the generalizability of the findings and support the formulation of more resilient and sustainable decision-making models in the renewable energy industry.

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