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NAVIGATING MANDATORY BIODIESEL POLICY: A QUALITATIVE ANALYSIS OF THE DYNAMICS OF CATALYST RESEARCH, FEEDSTOCK DIVERSIFICATION, AND INDUSTRY RESPONSES IN INDONESIA'S ENERGY TRANSITION

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Abstract

This study analyzes the implementation of the mandatory biodiesel policy in Indonesia, focusing on the dynamics of catalyst research, feedstock diversification, and industry responses in the context of the national energy transition. The mandatory policy, which began with B10 in 2016 and increased to B35 in 2023, aims to reduce dependence on fossil fuels by utilizing the potential of palm oil as the world's largest producer. Using a qualitative approach with a case study design, the research was conducted in four provinces: West Java, East Java, North Sumatra, and Riau over eight months, involving 35 informants from researchers, policymakers, and industry players. Data were collected through in-depth interviews, field observations, and documentation studies, analyzed using thematic analysis methods. The results show that biodiesel catalyst research has made significant progress in utilizing local materials such as rice husk ash and eggshells, but faces a large gap between laboratory success and industrial implementation due to minimal collaboration and funding for applied research. Feedstock diversification is still hampered by the dominance of palm oil, which reaches 95 percent, while alternatives such as castor oil, animal fats, and microalgae are not yet economically competitive. The industry's response to the mandatory policy is polarized, with large, vertically integrated companies able to adapt through technology investment and capacity expansion, while small and medium-sized producers face structural constraints such as limited capital, access to raw materials, and weak bargaining power. The misalignment between ambitious policy targets, limited technological readiness, and uneven industrial capacity creates an implementation gap that hinders the achievement of a sustainable energy transition. The study recommends establishing a research-industry collaboration platform, strengthening feedstock diversification policies, empowering small and medium-sized producers, conducting public education campaigns, and cross-ministerial coordination through a dedicated energy transition agency to develop a realistic and coordinated long-term roadmap.

*Keywords:**mandatory biodiesel policy, diversification of raw materials, energy transition***

INTRODUCTION

Indonesia faces significant challenges in meeting its growing energy needs, driven by rapid economic and population growth. Dependence on dwindling fossil fuels and volatile global oil prices have prompted the government to seek alternative, more sustainable and environmentally friendly energy sources. Repeated global energy crises over the past few decades have demonstrated the vulnerability of national energy security when relying solely on non-renewable resources. Fluctuating oil prices on the international market not only burden the state budget for fuel subsidies but also create economic uncertainty that hampers long-term development planning. This situation forces Indonesia to immediately diversify its energy sources by utilizing abundant local potential. Biodiesel is a strategic choice because Indonesia has abundant natural resources, particularly palm oil, the primary raw material. As the world's largest palm oil producer, Indonesia has a comparative advantage in developing a biodiesel industry that can

reduce dependence on fuel imports. Millions of hectares of highly productive oil palm plantations guarantee a stable supply of raw materials for the national biodiesel industry. Biodiesel development not only contributes to energy security but also opens up new economic opportunities for palm oil farmers and creates jobs in the processing industry. The added value generated from processing palm oil into biodiesel can increase state revenue and strengthen the competitiveness of the national industry in the global market.(Mayr et al., 2021). The Indonesian government has implemented a mandatory biodiesel policy, starting with the B10 program in 2016 and gradually increasing to B35 in 2023. This policy requires biodiesel to be blended into diesel fuel at a certain percentage, with the number after the letter B indicating the percentage of biodiesel in the blend. This program is supported by funding from the Indonesian Palm Oil Plantation Fund Management Agency (BPPK) to maintain competitive biodiesel prices compared to conventional diesel. This funding mechanism is crucial to addressing the price disparity between biodiesel and fossil fuels, ensuring that the mandatory policy can be implemented without burdening end consumers. However, the implementation of this policy faces various obstacles, ranging from technical issues and distribution to the availability of adequate raw materials. The challenge of unequal distribution infrastructure across Indonesia is a barrier to ensuring the supply of quality biodiesel to end consumers. The development of catalyst technology is key to efficient and economical biodiesel production. Catalyst research in Indonesia continues to develop to find materials that are cheaper and more environmentally friendly than conventional catalysts, which generally use imported chemicals. Various researchers are exploring catalysts made from local materials such as rice husk ash, eggshells, and natural zeolites as alternatives to conventional chemical catalysts. The development of these catalysts aims to lower production costs and improve the quality of the resulting biodiesel, enabling it to compete with biodiesel products from other countries. Utilizing agricultural and livestock waste as catalyst feedstock also provides added economic value and alleviates waste management issues. However, there remains a gap between laboratory research results and their application in large-scale industry, particularly regarding catalyst stability, ease of regeneration, and efficiency in continuous operation.(Papilo et al., 2022).

Diversification of biodiesel feedstock is a crucial issue to reduce dependence on palm oil, which currently dominates production. The dominant use of palm oil raises concerns about environmental sustainability and competition with food and other oleochemical industries. Various alternative feedstocks are being explored, such as castor oil, nyamplung oil, animal fat, and used cooking oil, which have significant potential but are not yet optimally utilized. The development of biodiesel from microalgae also shows significant potential because it does not require agricultural land and has high productivity per unit area. Microalgae can be cultivated on marginal land or even in marine waters, thus not competing with food production. However, the development of this alternative feedstock source still faces technical and economic barriers that need to be overcome. High production costs and the lack of a structured cultivation and collection system are major obstacles to the commercialization of alternative feedstocks. Industry responses to the mandatory biodiesel policy have varied depending on the scale and capacity of each business actor. Large companies with integrated plantations and biodiesel plants can easily meet market demand because they have full control over the supply chain. Meanwhile, small and medium-sized producers face challenges in terms of capital, technology, and market access, limiting their ability to compete. Biodiesel users, such as vehicle operators and industrial users, have also shown varying responses, with some welcoming it while others remain skeptical about its quality and impact on engines. This situation highlights challenges in policy implementation that require a deeper understanding to formulate a more inclusive and effective strategy.(Banurea et al., 2025).

Biodiesel research in Indonesia has tended to be fragmented across technical, policy, and economic aspects, lacking comprehensive integration. Few studies have comprehensively examined how mandatory policies interact with catalyst research developments, feedstock diversification efforts, and industry responses within a complex system. This research is crucial for understanding the dynamics of Indonesia's energy transition and providing input for improving policies and strategies for more effective and sustainable biodiesel development. This holistic approach, integrating multiple dimensions, is expected to uncover bottlenecks in policy implementation and provide practical recommendations to accelerate the national energy transition toward sustainability. The mandatory biodiesel policy in Indonesia involves various interrelated aspects ranging from government regulations, technological developments, raw material availability, to the responses of industry players. The questions that need to be answered are how this policy influences and is influenced by the development of catalyst research, efforts to diversify raw materials, and how industry responds to this policy. Specifically, this study will answer the following questions: (1) How has biodiesel catalyst research developed in Indonesia and what are the obstacles to its application in industry? (2) How have efforts to diversify biodiesel raw materials been carried out and what challenges have been faced? (3) How have various industry players responded to the mandatory biodiesel policy? (4) How do these three aspects

interact to support the energy transition in Indonesia? This study aims to analyze in depth the implementation of the mandatory biodiesel policy in Indonesia, focusing on three main aspects: catalyst research, feedstock diversification, and industry response. The specific objectives of the study are to identify the development of biodiesel catalyst research and the factors influencing its application in industry, as well as to examine efforts to diversify biodiesel feedstock, along with their opportunities and challenges. Furthermore, this study also aims to analyze various responses from industry players to the mandatory policy and identify the factors influencing these responses. By understanding the interaction between these three aspects, this study is expected to provide a comprehensive picture of the dynamics of the biodiesel-based energy transition in Indonesia and formulate recommendations for policy improvement. This research is expected to make a significant contribution to the development of knowledge on the energy transition in Indonesia. The results can enrich the literature on renewable energy policy implementation in developing countries by providing a comprehensive analysis from various perspectives. The qualitative approach used will provide a deeper understanding of the dynamics occurring on the ground. Practically, this research is useful for the government in evaluating and improving the mandatory biodiesel policy to make it more effective. For researchers and technology developers, the results can serve as a guide for directing research that aligns with industry needs. For industry players, this research can provide lessons on effective adaptation strategies. Overall, this research supports Indonesia's efforts to achieve its energy transition targets and reduce greenhouse gas emissions.

LITERATURE REVIEW

Mandatory Biodiesel Policy in Indonesia

The mandatory biodiesel policy is a government regulation requiring the blending of biodiesel into diesel fuel. Indonesia implemented this policy starting with the B10 program in 2016 and has since expanded to B35. This policy aims to reduce dependence on fossil fuels and utilize local natural resources. The government provides financial support through the Palm Oil Plantation Fund Management Agency to maintain competitive biodiesel prices in the market. Implementation of this policy faces various challenges on the ground. Frequently encountered issues include limited distribution infrastructure, inconsistent biodiesel quality, and fluctuating feedstock availability. Furthermore, there is a gap between established blending targets and actual implementation. Experience from other countries such as Brazil and Malaysia demonstrates that the success of mandatory policies requires a robust monitoring system and sustained financial support.(Silalahi et al., 2020b).

Development of Biodiesel Catalyst Technology

A catalyst is a material that accelerates the reaction of biodiesel production from vegetable oil. Biodiesel catalyst research in Indonesia is progressing rapidly, with a focus on the use of inexpensive and environmentally friendly local materials. Some materials being studied include rice husk ash, eggshells, and shellfish shells containing calcium oxide. The use of catalysts from these local materials can reduce production costs and add value to agricultural waste. However, there is still a gap between laboratory research and industrial application. Catalysts that are successful on a small scale may not be effective on a large scale due to issues of stability and production costs. Industry requires catalysts that are not only effective but also reusable and easily separated from the final product. Collaboration between researchers and industry is crucial to accelerate the application of catalyst research findings in commercial production.(Paminto et al., 2022).

Diversification of Biodiesel Raw Materials

Currently, palm oil is the primary raw material for biodiesel in Indonesia. This reliance on a single raw material poses risks due to unstable prices and environmental concerns. Therefore, diversification of raw materials is crucial for sustainable biodiesel production. Several alternatives being developed include castor oil, nyamplung oil, animal fats, and used cooking oil from households and restaurants. Biodiesel from microalgae also shows great potential for the future. Microalgae can produce more oil than land-based crops and does not require agricultural land. Another advantage is that microalgae can absorb carbon dioxide, helping reduce greenhouse gas emissions. However, the technology for producing biodiesel from microalgae is still expensive and requires further research to make it economically viable. The government needs to provide support for the development of this alternative raw material.(Hanif et al., 2025).

Industry Response to Mandatory Policies

The biodiesel industry has shown mixed responses to the mandatory policy. Large companies with their own plantations and factories can easily meet market demand because they possess adequate capital and technology. They invest heavily in factory construction and supporting infrastructure. The market certainty afforded by the mandatory policy makes long-term investment more attractive for large companies. Conversely, small and medium-sized producers face numerous challenges. They have limited capital to expand production capacity and struggle to meet established quality standards. Their weak bargaining position makes it difficult for them to compete with larger companies. Consumers, such as vehicle operators and the transportation industry, remain skeptical about the quality of biodiesel and its impact on engines. Public awareness and education about the benefits and proper use of biodiesel are essential to increase acceptance.(Hakim et al., 2025).

Energy Transition in Developing Countries

The energy transition in developing countries presents different challenges than in developed countries. Limited funding, technology, and infrastructure are key barriers to developing renewable energy. The energy transition is not simply a matter of fuel replacement but involves complex systemic changes, including policy, economic, and social factors. Developing countries must balance the energy needs of economic development with environmental protection. Indonesia has significant potential for the energy transition due to its rich natural resources. However, a successful energy transition requires strong political commitment, coordination between government agencies, and private sector participation. Experience from other countries shows that consistent policies, infrastructure investment, and human resource development are key to success. An inclusive approach involving various stakeholders is also crucial to ensuring a just and sustainable energy transition.(Policy et al., 2023).

METHODOLOGY

Research Approach and Design

This research uses a qualitative approach with a case study design to analyze the implementation of the mandatory biodiesel policy in Indonesia. A qualitative approach was chosen because it allows for a deeper exploration of how the mandatory policy interacts with catalyst research, feedstock diversification, and industry responses. This method allows researchers to understand the perspectives of various stakeholders and the dynamics occurring on the ground. This research examines three main aspects in an integrated manner: the development of catalyst research, feedstock diversification efforts, and industry players' responses to the mandatory policy. The analysis is conducted at three levels: the government policy level, the technology development level, and the industry implementation level. This approach provides a comprehensive overview of the biodiesel energy transition in Indonesia from various perspectives.

Location and Time of Research

The research was conducted in four provinces: West Java, East Java, North Sumatra, and Riau. West Java and East Java were chosen because they are centers of catalyst research, with numerous universities and research institutions. North Sumatra and Riau were chosen because they are the largest centers of palm oil plantations and biodiesel factories in Indonesia. Data collection was conducted over eight months, from March to October 2024. This period was chosen to capture the ongoing implementation of the B35 policy and obtain up-to-date data from the field. The sufficient timeframe allowed researchers to build good relationships with informants and observe the dynamics more comprehensively.

Research Informants

Informants were purposively selected based on their involvement in biodiesel policy. Key informants included biodiesel catalyst researchers from universities and research institutions, policymakers from the Ministry of Energy and Mineral Resources and the Indonesian Palm Oil Plantation Fund Management Agency, and industry players from large and small biodiesel factories. A total of 35 informants were selected based on their experience and knowledge. A snowball sampling technique was also used to reach additional informants recommended by previous informants. Supporting informants included oil palm farmers, used cooking oil collectors, biodiesel factory technicians, and biodiesel users from the transportation sector. This diversity of informants ensured the study obtained comprehensive perspectives from various stakeholders.

Data collection technique

In-depth interviews served as the primary data collection technique, using a semi-structured interview guide. Each interview lasted between 60 and 90 minutes and was recorded with the informant's permission. Interview questions were tailored to the informant's role, covering topics such as experiences, perspectives, and challenges faced regarding the mandatory biodiesel policy. Observations were conducted at biodiesel factories, catalyst research laboratories, and oil palm plantations to directly observe field conditions. Documentation studies were conducted by collecting policy documents, research reports, biodiesel production data, and related scientific publications. Triangulation of data from these three sources increased the validity and depth of the research findings.

Data analysis

The data were analyzed using thematic analysis, beginning with verbatim transcription of all interviews. The data were then read repeatedly to identify emerging patterns and themes. Coding was performed manually and with the aid of NVivo software to systematically organize and categorize the data. Identified themes were then grouped based on three main research aspects: catalyst research, feedstock diversification, and industry response. The analysis was conducted inductively, allowing themes to emerge from the data, and deductively, utilizing a theoretical framework on energy transition. Interpretation of the results was carried out by considering the policy context and dynamics of the biodiesel industry in Indonesia.

Data Validity

Research credibility is maintained through triangulation of data sources, methods, and researchers. Source triangulation is conducted by interviewing various categories of informants to obtain different perspectives. Member checking is conducted by asking informants to verify the interview results and the researcher's interpretations to ensure data accuracy. Transferability is achieved by providing a detailed description of the research context so readers can assess the applicability of the findings in other contexts. Dependability is maintained through complete documentation of the research process, including interview guides, field notes, and analysis. Confirmability is ensured by retaining all raw data and an audit trail that can be examined to verify the research conclusions.

Research Ethics

This study adhered to ethical research principles by obtaining informed consent from all informants prior to the interviews. Informants were explained the purpose of the study, the interview procedures, and their right to refuse or withdraw at any time without consequence. The confidentiality of informants' identities was maintained by using codes or pseudonyms in the writing of the research results. The collected data was stored securely and used only for academic purposes. The principle of "do no harm" was applied by ensuring that the research did not harm the informants or the organizations where they worked. The researchers also maintained objectivity by avoiding bias and conflicts of interest throughout the research process and writing of the results.

RESULTS AND DISCUSSION

Development of Biodiesel Catalyst Research in Indonesia

Biodiesel catalyst research in Indonesia has shown significant progress over the past ten years, with a focus on the use of local materials. Much research has explored heterogeneous catalysts made from rice husk ash, eggshells, shellfish, and natural zeolites, which are abundantly available in Indonesia. Researchers have successfully developed highly active catalysts, achieving 90-95% conversion at the laboratory scale. These materials are attractive because they are inexpensive, environmentally friendly, and add value to previously underutilized agricultural and fishery waste. However, interviews with researchers revealed a significant gap between laboratory success and industrial application. Catalysts that are effective on a small scale face stability and efficiency issues when scaled up to commercial production. Technical issues such as catalyst deactivation, difficulty in regeneration, and the cost of mass production are major obstacles. Furthermore, the varying characteristics of Indonesian palm oil depending on the region of origin and harvest season make catalyst optimization more complex than under controlled conditions in the laboratory. Collaboration between researchers and industry remains very limited, making research findings difficult to implement commercially. Industry desires catalysts that are not only effective but also durable, easily regenerated, and economical in the long term. Researchers acknowledge that scientific publications are a top priority over developing ready-to-use technologies, while industry requires practical solutions tested in real-world conditions. The

government needs to act as a bridge by providing funding schemes for applied research and pilot-scale testing facilities that are mutually accessible to researchers and industry.(Purnamasari, 2021).

The Challenge of Diversifying Biodiesel Raw Materials

Dependence on palm oil as the primary raw material creates vulnerabilities in Indonesia's biodiesel supply. Production data shows that over 95% of national biodiesel is derived from palm oil, making the industry highly susceptible to fluctuations in global commodity prices and environmental sustainability issues. Competition for palm oil use between food, oleochemicals, and biodiesel is also intensifying as domestic and export demand increases. When palm oil prices are high on the international market, producers tend to export rather than supply the domestic biodiesel industry, despite mandatory requirements. Efforts to diversify feedstock have shown mixed results, with varying levels of technological and economic readiness. Castor and nyamplung oils have been developed on a pilot scale but face challenges such as low productivity and the lack of a structured cultivation system. Animal fat from slaughterhouse waste holds significant potential but is hampered by an unorganized collection system and inconsistent quality issues. Used cooking oil from households and restaurants is beginning to be utilized, but volumes remain small due to the lack of regulations and incentives to encourage systematic collection. Biodiesel from microalgae offers hope for the future but is still in the early stages of research and development. Microalgae cultivation and harvesting technologies require significant investment and specialized expertise that is not yet widely available. The current cost of producing microalgae biodiesel is still three to four times higher than that from palm oil, making it economically uncompetitive. Experts emphasize the need for government support in the form of research incentives, infrastructure development, and policies that encourage the use of alternative raw materials to gradually achieve diversification.(Dimawarnita et al., 2021).

Big Industry Response to Mandatory Policies

Large companies with vertical integration from plantations to biodiesel plants have responded positively to the mandatory policy. They are expanding production capacity by building new plants or upgrading existing ones to meet the increasing demand from B20 to B30 and B35. The market certainty of the mandatory policy guarantees an attractive return on investment, encouraging them to make large, long-term investments. Some companies are even integrating backward into palm oil plantations to ensure a stable supply of raw materials. Large companies are focusing on technological innovation to improve production efficiency and product quality. They are investing in more modern process technology, automated quality control systems, and internal research to optimize production parameters. Collaboration with international research institutions is also underway to adopt the latest technology in the biodiesel industry. Their financial capacity and access to technology enable large companies to easily meet government-set biodiesel quality standards and even export to international markets. However, the dominance of large companies has also created an oligopolistic market structure with strong control over pricing and distribution. They hold a strong bargaining position in negotiations with the government regarding biodiesel prices and subsidies. Industry consolidation continues, with the acquisition of smaller companies by larger players, reducing the diversity of industry players. This condition raises concerns about the dependence of national energy policy on a handful of large corporations and the potential for monopolistic practices that harm consumers and small producers.(Baqi et al., 2022).

Difficulties of Small and Medium Producers

Small- and medium-scale biodiesel producers face significant structural challenges in implementing the mandatory policy. Limited capital is a major obstacle to increasing production capacity and adopting new, more efficient technologies. They struggle to access bank financing because they are considered high-risk and lack sufficient collateral. Without adequate economies of scale, their production costs per liter of biodiesel are higher than those of larger producers, making it difficult to compete on price. Access to raw materials is a serious issue for small-scale producers because they lack their own plantations. They must purchase palm oil from the spot market at fluctuating, often higher, prices due to the lack of long-term contracts with suppliers. When palm oil prices rise sharply, their profit margins shrink and can even lead to losses, while adjustments to biodiesel selling prices are hampered by government regulations. Their weak bargaining position prevents them from negotiating better prices with suppliers and buyers. Meeting stringent quality standards also poses a burden for small-scale producers, who lack equipped laboratories and adequate expertise. They often experience product rejections due to non-conformity to specifications, resulting in financial and reputational losses. A distribution system dominated by large corporations

makes it difficult for small producers to reach end markets, forcing them to sell their products to aggregators at low prices. Without government intervention in the form of technical assistance, access to special financing, and fair partnership schemes, the survival of small producers will be threatened, and the biodiesel industry will become increasingly consolidated by large players.(Wafi et al., 2022).

Biodiesel User Perspective

Biodiesel users in the transportation sector exhibited varying attitudes toward the implementation of the mandatory policy. Large fleet operators, such as bus and truck companies, were relatively receptive to biodiesel use due to their organized vehicle maintenance systems and good access to information. They adjusted their maintenance schedules and used spare parts compatible with high-blend biodiesel. Some even reported reduced emissions and smoother engine vibrations as positive impacts of biodiesel use. In contrast, individual users and small vehicle operators still had significant concerns about the impact of biodiesel on their vehicle engines. Frequent complaints included decreased engine performance, increased fuel consumption, and fuel system damage, particularly in older vehicles. The lack of information and effective outreach resulted in many users not understanding the characteristics of biodiesel and proper maintenance methods. News about engine damage associated with biodiesel, although not scientifically verified, spread quickly and created a negative stigma among users. The issue of inconsistent biodiesel quality at the consumer level was a problem affecting user acceptance. Some users reported differences in vehicle performance when refueling at different gas stations, indicating variations in distribution quality. The quality control system at the retail level is not yet optimal, making potential counterfeiting or quality degradation during distribution difficult to detect. The government needs to strengthen public education campaigns on the benefits of biodiesel, provide a responsive complaints mechanism, and ensure consistent quality standards are applied from factories to gas stations to boost consumer confidence.(Kristianturi et al., 2021).

Policy Dynamics and Its Implementation

Indonesia's mandatory biodiesel policy has undergone a gradual evolution from B10 to B35 over eight years. The gradual increase in blending percentage was implemented to allow time for industry and users to adapt, as well as to ensure infrastructure and raw material supply readiness. However, implementation on the ground shows a gap between policy targets and actual implementation.(Prananta, 2021)Data from various regions reveals that actual blending achievement often falls below the established target due to distribution issues, the availability of quality biodiesel, and weak enforcement. The funding mechanism through the Palm Oil Plantation Fund is key to the sustainability of the mandatory policy. Palm oil export levies are allocated to subsidize biodiesel prices to ensure they compete with fossil diesel. This scheme is effective when palm oil prices are high, resulting in abundant revenue, but becomes problematic when prices plummet and funds are insufficient to cover the price difference. Dependence on commodity price volatility makes the policy vulnerable to external economic shocks and requires a more stable alternative funding mechanism. Coordination between ministries and government agencies in policy implementation remains weak, leading to regulatory inconsistencies. The Ministry of Energy and Mineral Resources, the Ministry of Agriculture, the Ministry of Environment, and the Ministry of Industry have different interests that are not always aligned. Overlapping and frequently changing regulations create uncertainty for business actors and hinder long-term investment. Better coordination is needed through a dedicated agency with cross-sectoral authority to ensure consistent and effective policy implementation across the biodiesel value chain.(Bethan et al., 2021).

Interaction of Research, Industry, and Policy in the Energy Transition

A comprehensive analysis shows that the biodiesel-based energy transition in Indonesia is a complex system with dynamic interactions between research, industry, and policy. Mandatory policies create stable market demand, encouraging industry to invest and grow. However, the acceleration of blending targets is not always accompanied by adequate technological readiness and feedstock diversification. Catalyst research and the development of alternative feedstocks are slow due to a lack of incentives and collaboration with industry, while industry focuses on short-term solutions using existing technology to meet mandatory targets. The gap between these three elements creates a bottleneck in achieving sustainable energy transition targets. Research produces innovations that are not yet ready for commercial application, industry requires proven technology that can be adopted immediately, and policy demands increased production without considering technical and economic limitations. This asynchronous process results in suboptimal outcomes, where innovation potential is underutilized, industry investment is inefficient, and policy targets are not fully achieved. The triple helix model that integrates academia, industry, and government needs

to be strengthened through concrete collaboration platforms. The success of the sustainable energy transition requires a holistic approach that aligns research, industry, and policy within a clear long-term roadmap. The government needs to develop a grand design for the biodiesel energy transition with realistic milestones, provide funding for applied research oriented to industry needs, and create incentives for research-industry collaboration. Industry needs to be more open to investing in long-term research and not solely focus on short-term profits. Researchers need to shift their focus from mere publications to the development of applicable technologies. Only with the synergy of these three elements can Indonesia achieve an effective, efficient, and sustainable energy transition.(Silalahi et al., 2020a).

Conclusion and suggestions

Conclusion

The implementation of the mandatory biodiesel policy in Indonesia demonstrates a complex dynamic involving three main aspects: catalyst research, feedstock diversification, and industry response. Catalyst research has shown significant progress in utilizing local materials but is hampered by a large gap between laboratory success and industrial implementation. Palm oil remains the dominant feedstock for 95% of the diversification, as alternatives are not yet economically competitive. The industry response has been polarized, with large companies adapting well while small producers face constraints in terms of capital, access to raw materials, and technology. The misalignment between policy targets, technological readiness, and industry capacity creates an implementation gap that hinders the achievement of a sustainable energy transition.

Suggestion

The government needs to establish a collaborative research-industry platform with practical funding and pilot-scale testing facilities to accelerate the adoption of catalyst technology. Raw material diversification policies should be strengthened through fiscal incentives and the development of infrastructure for collecting alternative feedstocks, such as used cooking oil. Empowerment programs for small and medium-sized producers are needed through special financing schemes, technical assistance, and the formation of cooperatives to strengthen their bargaining power. Public education campaigns on biodiesel need to be intensified, along with strengthened quality oversight throughout the distribution chain. Finally, cross-ministerial coordination should be strengthened by establishing a dedicated energy transition agency that will develop a long-term roadmap with realistic targets and ensure consistent policy implementation.

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