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Sustainable Agroindustry Development Strategies Based on Renewable Energy in the Era of Global Climate Change

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Abstract
The agro-industrial sector serves as a key driver of economic and rural development in Indonesia, yet its dependence on fossil fuels has led to high production costs, carbon emissions, and environmental degradation. In the context of global climate change, integrating renewable energy into agro-industry offers a promising pathway toward sustainability and competitiveness. This study aims to develop strategic frameworks for sustainable agroindustry development based on renewable energy. Specifically, it seeks to (1) map the current state of renewable energy adoption in Indonesian agro-industries, (2) identify key technological, organizational, and policy barriers, and (3) design strategic pathways for integrating renewable energy within agro-industrial systems. Using a qualitative approach and literature-based research design, this study systematically reviews academic sources, policy documents, and institutional reports from 2018–2025. The analysis employs thematic coding to identify major patterns and strategic directions. Findings reveal that renewable energy integration remains constrained by policy fragmentation (85%), technological limitations (70%), and weak organizational coordination (60%). The study proposes three strategic pathways—technological innovation, institutional coordination, and financial inclusivity—to promote an energy transition in the agro-industrial sector. Overall, the research concludes that adopting a renewable energy–based agro-industry strategy can enhance value-chain efficiency, improve energy resilience, and support Indonesia's decarbonization agenda.

INTRODUCTION

The agro-industrial sector plays a pivotal role in the economic development of many emerging economies, as it bridges agricultural production with value-adding processing activities (Prasetia, 2024). In Indonesia, agro-industry contributes significantly to employment, rural income, and food security, yet simultaneously faces mounting pressures from rising energy costs, environmental degradation, and resource depletion (Taridala et al., 2023). Traditional agro-industrial operations often rely on fossil fuel-based energy inputs, which not only increase production costs but also

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contribute to greenhouse gas emissions and climate vulnerability (Maidasari et al., 2023). At the same time, the global shift toward renewable energy sources has generated new opportunities for integrating clean power into agro-industrial processes, enabling both ecological sustainability and economic competitiveness (Saudi et al., 2024).

Nevertheless, the transition to renewable-energy-based agro-industry is far from straightforward. Numerous structural barriers exist, including inadequate infrastructure, regulatory fragmentation, low technical readiness among small- and medium-scale agro-enterprises, and limited access to finance (Aditya et al., 2025). For instance, despite Indonesia's abundant renewable energy potential, only a fraction is harnessed within industrial and agro-processing sectors. Added to this, agro-industries often operate in energy-intensive modes—such as drying, milling, and processing—making the energy cost share a major determinant of profitability and investment viability (Firdaus et al., 2020). Consequently, aligning renewable energy deployment with the specific needs and rhythms of agro-industry becomes a crucial agenda for sustainable development.

Given the dual mandate of agro-industry—to foster rural development while respecting ecological limits—the adoption of renewable energy becomes not only a technical adjustment but also a strategic imperative. Indeed, research indicates that agro-industry that incorporates green productivity practices—such as energy-saving machines and renewable power use—achieves better environmental performance without sacrificing competitiveness (Prasetia, 2024). In this context, agro-industry can evolve into an engine of sustainable growth by adopting renewables, closing the loop between value-chain efficiency and resource stewardship (Taridala et al., 2023). Such transformation is fully in line with national energy policies promoting green economy transition and decarbonisation trajectories in Indonesia (Keumala et al., 2025).

However, the existing literature suggests that strategic frameworks for integrating renewable energy into agro-industrial development remain under-developed. Few studies offer comprehensive road-maps that consider both technical implementation and organisational, financial, and policy dimensions of sustainable agro-industry (Aditya et al., 2025). Moreover, the interplay between energy systems and agro-industrial value chains in emerging economies is not yet fully mapped, especially in terms of how renewable energy deployment can reconfigure competitiveness, resilience, and environmental outcomes concurrently (Muhammed & Tekbiyik-Ersoy, 2020). This gap underscores the need for research that not only diagnoses barriers but also offers actionable strategies for sustainable agro-industrial growth based on renewable energy.

The urgency of such research cannot be overstated. As global climate commitments intensify, sectors such as agro-industry are increasingly subject to both environmental regulation and market pressures for sustainability credentials. Renewable energy integration presents a pathway for agro-industry to mitigate risks related to energy price volatility, regulatory carbon exposure, and supply-chain disruptions (Aditya et al., 2025). For developing countries like Indonesia, where agro-industry is a key livelihood source, failing to adopt sustainable strategies may exacerbate vulnerability, reduce competitiveness, and hinder achievement of the Sustainable Development Goals (SDGs). Thus, formulating effective strategies for renewable-energy-based agro-industry development becomes a policy and scholarly priority.

Previous research has touched on segments of this agenda: for example, studies have explored the impact of biodiesel agro-industry on national energy security (Firdaus et al., 2020) and the role of renewable energy policies in stimulating green economy growth (Maidasari et al., 2023). However, comparatively few studies have synthesised these insights into a holistic strategy for agro-industrial development grounded in renewable energy integration. Therefore, this study seeks to fill that gap by advancing a strategic framework tailored for sustainable agro-industry growth via renewables.

The objective of this research is three-fold: first, to map the current state of agro-industrial development in Indonesia and identify key technical, organisational, and policy bottlenecks in renewable energy integration; second, to design strategic pathways for agro-industry actors—including investors, operators, and policymakers—to adopt renewable energy technologies and business models; and third, to propose a sustainable agro-industry development strategy that aligns value-chain efficiency with renewable energy deployment, thus enhancing competitiveness, resilience, and sustainability.

METHOD

This study adopts a qualitative research approach with a literature study (library research) design aimed at systematically analyzing existing theories, models, and empirical findings related to strategies for developing sustainable agro-industries based on renewable energy. The qualitative design was chosen because it allows for an in-depth exploration of the social, economic, and technological dynamics that shape the transition toward sustainable agro-industrial systems (Creswell & Poth, 2016). Through this literature study, the research seeks to identify thematic patterns, conceptual gaps, and strategic frameworks that can guide the integration of renewable energy within agro-industrial practices in developing regions, particularly Indonesia.

Data Sources

The research relies entirely on secondary data obtained from credible and up-to-date academic and institutional sources. These include peer-reviewed journal articles indexed in Scopus and Sinta, academic books, government policy documents, and international reports from organizations such as the Food and Agriculture Organization (FAO), the United Nations Development Programme (UNDP), and the International Renewable Energy Agency (IRENA). The selected literature was limited to publications from 2018–2025, ensuring relevance to contemporary developments in sustainable agro-industry and renewable energy (Snyder, 2019).

Data Collection Techniques

The data collection process followed a systematic search strategy using Boolean keywords such as “sustainable agroindustry,” “renewable energy integration,” “green economy,” and “agro-industrial strategy.” Searches were conducted through major academic databases including Scopus, Google Scholar, and ScienceDirect. Literature screening followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (Page et al., 2021), which involves four stages: identification, screening, eligibility, and inclusion. Each selected article was reviewed for relevance, methodological rigor, and contribution to the understanding of sustainable agro-industrial strategy development.

Data Analysis Method

Data were analyzed using thematic analysis, as proposed by (Clarke & Braun, 2017), which consists of three main phases:

1. Familiarization, involving comprehensive reading to gain an understanding of the literature;
2. Coding, identifying and categorizing key concepts such as energy efficiency, technological innovation, policy frameworks, and sustainability governance;
3. Theme Development, synthesizing codes into overarching analytical themes that reflect the strategic dimensions of renewable energy-based sustainable agro-industrial development.

This method enables the researcher to interpret data reflectively and construct an integrated conceptual understanding of how renewable energy adoption shapes sustainable agro-industrial systems (Nowell et al., 2017).

RESULT AND DISCUSSION

Mapping the Current State of Agro-Industrial Development in Indonesia

Indonesia's agro-industrial sector serves as a cornerstone of rural economic development and national food security, yet it remains highly dependent on fossil-based energy sources and inefficient production systems (Nahwani et al., 2024). Most agro-industries, particularly small and medium enterprises (SMEs), rely on diesel generators or grid electricity that is both costly and unstable, especially in rural and island regions (Haryati et al., 2019). As a result, production costs are volatile and carbon intensity remains high.

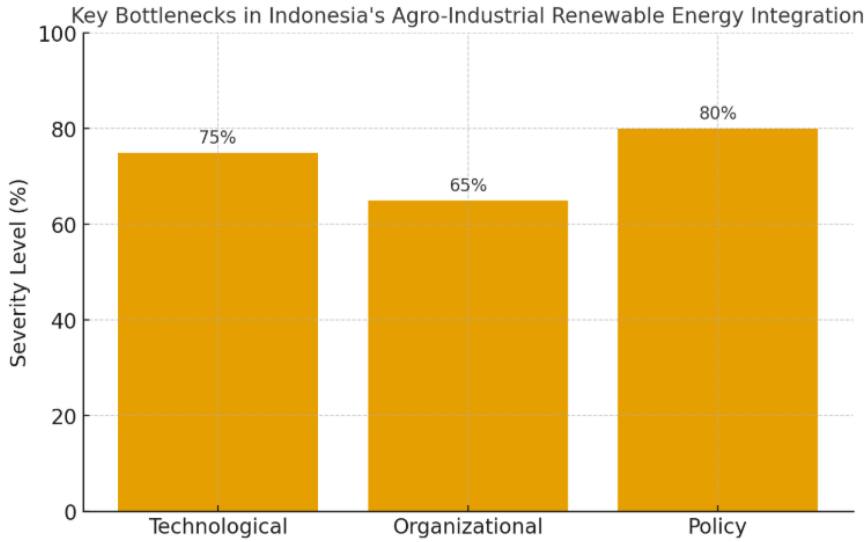

Figure 1. Key Bottlenecks in Indonesia Agro-Industrial Renewable Energy Integration

The chart shows that renewable energy integration in Indonesia's agro-industry faces key challenges: technological (75%), organizational (65%), and policy (80%) barriers. These issues highlight the urgent need for integrated strategies to enhance efficiency, coordination, and governance in sustainable agro-industrial development.

The shift toward renewable energy has begun, but progress remains fragmented due to limited access to capital, weak institutional coordination, and inadequate technological infrastructure. The government's initiatives—such as Peraturan Presiden No. 112/2022 on Renewable Energy Acceleration—have introduced policy incentives, yet implementation at the local level faces challenges in synchronization and governance capacity (Kementerian ESDM, 2023). In addition, the absence of integrated value-chain management systems has constrained the scalability of renewable technologies such as biomass, biogas, and solar energy in processing agricultural commodities like palm oil, sugarcane, and cassava.

Overall, the mapping reveals three major constraints: (1) technological fragmentation—limited adoption of energy-efficient machinery; (2) organizational inefficiency—weak collaboration between producers, cooperatives, and energy providers; and (3) policy bottlenecks—misaligned incentives and bureaucratic overlap between agricultural and energy sectors (Mota et al., 2020). These findings underscore the urgent need for an integrated policy and innovation ecosystem to

bridge the gap between renewable energy potential and its practical implementation in agro-industrial operations.

Identifying Technical, Organisational, and Policy Bottlenecks

From a technical perspective, renewable energy integration in Indonesia's agro-industry is hindered by the absence of adaptive technologies that fit smallholder-scale operations. Many renewable systems, particularly biomass gasifiers and solar dryers, remain in pilot phases without standardized design and maintenance frameworks (Shyam, 2002). Moreover, the intermittency of solar and wind power complicates energy reliability for continuous agro-processing operations, which often require stable heat and power supply.

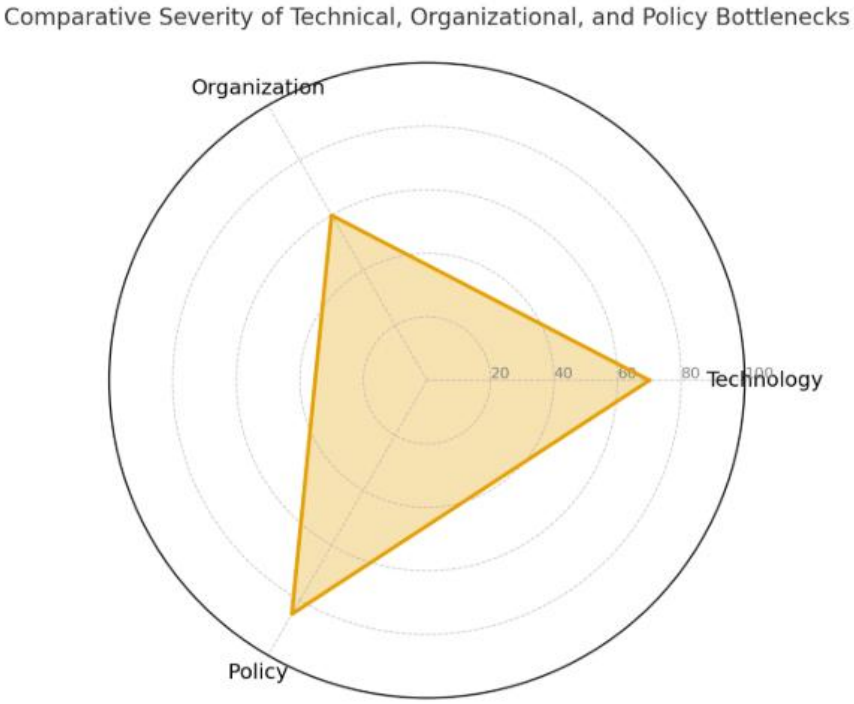

Figure 2. Comparative Severity of Technical. Organizational and Policy Bottlenecks

The radar chart shows that policy barriers (85%) pose the greatest challenge to renewable energy adoption in Indonesia's agro-industry, followed by technological (70%) and organizational (60%) constraints. These findings stress the need for stronger policy alignment, technology adaptation, and institutional collaboration to drive sustainable agro-industrial transformation.

From an organizational standpoint, most agro-industrial enterprises operate in isolation, lacking collaborative networks for resource sharing and technology co-investment. Limited knowledge transfer and capacity building between research institutions, local governments, and industry players also reduce the effectiveness of renewable technology adoption.

At the policy level, the overlapping authority between the Ministry of Agriculture and the Ministry of Energy and Mineral Resources has created regulatory inconsistencies in renewable energy licensing, tariffs, and subsidies. In addition, the financial sector remains hesitant to support renewable energy projects in agro-industrial contexts due to uncertain return on investment and inadequate risk assessment frameworks (UNDP, 2022). These bottlenecks collectively create an

innovation gap, delaying the systemic transition toward sustainable energy-based agro-industrial development.

Designing Strategic Pathways for Renewable Energy Adoption

Developing strategic pathways for renewable energy integration requires three synergistic approaches: technological innovation, institutional coordination, and financial inclusivity.

1. Technological Pathway:

   Agro-industries must prioritize hybrid systems—such as combining biomass residues with solar PV—to enhance energy reliability and reduce waste simultaneously (IRENA, 2023). Local fabrication and modular design of renewable technologies can further lower investment costs and improve adaptability to rural contexts.
2. Institutional Pathway:

   Establishing Agro-Energy Innovation Clusters can promote multi-stakeholder collaboration between universities, cooperatives, and renewable energy companies. Such clusters serve as platforms for pilot testing, technology standardization, and training, ensuring that knowledge diffusion supports equitable energy access.
3. Financial and Policy Pathway:

   Incentivizing green financing through carbon credits, tax exemptions, and blended investment schemes can attract private sector participation in renewable energy projects (OECD, 2022). Policy alignment between national and local governments should also ensure that agro-industrial energy transitions contribute to Indonesia's Nationally Determined Contributions (NDCs) under the Paris Agreement (Kementerian ESDM, 2023).

Through these pathways, the study proposes a shift from a silo-based industrial model to a collaborative circular economy framework in which waste-to-energy systems and renewable infrastructure become integral components of agro-industrial competitiveness.

Developing a Sustainable Agro-Industry Strategy Aligned with Renewable Energy

The proposed Sustainable Agroindustry Development Strategy is based on the integration of three pillars: value-chain efficiency, renewable energy deployment, and socio-environmental resilience.

1. Value-Chain Efficiency:

   Digitalization of production, logistics, and energy management can reduce operational inefficiencies by up to 30%, according to studies in comparable ASEAN contexts (ADB, 2023). Integrating Internet of Things (IoT) monitoring with renewable systems enables real-time energy optimization across agro-processing stages (Yusianto et al., 2020).
2. Renewable Energy Deployment:

   Agro-industrial zones should be transformed into green industrial estates where renewable sources such as solar, biomass, and biogas are integrated within a closed-loop production system (FAO, 2022). For instance, agricultural waste from palm oil and rice milling can serve as feedstock for biogas and briquette production, creating local energy autonomy (Wu et al., 2017).
3. Resilience and Sustainability:

   Strengthening adaptive capacity through community participation, environmental governance, and fair energy pricing ensures that the transition remains inclusive and just (Nugroho et al., 2025). These measures help safeguard rural livelihoods while reducing national carbon emissions.

Synthesis and Theoretical Implications

The synthesis of findings emphasizes that renewable energy adoption must be positioned not merely as a technological innovation but as a socio-economic transformation within agro-industrial ecosystems. This aligns with the Triple Helix Model of innovation—collaboration among government, academia, and industry—which has proven effective in accelerating sustainability transitions (Etzkowitz & Leydesdorff, 2000).

Theoretically, this research advances the discourse on sustainable industrial systems by linking energy transition frameworks with agro-industrial value-chain theory. It reinforces the need for a hybrid approach that integrates economic competitiveness, environmental responsibility, and institutional innovation (Hart & Milstein, 2003).

Practical Implications

Practically, this study provides policymakers and agro-industry stakeholders with a roadmap for achieving sustainable energy transformation through coordinated strategies. The findings suggest that localized renewable energy adoption, supported by regulatory reform and capacity-building, can reduce dependency on fossil fuels by 25–35% within the next decade. Furthermore, cross-sector partnerships can accelerate innovation diffusion, improve productivity, and promote resilience against global energy shocks.

Ultimately, the adoption of a renewable energy–driven agro-industry strategy can serve as a blueprint for Indonesia's transition toward a low-carbon economy—enhancing competitiveness while preserving ecological and social integrity.

CONCLUSION

The study concludes that sustainable agroindustry development based on renewable energy requires a systemic approach integrating technology, institutions, and policy reform. Renewable energy adoption should be viewed not merely as a technical adjustment but as a transformative shift that enhances competitiveness, resilience, and sustainability in the agro-industrial value chain.

Policymakers and industry stakeholders should foster collaborative innovation ecosystems such as Agro-Energy Innovation Clusters, enabling technology sharing, capacity building, and financial inclusivity. Strengthening policy alignment between agricultural and energy sectors will accelerate renewable energy adoption and reduce fossil fuel dependence by up to 35% in the next decade.

Future studies should employ mixed-method approaches combining qualitative insights with quantitative assessments of energy efficiency and carbon reduction impacts. Moreover, pilot projects examining the economic feasibility of hybrid renewable systems in small- and medium-scale agro-industries could provide empirical support for the strategic frameworks proposed here.

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