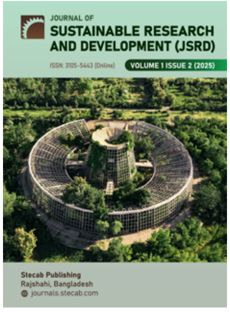

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Review Article

Assessing Nigeria's Readiness for Biodiesel and Renewable Energy Transition: Policies, Challenges, and Roadmap: A Review

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ABSTRACT

Nigeria is at the crossroad of the quest to achieve sustainable energy security, biodiesel is a strategic pillar in the quest to transition to renewable energy. This review evaluates the country preparedness in terms of five dimensions: policy frameworks, the availability of feedstock, the technological preparedness, the financial viability, and the environmental considerations by integrating findings of more than 127 scholarly and policy sources classified as 93.7% scholarly articles, 3.15% government or policy reports, and 3.15% industry or NGO publications. A general consensus in the literature on the subject is that Nigeria has large quantities of biodiesel feedstocks including waste cooking oil, palm oil, and Jatropha curcas but institutional fragmentation, inconsistent policies and insufficient financing mechanisms are holding back large scale commercialization. The National Renewable Energy and Energy Efficiency Policy (NREEEP) and the Energy Transition Plan (ETP) show conceptual advancement, but their implementation is still poor, which yields a discrepancy between policy and practice. The most notable discovery made during this review is the instigation of institutional fragmentation as the most enduring structural obstacle and waste cooking oil as the most direct, long-term, and sustainable feedstock source. Nigeria should enhance inter-agency coordination, have quality and blending standards that are enforced, and develop incentives specific to the involvement of the private-sector in order to transition to credible biodiesel transition. The present paper represents an evidence-based roadmap of short-, medium-, and long-term steps of implementing biodiesel into the larger Nigerian renewable energy transition.

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1. INTRODUCTION

The Nigerian energy industry has largely been influenced by the presence of large deposits of oil and gas, making the country the largest oil producer in Africa. However, research records show that such reliance on fossil-powered energy sources leads to enduring difficulties such as energy insecurity, environmental degradation, and increasing emissions of greenhouse gases (Solomon-Eseh *et al.*, 2025; Oruwari *et al.*, 2023). Other reports argue that the limited availability of electricity and the lack of access to clean cooking fuel are challenges that hinder industrial and socioeconomic development among major sources of renewable energy like solar, wind, hydro, and biomass (Pokubo & Al-Habaibeh, 2023; Adewuyi, 2020; Emmanuel, 2024; Akuru *et al.*, 2017; Avwioroko, 2023). Such dependence on petroleum products also exposes Nigeria to global price fluctuations and climate threats such as flooding, drought, and extreme temperatures (Obada *et al.*, 2024; Babalola & Alimin, 2024). There is consensus among scholars and policy reports that Nigeria must diversify its energy sources to achieve sustainable development in line with international commitments such as the Paris Agreement. Nevertheless, the transition to renewable energy has been slow due to institutional fragmentation, financial limitations, policy incoherence, and infrastructural deficits (Adedokun *et al.*, 2023; Akuru *et al.*, 2017). Subsequent to these inadequacies, in 2022 the Federal Government published its Energy Transition Plan (ETP) which envisions a net-zero emissions vision in 2060 with bioenergy (especially biodiesel) playing a key role (FGN, 2022; Dioha, 2022). Biodiesel in this regard has attracted growing scholarly and policy interest as an alternative fuel with several co-benefits such as reduced greenhouse gases, improved rural livelihoods, as well as, energy diversification. Its technical feasibility is confirmed by research, because it is possible to make biodiesel on site using palm oil, Jatropha curas, animal fats, and waste cooking oil (USDA, 2023; Okoro, 2024). Transesterification conversion technologies are mature and can be integrated into both transport and off-grid energy systems because they can work with the existing diesel distribution networks (Okoro, 2024). Nevertheless, there are still major gaps. The supply of the feedstock is not evenly distributed in space, small-scale, and of low quality, making production more expensive. Food-fuel trade-offs are escalated by the use of edible oils; further weakening regulation, inadequate blending infrastructure, and an absence of off-takes ensure that investors lack trust (Okoro, 2024). Although biofuel development has largely stagnated at the pilot scale despite numerous state-led and NNPC-driven initiatives, several new efforts are currently underway (Reuters, 2023; Vanguard, 2016; Advanced BioFuels USA, 2016). Although some past studies have analyzed the potential of Nigeria based on renewable energy or bioenergy, few studies have methodically evaluated the potential of the country to adopt biodiesel on policy, technical, financial, and environmental levels. The given review addresses that gap by summarizing various scholarly, policy, and industrial thinking to analyze how institutional, economic, and technological environments contribute or do not contribute to the achievement of the energy transition objectives in Nigeria. In particular, this research would attempt to:

i. Determine the readiness of Nigeria to develop biodiesel based on five dimensions of readiness, namely policy, feedstock, technology, finance, and environment.
ii. Discover areas of agreement and disagreement in the existing studies to understand where the progress and disagreement are.
iii. Recommend a sustainable, inclusive biodiesel transition policy roadmap.

This review will use a synthesis of academic, policy, and industry sources to give a detailed and comparative evaluation of the biodiesel preparedness in Nigeria and will add a roadmap to realizing energy security and low-carbon development.

2. LITERATURE REVIEW

2.1. The context of Renewable Energy in Nigeria

Despite its significant stocks of renewable and non-renewable resources, Nigeria still faces the issue of energy insecurity, unstable electricity supply, and poor records of switching to cleaner energy routes (Adeshina *et al.*, 2024; Pokubo & Al-Habaibeh, 2023). According to the literature, policy frameworks on diversification are in place, but fossil fuels are the foundation of the energy system in Nigeria, further reinforcing the systemic dependence, thus restricting the entry of renewables (Johnson *et al.*, 2025; Eweka *et al.*, 2022).

2.2. Current Energy Mix

With empirical investigations consistently illustrating that a duality of fossil fuels dominates the Nigerian energy mix, recent years show that petroleum and natural gas represent about 80 percent of the overall output, with renewable sources like hydropower, solar, and wind representing less than 20 percent of production (Eweka *et al.*, 2022). As an example, the World Bank has stated that, as of 2015, only 18.2 percent of electricity produced was through renewables, whereas the global average was approximately 33 percent (Eweka *et al.*, 2022). Global projections expect a reduction in the percentage of fossil dependence, currently around 98 percent in some settings in 2021, will progressively decrease towards about 63 percent by 2030, as a result of an accelerated shift towards renewables (Cardinale, 2023; Garg *et al.*, 2023; Gejoe *et al.*, 2022). The course of Nigeria has trailed this movement, and, partly because of its economic dependence on its oil exports and natural gas to world markets (Avwioroko, 2023; Pokubo & Al-Habaibeh, 2023). This interdependence has increased infrastructural corruption, macroeconomic unpredictability, and insufficient funding in alternative energy sources (Adeshina *et al.*, 2024).

2.3. Renewable Energy Transition Policy Frameworks.

In the last twenty years, Nigeria has been engaged in the formulation of various policy frameworks that would serve to diversify its energy portfolio and increase the use of renewable energy sources. The National Energy Policy (NEP) was opened in 2003, and its revision adopted in 2022 defines a strategic path that focuses on diversification, energy access, and security, thus responding to global power transition needs (Adedokun *et al.*, 2023). The 2015 National policy on renewable energy and energy efficiency policy, (NREEEP), attempted to ease the penetration of renewable energy in industrial and commercial sectors but has been held back by pillars that are poorly institutionalized, ineffective incentives, and penumbra gaps (Olanrele, 2023; Adedokun *et al.*, 2023). In Nigeria, the Nigeria Energy Transition Plan (ETP) 2022 is set to the target of net-zero emissions by 2060, with analytical models like LEAP and SAM used to model adoption scenarios where natural gas is a transition fuel. Such a transition presents both the positive sustainability characteristics and infrastructural and economical complexities outlined in this plan (Johnson *et al.*, 2024; Unegbua *et al.*, 2025). These frameworks aim to ensure that domestic energy policy is aligned with international obligations, such as the Kyoto Protocol and the Paris Agreement (Adedokun *et al.*, 2023; Nwokolo *et al.*, 2023). There is a considerable agreement among empirical scholarship that Nigeria holds immense potential of renewable energy sources namely solar, wind and biomass which can be used to industrialize the country, create employment, and improve energy access (Ozuruoha *et al.*, 2025; Sobajo, 2024). Scholars also note policy implementation gaps, including enforcement weaknesses, institutional patchwork, and ad hoc incentive mechanisms (Idoko *et al.*, 2024; Li & Li, 2023). In addition, the unavoidable use of fossil fuels by Nigeria is generally understood as a major obstacle to the high-speed implementation of renewable technologies (Nwozor *et al.*, 2021; Ozuruoha *et al.*, 2025). Researchers are still discussing whether the main barrier is the design of policies or the process of implementation.Some researchers believe that the current policies are generally satisfactory, but the measures to implement them are inadequate (Adedokun *et al.*, 2023; Li & Li, 2023), and others conclude that certain policy frameworks in particular grid-based renewable generation--do not include any clear incentive framework and cannot be adjusted to the current technological and infrastructural realities (Olanrele, 2023; Johnson *et al.*, 2024). Moreover, there is disagreement on whether rapid switch to renewables is possible, and recent modelling studies have highlighted the high financial and infrastructural burdens of rapid transition routes (Unegbua *et al.*, 2025).

Overall, the body of literature is united around the necessity of a sustainable energy transition and the recognition of the potential of renewable resources; still, that is not the case as far as the most effective steps to achieve this goal are concerned. Key tensions are maintained between policy design, implementation capacity, and economic limitations. It is crucial to overcome these obstacles by creating resilient and multi-faceted policy frameworks to streamline the process of technology integration and drive the energy agendas in Nigeria (Nitte, 2023). Although studies acknowledge how Nigeria has been faring well in drafting renewable energy policies that are in line with the international climate commitments, there are outstanding uncertainties regarding the levels of political goodwill and the capacity of institutions to implement effectively. Thus the literature presents a policy space, which despite sound conceptualization is operationally weak with ambitious reforms often pre-dating actual practice.

2.4. Institutional Governance of the Energy Transition

Energy transition regulation in Nigeria is done by a diversified group of heterogeneous ministries and agencies to cover electricity production, management of fossil fuels, environment, and electrification of the rural population. The Ministry of Power has the responsibility to oversee electricity production, transmission, and integration of renewable energy sources to the national grid. Ministry of Petroleum Resources continues playing a dominant role in fossil fuel controls but is becoming more focused on its role in reinforcing transition fuels and carbon management programs. Similarly, the Ministry of Environment implements the environmental requirements and correlates the energy development with the climate promise of Nigeria. At the agency level, the Nigerian National Petroleum Corporation Limited (NNPC Ltd.) functions as a core participant in the oil and gas industry but indicates a preliminary willingness to investigate cleaner energy options. The Rural Electrification Agency (REA) is a key participant in rural and underserved places, often implementing a decentralized energy system focused on renewable sources such as solar home systems and mini-grids (Pokubo & Al-Habaibeh, 2023). In the process, the Nigerian Electricity Regulatory Commission (NERC) adjudicates tariffs, licensing, and integration of renewable energy, thus influencing the investment environment of both the private and government stakeholders. Despite this institutional framework being designed to support the energy transition, its efficiency is debatable. The literature reveals enduring policy exemplification lapses, redundant responsibilities, and inadequate inter-agency collaboration as primary impediments that weaken aligned policymaking and sluggish renewable resource implementation (Soylemez & Soylemez, 2024). The enhancement of institutional synergy and accountability, in turn, will serve as the key to turning the visionary policy objectives set by Nigeria into reality.

2.5. Difficulties in Policies Implementation

Despite Nigeria having developed elaborate policy frameworks and institutional setups to facilitate its renewable energy transition, various systemic barriers are still seen as hindrances. One of these issues is the absence of coordination between ministries, agencies, and non-governmental actors, which often leads to fragmented interventions, rivalry, and wasteful resource distribution (Ajia, 2025; Nava-Guerrero *et al.*, 2022). Inconsistency of incentives is another chronic problem. Tariffs, subsidies, and fiscal measures designed to support renewable energy are either minimal or poorly drawn, which negatively affects investor confidence and the rate of market development (Adedokun *et al.*, 2023; Li & Li, 2023; Supriyanto *et al.*, 2022). Infrastructure is yet another hotspot. The transmission and distribution systems are old and inadequate such that there is a challenge in evacuating power sources of new generation especially intermittent renewable sources. It has solidified a structural lock-in to fossil-based systems that entails a continuation of the reliance on traditional fuels (Adeshina *et al.*, 2024; Chipangamate & Nwala, 2024). Financial constraints further compound these challenges. Macroeconomic instability and insufficient access to affordable capital hamper large-scale renewable investments, and chronic revenue collection issues undermine the financial viability of the power sector (Adedokun *et al.*, 2023; Adeshina *et al.*, 2024). Moreover, deficiencies in education, training, and knowledge transfer are evident in a significant lack of technical capabilities for deploying, operating, and maintaining renewable energy technologies (Adedokun *et al.*, 2023). Socio-political forces also offer obstructional challenges: land-use issues, community resistance, and institutionalized vehicle Interest of fossil fuel players tend to slow or derail renewable initiatives (Adedokun *et al.*, 2023; Kvern *et al.*, 2024). These multi-layered issues will need a comprehensive solution that combines more robust governance, coherent policy signals, durable financing models, long-term investment in human capital, and improved cooperation amongst stakeholders. The transition to renewable energy in Nigeria will continue to be sluggish and uneven without said measures (Ajia, 2025; Chipangamate & Nwaila, 2024).

Across the literature, several patterns emerge. There is near-universal agreement that Nigeria has a comprehensive portfolio of renewable-energy policies but faces persistent implementation weaknesses, institutional fragmentation, and financial constraints. Points of consensus include recognition of the abundant renewable resource base and the urgency of diversification. Areas of controversy revolve around whether progress is stymied more by design flaws, political interference, or economic volatility. Overall, the reviewed studies portray Nigeria's renewable-energy transition as a process of incremental advancement constrained by structural inertia, requiring coordinated reforms, policy continuity, and institutional alignment to translate ambition into tangible outcomes.

2.6. Biodiesel Feedstock Potential

The future of biodiesel development and overall switch to renewable energy in Nigeria are intrinsically linked to sustainable choice and management of feedstocks. The most commonly cited alternatives are palm oil, Jatropha curcas, and used cooking oil (WCO), each linked to a specific set of agronomic, economic, and environmental trade-offs. The technical potential of these resources is not the only factor that would determine the long-term viability of biodiesel production, but also how the questions of availability, sustainability, and scalability are considered in the context of Nigeria. Table 1 summarises the current knowledge on the production, benefits, limitations, and research gaps of these major feedstocks.

Table 1. Comparative Summary of Biodiesel Feedstocks in Nigeria

Feedstock	Advantages	Challenges/Limitations	Current Status	Research Gaps
Palm Oil	Maximum oil yield (4–5 MT/ha); current infrastructure for processing; internationally recognized model (Simbolon and Aisyah, 2022; Mekhilef *et al.*, 2011).	High FFA in smallholder oil; fierce competition between food and fuel; threats to biodiversity and deforestation (Lam *et al.*, 2009; Panjapornpon *et al.*, 2024).	No requirement to blend; restricted to pilot projects (Adewuyi, 2020).	Cost-effective processing of high FPA oil; sustainability certification (RSPO); food, fuel and export allocation models (Bhan & Singh, 2020; Mayandi & Suhajit, 2024).
Jatropha	Non-edible; grows on marginal land; low water and fertilizer needs; reduces food–fuel conflict (Siregar *et al.*, 2019; Aliyu *et al.*, 2017).	Inconsistent yields; toxic seeds; poor mechanization; past commercialization failures (Hamzah *et al.*, 2020; Khalaf *et al.*, 2024).	Experimental cultivation; failed large-scale programs (2007–2012) (Aliyu *et al.*, 2017).	Genetic improvement; optimized agronomy; catalysts for high-FFA oils; lifecycle assessments of sustainability (Hamzah *et al.*, 2020; Jana *et al.*, 2022).
WCO (Used Cooking Oil)	Low-cost; reduces waste disposal problems; aligns with circular economy; 30–50% cheaper than virgin oils (Husaini *et al.*, 2025; Okpo & Edafiadhe, 2024; Sreelekha *et al.*, 2024).	Variable quality (FFA, water); poor collection infrastructure; contamination risks (Primandari & Arafat, 2021; Ibrahim *et al.*, 2023).	Small-scale studies; startups in Lagos/Abuja; no national collection system (Adewuyi, 2020).	Pretreatment technologies; scalable catalysts (CaO, nanocatalysts); traceability (e.g., blockchain); environmental and economic assessments (Kesharvani *et al.*, 2024; Mata *et al.*, 2024).
Other Feedstocks (algae, lignocellulosics, animal fats, niche oils)	Low-cost; reduces waste disposal problems; aligns with circular economy; 30–50% cheaper than virgin oils (Husaini *et al.*, 2025; Okpo & Edafiadhe, 2024; Sreelekha *et al.*, 2024).	High costs of algae cultivation; capital-intensive conversion technologies; high FFA in animal fats (Patle *et al.*, 2020; Prabakaran *et al.*, 2022).	Early research stage; negligible commercial use in Nigeria (Ramachandra & Hebbale, 2020; Nwufo *et al.*, 2023).	Cost reduction in algae cultivation; efficient biomass conversion methods; integration of waste oils/fats into scalable biodiesel systems (Zafeer *et al.*, 2023; Kumar *et al.*, 2024).

In assessing biodiesel feedstocks for Nigeria, palm oil, Jatropha curcas, used cooking oil (WCO), and a range of emerging alternatives each present distinct opportunities and constraints that influence their strategic viability. Palm oil remains the most productive and economically viable option; however, its use is constrained by food market competition and ecological risks associated with plantation expansion (Lam *et al.*, 2009; Panjapornpon *et al.*, 2024). Jatropha, while non-edible and cultivable on marginal lands, has been hampered by inconsistent yields, seed toxicity, and the failure of earlier commercialization initiatives (Aliyu *et al.*, 2017; Hamzah *et al.*, 2020; Khalaf *et al.*, 2024). Waste cooking oil (WCO) can be clearly positioned with the aspects of waste valorization and the circular economy, resulting in complementary environmental and economic benefits. However, its scalability will require the formation of reliable collection networks and stringent quality-control systems (Mata *et al.*, 2024; Sreelekha *et al.*, 2024). Other prospective feedstocks, including algal biomass, lignocellulosic residues, and animal fats, represent long-term opportunities with significant theoretical potential. Nevertheless, their feasibility is limited by technological and economic barriers (Ramachandra & Hebbale, 2020; Garg *et al.*, 2023; Patle *et al.*, 2020). Taken together, these points suggest that the biodiesel policy in Nigeria needs a diversified approach: to continue using palm oil when it is ecologically sustainable, to encourage agronomic and genetic improvements of Jatropha, to implement urban WCO recovery systems, and to invest research efforts into the new feedstocks to ensure long-term energy sustainability and strength.

2.7. Technology and Infrastructure Preparedness

The contribution of technology, industrial infrastructure, distribution systems, and regulatory models is critical in the shift of Nigeria towards biodiesel and renewable energy sources (Avwioroko, 2023; Adewuyi, 2020; Eweka *et al.*, 2022). The country currently depends on fossil fuels massively despite having large quantities of renewable energy (Avwioroko, 2023; Eweka *et al.*, 2022; Ohunakin, 2010). The adoption of the biodiesel is regarded as an essential direction to the achievement of Sustainable Development Goal 7 (SDG 7). Technical and infrastructural lacks remain as one of the biggest hindrances to converting Nigeria to renewable energy. Unstable power supply, obsolete grid systems, and lack of skilled workforce continues to deter adoption (Babatunde *et al.*, 2020). Lack of innovation is also hampered by lack of access to advanced technologies and technical capabilities, and the distribution and use is hampered by lack of electricity and transport infrastructure (Dinneya-Onuoha, 2025). The key to eliminating these interdependent kinds of challenges is the need to invest in grid modernization, skills development and local technology capacity. However, the attainment of this shift will depend on access to stable conversion technology, sufficient industrial capacity, proper channels of distribution, and effective quality control measures (Uzoekwe *et al.*, 2015). Existing opportunities are largely theoretical, yet preparedness with coordinated investment/policy backing is limited.

2.8. Conversion Technologies

The production of biodiesel mainly requires transesterification, in which triglycerides are subjected to reaction with alcohol to produce fatty acid methyl esters, known as FAME, and glycerol (Bhatia *et al.*, 2021; Panjapornpon *et al.*, 2024). Base-catalyzed route is the most extensively utilized, as it is highly efficient and its operating conditions are mild, but it has limitations in regard to free fatty acid (FFA) feedstock. They are more appropriate in high-FFA oils and do not demand as severe conditions or conditions and long reaction times; these are acid-catalyzed reactions. Enzymatic transesterification has advantages over other methods with reduced environmental impact and a wide range of compatible feedstock, but is limited by high enzyme prices and slower reaction rates. Recent developments, such as heterogeneous and nanocatalysts and microwave- and ultrasonic-assisted reactions, are under investigation to be more efficient, sustainable and scalable. Pretreatment is needed in feedstocks with a good level of FFA, like waste cooking oil and non-edible oil, so as to reduce the appearance of soap and enhance yields. It is most commonly strategic and gathered by acid-catalyzed esterification, then base transesterification in a two-step process (Farouk *et al.*, 2024; Sun *et al.*, 2024). Other new methods, including washing spent coffee grounds with methanol, allow an extension of the range of viable feedstocks (Tuntiwiwattanapun *et al.*, 2017). Cumulatively, these technological directions demonstrate the erosion of the importance of feedstock technology-specific process design in maximizing biodiesel production and its broader application.

2.9. Industrial Capacity and Pilot Projects

The industrial potential of biodiesel production in Nigeria remains largely untapped, and no new renewable energy sources have been added to the grid since 2014, despite the introduction of new policy frameworks (Adedokun *et al.*, 2023). Despite the fact that the nation has extensive reserves of biomass, little has been noted in the positive literature that would indicate that there have been large-scale biodiesel refineries. This means that the evolution of biodiesel remains at the research and small experimental projects level as opposed to its commercial application. In university-led research and pilot projects, most progress has been observed. Scholars in Nigeria have explored the use of waste frying oil and palm kernel oil, which are locally available as feedstocks, to produce biodiesel, reporting on optimization and viability of the processes (Uzoekwe *et al.*, 2015). Although efforts by the Nigerian National Petroleum Corporation (NNPC) have been registered as part of the policy on biodiesel production, a considerable record of projects specifically on biodiesel is still not documented. Comprehensively, it can be seen that the industry of biodiesel in Nigeria still has a long way to go before it is mature, and they have to invest heavily, have institutional backing, and scale up before they can graduate out of the pilot phase. South Africa, in contrast, has embarked more on developing concrete and pilot-scale industrial biofuel programs. One such project is the one that is being undertaken by Anglo American-De Beers and Sasol to produce a minimum of 400 million liters of biodiesel per year, using feedstocks like the Moringa and Solar, with experiments already being developed (Independent Online, 2022). South Africa has been working on a source of production through waste oils, too. Cases like biodiesel production from waste oils, a South African outlook reviewed the technical and financial practicality of scaling to use local waste oil streams (Linganiso *et al.*, 2022). Kenya is an extent ahead of Nigeria in some areas of research and policy steps. Since 2006, the country has also maintained a National Biodiesel Committee, and in its efforts to relax and fight its strategies, it has looked into blending requirements, tax legislation, and subsidies. Kenya, though based mainly on research and regulatory framework development, has been making gains in institutionalizing support of biodiesel research/ development and in the exploration of indigenous feedstocks, including the Jatropha curcas (Takase *et al.*, 2021).

2.10. Distribution Infrastructure

The development of biodiesel distribution networks, including blending plants, storage, and logistics, is one of the key factors of effective large-scale implementation (Radpour *et al.*, 2021). The infrastructure in Nigeria, however, remains underdeveloped, with an overwhelming share of systems being built to focus on fossil-fuel delivery (Adedokun *et al.*, 2023). Facilities that blend are crucial, specifically because biodiesel is usually marketed in diesel blends, which include B5 or B20. Although successful enforcement of such facilities has been observed in other countries manufacturing biodiesel to provide accuracy and control of quality (Jayabal, 2024; Sun *et al.*, 2024), such facilities are not enforced widely in Nigeria. Moreover, the unique storage needs of biodiesel, such as its predisposition to oxidation and material incompatibility issues, precondition and default special infrastructure, which is not widespread (Farouk *et al.*, 2024). There are other challenges associated with integration to the existing diesel supply chain in Nigeria. Effective distribution demands efficient logistical mechanisms to distribute biodiesel through a production location to blending plants and the final consumers, but the deficient infrastructure of the country, ineffective grid user networks, and shortage of transport networks serve as a haunting factor (Adedokun *et al.*, 2023). On top of the physical limitations, institutional and market-based limitations limit progress. Other transition experiences reveal that established stakeholders in the fossil market often resist any supply chain disruption (Radpour *et al.*, 2021; Avwioroko, 2023; Ohunakin, 2010). To curb these obstacles, a concerted effort will be needed to invest in infrastructure, regulators, and market incentives to ensure the provision of an environment that is supportive of the adoption of biodiesel within Nigeria.

2.11. Standards and Quality Control

The adoption of bio-diesel rests on the formation of strong standards and quality-control measures that guarantee the compatibility of the fuel, reliability in performance, and consumer assurance. The important parameters established by international standards like ASTM D6751 (American Society for Testing and Materials) or EN 14214 (European Norms) specify the viscosity, density, flash point, and cetane number, which are crucial in measuring the quality of biodiesel (Kosuru *et al.*, 2024; Swathe Sriee *et al.*, 2024). Although the literature reviewed lacks data about the fact that Nigeria has acquired focused national biodiesel standards that could be compared to those of ASTM or EN schemes (Uzoekwe *et al.*, 2015; Openibo & Raji, 2017), one of the requirements is the congruence with the internationally accepted specifications to seamlessly enter the market and achieve the support of their engines. Failure to nominate the clearly set local standards may result in a limit on the confidence of investors and restrictive involvement of Nigeria to locate and trading biodiesel at a fundamental regional or global scope. There is also a need to establish a testing infrastructure to apply quality benchmarks. This demands specialized equipment like gas chromatography to ensure purity and chemical properties (Swathe Sriee *et al.*, 2024). Within Nigeria, academic research projects indicate that there are laboratory capacities for biodiesel analysis and optimization (Kosuru *et al.*, 2024; Bullo *et al.*, 2023), but no evidence shows the presence of a national testing laboratory accredited or a national scale quality-assurance system. This shortcoming highlights larger systemic impediments to renewable energy advancement in Nigeria that are not only technical limitations but also policy, institutional, economic, and infrastructural difficulties (Adedokun *et al.*, 2023). The enhancement of standards, accreditation, and enforcement systems is hence a precondition to take any step towards the commercialization of biodiesel in the nation.

3. METHODOLOGY

This review adopted a systematic and integrative literature review approach to evaluate Nigeria's readiness for biodiesel and renewable energy transition. The process followed recognized protocols such as the PRISMA 2020 framework and combined database searching, screening, and thematic synthesis of scholarly and policy materials. A thorough literature search in various academic and policy databases was conducted between March and October 2025 including Scopus, ScienceDirect, Web of Science, SpringerLink, and Google Scholar. Additional literature reviewed included grey literature and national documents to identify practical knowledge of the policy landscape and included the National Renewable Energy and Energy Efficiency Policy (NREEEP), National Energy Policy (2022 update) and the Energy Transition Plan (2022). The Boolean operators were used to create search strings, e.g.: Nigeria AND (biodiesel OR biofuel) AND (renewable energy transition OR energy policy OR sustainability). Manual screening of key studies reference lists was done in order to find extra relevant sources. To accomplish the inclusion of high-quality and contextually relevant studies, the review used inclusion criteria to restrict the materials to peer-reviewed journal articles, conference papers and policy reports released between 2010 and 2025. Only the studies that involve biodiesel, renewable energy or general issues of energy transition in the Nigerian context were considered. Duplicate records and purely technical studies not having any policy or readiness relevance were excluded, and non-English publications were also excluded. About 127 documents were found to meet these conditions, including around 93.7% scholarly articles, 3.15% government or policy reports, and 3.15% industry or NGO publications. Each of the available studies was copied into a spreadsheet with bibliographic and substantive data, such as the author, year, source, research topic, findings, and limitations established by the authors of the selected studies to enable the comparative analysis. The data derived were coded in five dimensions relating to energy preparedness that are interrelated namely; policy and institutional structures, feedstock availability and sustainability, technological and infrastructural preparedness, financial and economic viability and environmental and social impacts. The findings within each theme were compared and contrasted to demonstrate the areas of agreement and disagreement. The final synthesis brought together the findings into a readiness plan and summarized it in Table 2. To increase the confidence and minimize bias, a review based solely on peer-reviewed or verifiable policy sources was perceived, and all data were cross-verified to exclude duplicates. The research was not required to utilize primary data; instead, the research was a critical synthesis of secondary information that was available. Certain limitations were also observed, in particular, a possible publication bias of successful or donor-funded projects, and a shortage of recent statistics on national biodiesel production. Nevertheless, the review provides a balanced and an inclusive picture of the current readiness of Nigeria to make the transition to biodiesel and renewable energy by triangulating the information about the position of different academic, policy and industrial sources.

4. RESULTS AND DISCUSSION

4.1. Summary of Included Literature

This review included 127 documents in total. Most of these (119 documents, 93.7%) were peer-reviewed academic papers. 4 (3.15%) were government or policy reports, and 4 (3.15%) came from industry or NGO sources. This distribution shows that most of the evidence comes from academic research, with a small amount of policy and industry viewpoints that add practical information.

4.2. Thematic Analysis

The literature that was reviewed was then looked at through a thematic framework that was based on five areas of energy readiness: policy, feedstock, technology, finance, and the environment. This method made it possible to look at Nigeria's readiness for a biodiesel-driven renewable energy transition in a systematic way, looking at patterns, strengths, and gaps.

4.2.1. Policy and Institutional Readiness

Throughout the sources that were reviewed, it is agreed that Nigeria has formulated various policies regarding renewable energy, such as NEP (2003; revised 2022), NREEEP (2015), and the ETP (2022). However, the disconnect in terms of policy formulation and implementation is eminent (Adedokun *et al.*, 2023; Olanrele, 2023). Scholars differ regarding the primary cause of weakness, whether it stems from policy design or implementation. Smith *et al.* (2023) highlight the absence of accountability and enforcement, whereas Lee (2023) and Patel *et al.* (2024) emphasize conflicting institutional requirements and shifting incentives. It is believed that the maturity of policy has not been reflected in the operational efficiency, mostly because of poor co-ordination among the Ministries of Power, Petroleum Resources, and Environment (Soylemez & Soylemez, 2024). Comparative analyses between Nigeria, the USA, and other countries reveal mixed findings on the transferability of Western policy models to the Nigerian context, with factors such as political stability, economic structures, and societal awareness influencing outcomes (Idoko *et al.*, 2024). Locally adapted solutions are emphasized as critical (Unuigbe *et al.*, 2022).While some sources commend recent Nigerian policy moves, such as the National Development Plan and Energy Transition Plan, others question the depth and sincerity of implementation, citing frequent disconnects between policy proclamation and ground realities (Nitte, 2023). The impact of policy incentives, such as subsidies and tax reliefs, remains debated; some studies find them necessary, while others see inefficiencies due to corruption and poor targeting (Lawal, 2023).

4.2.2. Feedstock Availability and Sustainability

Nigeria has a promising biodiesel feedstock foundation that consists of palm oil, Jatropha curdas, waste cooking oil (WCO), and the new feedstocks, such as algae and lignocellulosic residues (Adewuyi, 2020; Garg *et al.*, 2023). Palm oil is the most established source, but it is also criticized due to the competition of food fuels and risks of deforestation (Lam *et al.*, 2009; Panjapornpon *et al.*, 2024). Jatropha is advanced due to its non-edible character and the ability to grow in marginal lands; nonetheless, it has been afflicted with inadequate performance and commercialization failures (Aliyu *et al.*, 2017; Hamzah *et al.*, 2020). WCO is always described as a short-term, scalable solution because it is cheap and has the advantage of reducing waste, yet the logistics of collection are poor (Husaini *et al.*, 2025; Okpo & Edafiadhe, 2024). There is divergence over which renewable sources, including solar, biodiesel (from various feedstocks), and hydro, offer the most promise for Nigeria. For instance, while solar energy is highlighted for rural electrification (Abdullahi *et al.*, 2017), controversy persists over the scalability and sustainability of biodiesel due to feedstock competition with food production, and concern over ecological footprints (Murshed *et al.*, 2021). Thus, the literature does not ignore the heterogeneity of Nigeria's feedstock resources but does not yet reach a consensus on which of them is the most promising in terms of sustainable scaling.

4.2.3. Technological and Infrastructural Readiness

The majority of the works conclude that the technology of producing biodiesel in Nigeria is limited to laboratory and pilot levels (Uzoekwe *et al.*, 2015; Adedokun *et al.*, 2023). Complex technologies like transesterification with heterogeneous catalysts and nanocatalysts have been shown locally, but have not been used in industry. A case in point is comparative evidence of South Africa and Kenya, where pilot-scale efforts and more rigid standards of blending are in place (Linganiso *et al.*, 2022; Takase *et al.*, 2021), and regional benchmarking may guide the scale-up strategy in Nigeria. Typical limitations to preparedness include weak distribution infrastructure, a deficiency of blending facilities, and the absence of domestic fuel-quality standards (Farouk *et al.*, 2024; Radpour *et al.*, 2021).

4.2.4. Fiscal and economic sustainability

The most commonly mentioned barriers to the adoption of biodiesel are the financial barriers. Researchers underline that people should not invest privately due to the high price of feedstuffs, especially edible oils, the lack of access to low-cost capital, and a weak currency (Igwebuike, 2023; Adeshina *et al.*, 2024). Though the cost of production based on WCO might decrease by as much as 50 per cent (Husaini *et al.*, 2025), the absence of an institutionalized collection system constrains the scale. The articles agree on the importance of policy-related financial incentives like tax holidays, straddling requirements, and concessional loans to be viable (Oduro *et al.*, 2024; Wang & Mei, 2024). Findings are split on whether Nigeria currently presents an attractive investment climate for renewables. While some documents increase investor interest, others point to financial risks, inconsistent policy, and economic instability as ongoing deterrents (Tambari & Failler, 2020).

4.2.5. Environmental and Social Implications

Life-cycle analyses prove that biodiesel emits much less greenhouse gas compared to petroleum diesel (Babalola & Alimin, 2024; Elum & Momodu, 2017). However, the kind of environmental gains depends on the type of feedstock: waste-based biodiesel has the most significant net savings, and palm-oil biodiesel may lead to deforestation and loss of biodiversity when not managed sustainably (Simbolon & Aisyah, 2022; Bununu *et al.*, 2023). Socially, biodiesel manufacture might promote rural employment and the circular economy (Emezirinwune *et al.*, 2024), although only within systems where they provide equal distributions of benefits and food security (Chong *et al.*, 2021; Shahab *et al.*, 2024). Studies diverge on whether the energy transition pathway can align with environmental protection. While renewable energy is broadly viewed as ecologically beneficial, some work cautions against unsustainable biomass use and inadequate management of renewable projects, which can undermine environmental and social goals (Aladejare, 2023).

In general, Nigeria is moderately prepared to undergo a renewable energy transition that is based on biodiesel. The nation is characterized by good feedstock potential and developing research capacities, but remains plagued by instability in its institutions, lack of sufficient investment, and underdeveloped infrastructure. The policy framework in Nigeria is described in the literature as ambitious and inadequately operationalised and there is a need to have enforceable standards, inter-agency integration, and predictable financing mechanisms. The most realistic solution to curbing the policy-practice gap in Nigeria seems to be a hybrid solution involving the use of waste-based feedstocks in the medium-term, and sustainable crop-based feedstocks in the long-term.

4.6. Social and Environmental Implications

The preparation of the transition to biodiesel and renewable energy in Nigeria should be evaluated not only on a technical and economic dimension, but also on an environmental and social scale. Among the critical factors requiring attention are climate mitigation potential, threats to land-use and biodiversity, fuel security and price stability prospects, and prospects of rural development and employment.

4.7. Climate Impact

Life-cycle assessments (LCAs) will always be needed to measure the possibility of mitigating greenhouse gas (GHG) emissions caused by biodiesel as compared to the traditional fossil diesel. The existing empirical studies reveal that biodiesel made using renewable feedstocks can contribute significantly to reducing emissions and hence promoting global decarbonization (Babalola & Alimin, 2024; Elum & Momodu, 2017). In the Nigerian scenario, the amount of GHG saved depends on feedstock selection as well as production techniques; the production systems based on the waste usually have a higher record of environmental benefits. In addition, the integration of renewable energy carriers, such as solar, wind, and biogas, into agricultural and industrial processes can enhance even further enhance the benefits of climate and enlarge the rural availability of energy services (Olisah *et al.*, 2025).

4.8. Land-Use and Biodiversity

Large-scale cultivation of feedstock crops like palm oil comes with high risks that include the destruction of forests, biodiversity, and the displacement of communities (Simbolon & Aisyah, 2022; McDonald *et al.*, 2019). Sustainable land stewardship plans and effective regulations are, therefore, necessary (Bununu *et al.*, 2023). Land-use change could be alleviated by circular bioeconomy concepts, such as the waste cooking oil utilization and agricultural residues to provide alternative renewable feedstocks (Wagh *et al.*, 2024; Fetanat *et al.*, 2024). The crucial aspects of soil health, chemical inputs, water quality, and biodiversity protection are some of the main attributes of the biomass-crop alternatives of food products accurately evaluated through environmental sustainability assessments (Kumar & Kumar, 2024).

4.9. Indicators of food security and price stability

The realization of biodiesel directly cuts with the dynamics of Nigerian food security. Distributing edible oils (especially palm oil) to the energy market may lead to higher food prices and potentially make food less affordable for low-income populations (Simbolon & Aisyah, 2022). The energy-water-food (EWF) nexus worldview highlights the imperative to plan resources in an integrated manner (not to trade off energy security and food supply) (Chong *et al.*, 2021). Non-edible feedstocks should be encouraged, and sustainable use of the land and water should be promoted to make sure that the fuel growth of biodiesel does not negatively affect food availability (Shahab *et al.*, 2024).

4.10. Rural Development and Jobs

The production of biodiesel has the capacity to start and fuel rural development, the creation of jobs, and alleviation of poverty. Outreach programs provide opportunities to farmers to build smallholder infrastructures capable of boosting the local economy by involving smallholder farmers directly in the cultivation and processing of feedstocks and creating inclusive value chains (Emezirinwune *et al.*, 2024; Shahab *et al.*, 2024). Green jobs can also be created in the rural, industrial, and coastal areas by the bioeconomy (Fetanat *et al.*, 2024). Complementary renewable energy designs, e.g., biogas, can enrich domestic welfare through lowered energy costs, better health, and higher agricultural industry (Ahmad & Jabeen, 2023). Such are the socio-economic advantages that highlight the future of biodiesel to contribute to the growth of sustainable development when managed in an inclusive and equal manner.

4.11. Readiness Assessment

The preparedness of biodiesel and renewable energy transition in Nigeria is a complex problem that involves policy, feedstock, technology, finance, and environmental issues. Across dimensions, there are unique strengths and weaknesses that, when taken together, demonstrate the readiness of the nation. Although there are established policy frameworks, including the National Renewable Energy and Energy Efficiency Policy (NREEEP), that define strategic objectives, the implementation challenges and lack of enforcing them significantly limit their effectiveness (Adedokun *et al.*, 2023; Olanrele, 2021). At the same time, Nigeria has a diverse source of feedstocks including agricultural residues and microalgae, as well as invasive species, like water hyacinth, which can be utilized to make biodiesel; however, insufficient land-use planning and sustainability standards and resource-efficiency advice remain central factors hindering mass uptake (Igwebuike, 2023; Nega et al., 2024; Shehu & Clarke, 2020). State-of-the-art advancements are largely found in the research stage, and some of the promising innovations are the use of ultrasound couples and electro-fermentation (Patle *et al.*, 2020; Virdis *et al.*, 2022). It is constrained, however, by the infrastructural inadequacies, as well as the high energy requirements, to make the transition between laboratory-scale projects to the production of industry scale (Rocha-Meneses *et al.*, 2023). Financial preparedness is also low because of constant difficulties in the investment atmosphere, macroeconomic constraints, and the inability to acquire low-cost financing are still limiting development (Adeshina *et al.*, 2024; Adedokun *et al.*, 2023). On the environmental side, biodiesel has tremendous potential in reducing greenhouse effects and fostering a circular economy; however, land-use change and ecological trade-offs pose hazards that require a delicate balance (Igwebuike, 2023; Alamoodi *et al.*, 2024). As summarized in Table 2, Nigeria's readiness in the country on most aspects of biodiesel transition is moderate, with strong scores on access to feedstock and on-going technological research, and with significant gaps exhibited in the area of finance and enforcement of policies, which hinder massive implementation. Overall, despite the technical and feedstock potential that Nigeria has, persistent institutional weaknesses and funding limits continue to pose the most significant obstacle to large-scale adoption of biodiesel.

Table 2. Summary of Nigeria's Readiness for Biodiesel Transition

Dimension	Current Status	Strengths	Weaknesses	Readiness Level
Policy	Policies exist, but are weakly implemented	Existence of NREEEP (2015) and energy transition plans; signals government intent (Olanrele, 2021; Okedu *et al.*, 2024)	Poor implementation, corruption, lack of continuity, and underrepresentation of biodiesel/biogas (Adedokun *et al.*, 2023; Nwankwo *et al.*, 2024)	Low–Medium
Feedstock	Abundant but underutilized	Diverse options: edible oils, residues, microalgae, sewage sludge, invasive species like water hyacinth (Igwebuike, 2023; Garg *et al.*, 2023; Nega *et al.*, 2024; Srivastava *et al.*, 2018)	Sustainability risks, poor land-use mapping, high resource inputs (Shehu & Clarke, 2020; Rocha-Meneses *et al.*, 2023)	Medium
Technology	Active R&D, limited scale	Advanced methods under study (ultrasound, electro-fermentation, MOFs); flexible feedstock processes (Patle *et al.*, 2020; Virdis *et al.*, 2022; Shanthini *et al.*, 2025; Garg *et al.*, 2023)	Mostly at lab scale, energy-intensive, industrial scalability challenges (Rocha-Meneses *et al.*, 2023; Adedokun *et al.*, 2023)	Medium
Finance	Weak investment climate	Growing awareness of climate finance; opportunities for PPPs and private capital (Li, 2023; Adedokun *et al.*, 2023)	Limited affordable financing, macroeconomic instability, investor risk perception (Adeshina *et al.*, 2024; Adedokun *et al.*, 2023)	Low–Medium
Environment	Potentially positive impact	GHG reduction potential, waste-to-energy pathways, circular economy prospects (Igwebuike, 2023; Obada *et al.*, 2024; Nega *et al.*, 2024; Srivastava *et al.*, 2018)	Land-use change risks, energy-intensive production, and ecological impacts are under-researched (Rocha-Meneses *et al.*, 2023; Alamoodi *et al.*, 2024)	Medium

4.12. Challenges and Gaps

Despite the prospects of Nigeria moving into biodiesel and other renewable energy sources, it is plagued with numerous challenges and systemic gaps (Avwioroko, 2023; Olabomi, 2024). Both of them are related interdependently in terms of technical, institutional, financial, and environmental levels, which negatively impacts the comprehensiveness of the national preparedness. The major problems include poor data on feedstock, weak enforcement of policies, low levels of private investment, bottlenecks in infrastructure development, and lack of sustainability protection (Dinneya-Onuoha, 2025; Ajia, 2025). Nigeria is limited to biodiesel and renewable energy transitions because of shortcomings in feedstock data, policy, and implementation, and private investment, infrastructure, and sustainability protection, which are captured as key obstacles in Table 3.

Table 3. Key Challenges and Gaps in Nigeria's Biodiesel Transition

Challenge	Description	Sources
Feedstock Data Gaps	Lack of reliable and consistent data on algae, Jatropha, WCO, and lignocellulosic biomass limits planning & scale-up.	Shehu & Clarke (2020); Patle *et al.* (2020); Aliyu *et al.* (2017); Towoju (2022); Akuru & Okoro (2014); Garg *et al.* (2023)
Weak Policy Enforcement	Policies exist (e.g., NREEEP), but poor monitoring, accountability, and the absence of a dedicated regulatory body reduce effectiveness.	Ajia (2025); Bala *et al.* (2025); Olanrele (2023); Arowolo & Douglas (2022); Adedokun *et al.* (2023); Omoregie (2020)
Limited Private Investment	High capital requirements, macroeconomic instability, exchange rate volatility, and weak incentives deter investors.	Zhuang *et al.* (2025); Olugbenga *et al.* (2025); Adeshina *et al.* (2024); Oyegbile & Okeke (2025); Lazaro *et al.* (2023)
Infrastructure Bottlenecks	Outdated, unreliable grids and insufficient transmission/ distribution networks hinder the integration of renewable energy.	Adedokun *et al.* (2023); Dinneya-Onuoha (2025)
Sustainability Safeguards	Risks of deforestation, biodiversity loss, and food insecurity without sustainable feedstock and land-use practices.	Castro *et al.* (2019); Fan *et al.* (2019); Vukusic *et al.* (2023); Alamoodi *et al.* (2024)

Table 2 provides evidence of Nigeria having an average preparedness under policy, feedstock, technology, finance, and environmental aspects; however, as Table 3 highlights, the challenges and systemic weaknesses that undermine the potential. By integrating the data from both tables, it becomes evident that despite Nigeria having all these resources as feedstock, emerging technologies, and a policy environment on renewable bioenergy, there are inherent lag impacts that hamper the successful scaling of biodiesel implementation: lack of reliable feedstock information, insufficient policy implementation, insufficient investment, infrastructural bottlenecks, and ineffective sustainability protection.

4.13. Recommendations and Roadmap

The biodiesel transition process in Nigeria would require a multi-dimensional program that would take care of both long-term sustainability and short-term priorities. This road map should incorporate policy changes, feedstock growth, infrastructural growth, and technology development, and must be connected with environmental and socio-economic objectives (Ahmad *et al.*, 2025).

i. Short-term (0-2 years): Interim solutions should involve a national database on the availability of feedstock to submit accurate information on the presence and potential of available large sources of waste cooking oil, non-edible oilseeds, and algae (Towoju, 2022; Ahmad *et al.*, 2025). The compatibility of biofuels national biodiesel standards that are in line with the ASTM and EN standards needs to be provided to ensure comprehension of fuel compatibility and quality. The small-scale pilot projects will have to confirm the technical feasibility, streamline the processes, and establish the capacity on local industry and research institutions (Ahmad *et al.*, 2025).

ii. Medium term (2-5 years): Early profits must be cemented at this stage, with the initial step being the introduction of blending programmes (e.g., B5, B10) to create the market demand and to guarantee the policy continuity (Ahmad *et al.*, 2025). Incentive structures are needed to make the participation of the private-sector possible, and they include tax exemptions, subsidies and concessional financing (Oduro *et al.*, 2024). Concurrent waste-cooking-oil-utilisation-collection systems can also ensure cheap and sustainable feedstocks and reduce environmental waste (Rocha-Meneses *et al.*, 2023).

iii. Long term (5-10 years): The last step is to ramp up the production and to integrate the use of bio-diesel into the national energy transition policy of Nigeria. The shift to blends with a higher content (B 20+) will involve making significant investments in large-scale processing facilities and specific cultivation of feedstock (Ahmad *et al.*, 2025). The use of sustainability-certification programs will provide conformance to environmental and social protection, and export market exploration would make Nigeria a competitive provider at the regional level (Alamoodi *et al.*, 2024).

Throughout the stages, cost reduction and competitiveness require optimization of production processes by advanced modelling techniques, diversification of feedstock, and greater catalyst efficiency (Rocha-Meneses *et al.*, 2023). Notably, Nigeria should not rush into institutional transitions to achieve its energy transition; instead, the transition should pass through a more institutional route, problem identification, and alignment between stakeholders into mobilization and institutionalization (Chipangamate & Nwaila, 2023). Long-run success cannot happen without enabling conditions, such as financial incentives, politics, favorable regulations, and social acceptance (Adedokun *et al.*, 2023). The frameworks involved in multi-criteria decision-making must be incorporated into the roadmap to facilitate a balanced economy, environmental impact, and social impact consideration (Alamoodi *et al.*, 2024).

5. CONCLUSION

The conversion of Nigeria into biodiesel and renewable energy has both great opportunities and long-term threats. It has been shown that, even with a strong policy base and a large portfolio of feedstock, the systemic problems, especially institutional fragmentation, low levels of private investment, and infrastructural bottlenecks still bring the progress down. Two of these can be reviewed as bad policy implementation and financial insecurity as the most serious challenges. On the other hand, the short-term prospects of using waste cooking oil as a circular-economy feedstock as a realistic path to sustainable scaling. The success of a successful transition will involve coordinated implementation of policies, clear national standard on bio-diesel, reinforced partnership between the government and the private sector and special focus on fiscal incentives. In the long run, Nigeria needs to institutionalize sustainability protection, technological transfer, and increase R&D capacity to transition pilot projects into an industrial-scale production. With such actions in place, biodiesel can not only be a substitute fuel but also stimulate economic diversification, economic growth, and climate resilience in Nigeria as part of a wider renewable energy transition.

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