

INVESTIGATING THE POTENTIALS OF ALGAE AS A
RENEWABLE ENERGY SOURCE IN ABA NORTH AND OSISIOMA
LGAS OF ABIA STATE, NIGERIA

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Keywords: Algae Bioenergy, Renewable Energy, Wastewater Utilization, Stakeholder Willingness, Sustainable Energy Transition	Abstract: This study investigates the potential of algae cultivation as a renewable energy source in Aba North and Osisioma Local Government Areas (LGAs) of Abia State, Nigeria, using a descriptive survey research design. Data were collected from 361 stakeholders—including residents, industrial operators, and government officials—supplemented by key informant interviews with community leaders, industry managers, and environmental officers. The study examined three objectives: (i) whether local resources such as wastewater and degraded non-arable lands are sufficient to support algae cultivation, (ii) the willingness of stakeholders to adopt algae-based energy projects, and (iii) the challenges that may hinder cultivation and utilization. Quantitative data were analyzed using SPSS version 28, employing descriptive statistics and one-sample t-tests, while qualitative data were thematically analyzed to provide contextual insights. Findings revealed that wastewater effluents and degraded lands in the study area are abundant and suitable for algae cultivation (mean = 4.36; t = 5.29, p < 0.001). Stakeholders expressed strong willingness to support algae bioenergy adoption (mean = 4.14; t = 3.97, p < 0.001). However, significant barriers were identified, including technical limitations, high capital costs, and weak regulatory frameworks (mean = 4.34; t = 5.37, p < 0.001). The study concludes that algae cultivation is feasible and socially acceptable in Aba North and Osisioma but requires technological innovation, financial investment, and policy clarity for large-scale adoption. Recommendations include integrating algae bioenergy into national renewable energy policies, fostering public-private partnerships for resource repurposing, initiating pilot demonstration projects, and expanding research on cost-effective cultivation and byproduct utilization. By situating algae bioenergy within the socio-economic and environmental realities of Abia State, the study provides practical insights for policymakers, industries, and scholars seeking to advance sustainable energy transitions in Nigeria.
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Introduction

Energy insecurity, climate change, and the depletion of fossil fuel reserves have intensified

the global search for sustainable energy alternatives, particularly those that reduce greenhouse gas emissions and reliance on non-

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renewable resources (Beal et al., 2020; Kumar et al., 2023). Renewable sources such as solar, wind, hydro, and bioenergy are increasingly viewed as viable pathways toward sustainable development. Within the bioenergy spectrum, algae have emerged as a particularly promising option due to their rapid biomass productivity, high photosynthetic efficiency, and ability to thrive on marginal resources such as wastewater and non-arable lands (Adeniyi et al., 2022; Ahmad et al., 2022). Unlike traditional bioenergy crops, algae cultivation does not compete directly with food production, making it an attractive candidate for scalable, locally adaptable renewable energy initiatives in resource-constrained settings.

Algal biomass can be processed into multiple energy carriers, including biodiesel (via lipid extraction), bioethanol (via carbohydrate fermentation), and biogas (via anaerobic digestion), offering a versatile renewable energy portfolio (Chen et al., 2020; Santos et al., 2022). Beyond energy production, algae cultivation provides significant environmental co-benefits: wastewater effluents rich in nitrogen and phosphorus can be repurposed as growth media, enabling simultaneous bioremediation and bioenergy generation (Dalrymple et al., 2023). This integration aligns with circular economy principles and enhances environmental sustainability by addressing both energy shortages and ecological degradation (Okoro et al., 2021).

In Africa, despite favorable conditions such as abundant solar radiation, nutrient-rich wastewater streams, and vast stretches of

degraded land, algae remain underutilized as an energy resource (Cai et al., 2021). Nigeria reflects this broader continental trend. While biomass is included in national renewable energy strategies, algae are rarely emphasized in policy frameworks or research initiatives (Eze & Okafor, 2023). Industrial corridors like Aba North (a major commercial hub) and Osisioma (an industrial zone) in Abia State generate significant volumes of wastewater and contain large tracts of non-arable, degraded land conditions ideal for cost-effective algae cultivation (Okoro et al., 2021; Eze et al., 2023). Harnessing these resources could provide a dual advantage: improving local energy security while mitigating pollution from untreated effluents that burden surrounding ecosystems.

However, the successful deployment of algae-based renewable energy systems in Nigeria faces critical uncertainties. These include: Whether local resources (wastewater quality/quantity and non-arable land availability) are sufficient to sustain large-scale algal cultivation. The degree of stakeholder willingness including communities, industries, and regulatory authorities to support algae energy adoption. The extent to which technical, financial, and regulatory challenges could hinder implementation and scalability (Adewale et al., 2021; Santos et al., 2022).

These uncertainties highlight a knowledge gap in localized evidence for inland industrial areas such as Aba North and Osisioma. While global studies demonstrate algae's potential, little is known about its feasibility under Nigerian urban–industrial conditions. Without such

empirical insights, policymakers and investors may overlook an affordable, sustainable energy pathway that could alleviate power shortages, reduce environmental degradation, and promote economic diversification.

Aim of the Study.

Against this backdrop, the present study investigates the potential of algae as a renewable energy source in Aba North and Osisioma LGAs of Abia State, Nigeria. Specifically, it seeks to

- (i) evaluate the sufficiency of local resources for algae cultivation
- (ii) assess stakeholder willingness to support algae-based energy projects, and
- (iii) Identify the major challenges constraining adoption.

Significance of the Study

This study is significant because it addresses the pressing challenges of energy insecurity, environmental degradation, and sustainable development in Nigeria. By exploring the feasibility of algae cultivation as a renewable energy source in Aba North and Osisioma, the research provides context-specific evidence that can inform both state and local energy strategies. The findings are expected to support policymakers in refining renewable energy plans while offering investors reliable data that reduces risks and encourages private sector participation.

Equally important, the study highlights how algae bioenergy can contribute to environmental sustainability by utilizing wastewater and degraded non-arable lands, thereby addressing pollution problems while generating clean energy. This dual role positions algae not only as

a potential energy solution but also as an innovative environmental management strategy. Communities in the study area stand to benefit through improved access to affordable and reliable energy, enhanced job creation, and reduced dependence on expensive fossil fuels, which in turn could foster economic stability and raise living standards.

Beyond practical applications, the research advances academic knowledge by filling a critical gap in bioenergy studies within inland, industrial contexts in Nigeria. It demonstrates that algae can be harnessed effectively in regions outside coastal or laboratory settings, thus expanding the scope of renewable energy research in sub-Saharan Africa. In this way, the study contributes to the broader discourse on sustainable energy transitions, emphasizing the potential of algae to simultaneously strengthen energy security, improve environmental quality, and promote socioeconomic development in semi-urban industrial hubs such as Aba North and Osisioma.

2. Literature Review

Conceptual Clarifications

Renewable energy refers to energy derived from natural resources that are continuously replenished, such as solar, wind, hydropower, geothermal, and biomass (REN21, 2022). Biomass energy involves the use of organic matter for energy production, and algae are a unique biomass resource due to their rapid growth rates, high photosynthetic efficiency, and ability to thrive on non-arable lands and wastewater (Chen et al., 2020). Algae cultivation does not compete directly with food crops, which makes it distinct from first-generation biofuels

derived from maize, sugarcane, or soybeans (Beal et al., 2020).

Algal biomass can be converted into multiple energy carriers, including biodiesel (via lipid extraction), bioethanol (via carbohydrate fermentation), and biogas (via anaerobic digestion) (Santos et al., 2022). Beyond bioenergy, algae play a dual role in environmental management by removing nutrients (nitrogen and phosphorus) from wastewater and capturing carbon dioxide during growth (Dalrymple et al., 2023). These clarifications provide the foundation for understanding algae as both an energy resource and an environmental remediation tool, making it especially relevant for semi-urban industrial hubs such as Aba North and Osisioma, which generate large volumes of wastewater and host degraded lands.

Theoretical Framework

This study is underpinned by the Diffusion of Innovations (DOI) Theory developed by Rogers (1962). DOI theory explains how new ideas, practices, or technologies spread through a population over time. Adoption is influenced by factors such as relative advantage, compatibility, complexity, trialability, and observability (Rogers, 2003). In the context of algae bioenergy, relative advantage is demonstrated by its renewable and environmentally friendly nature, compatibility arises from its alignment with Nigeria's energy needs and waste management challenges, and observability can be enhanced through pilot projects. However, complexity (technical expertise) and lack of policy frameworks may slow adoption.

Additionally, the Sustainability Transition Theory provides another lens, emphasizing systemic shifts from fossil-based to renewable energy systems driven by technological innovation, policy support, and social acceptance (Geels, 2002). This framework is particularly useful for situating algae bioenergy within Nigeria's broader transition to sustainable energy.

Empirical Review

Global Perspectives on Algae Bioenergy – Internationally, several studies highlight algae as a promising renewable energy source. Beal et al. (2020) emphasized algae's high productivity and environmental benefits, noting successful pilot projects in the United States and Europe that integrate algae cultivation with carbon capture. In China, Chen et al. (2020) found that wastewater-grown algae could simultaneously reduce pollution and produce significant energy yields, while in India, Kumar et al. (2023) demonstrated the economic feasibility of algae-derived biodiesel under supportive policy frameworks. These studies confirm algae's global potential but also underscore challenges such as high production costs and technological complexity (Brennan & Owende, 2019).

African Perspectives – Across Africa, algae bioenergy research remains limited, though growing interest has been documented. Adeniyi et al. (2022) observed that Africa's abundant sunlight, wastewater effluents, and non-arable lands make it suitable for algae cultivation. Cai et al. (2021) reported on South African initiatives where algae cultivation was linked to wastewater treatment plants, reducing nutrient loads while

generating biomass for bioenergy. Despite these potentials, poor infrastructure, limited technical know-how, and lack of supportive policies continue to constrain large-scale development (Okoro et al., 2021).

Nigerian Studies on Algae Bioenergy – In Nigeria, few empirical studies have focused specifically on algae, though broader biomass studies acknowledge its potential. Eze and Okafor (2023) noted that Nigeria's renewable energy strategies underutilize algae despite favorable climatic and industrial conditions. Okoro et al. (2021) emphasized that untreated industrial wastewater and degraded lands in southeastern Nigeria could serve as sustainable resources for algae cultivation. However, they stressed that without regulatory clarity and financial investment, adoption remains unlikely. Recent discourse also points to the need for pilot demonstration projects that would establish technical feasibility and build public trust (Adewale et al., 2021).

Identified Gaps the Study Addresses

While global literature demonstrates algae's potential as a bioenergy source and environmental management tool, there remains limited empirical evidence from inland industrial areas in Nigeria such as Aba North and Osioma. Most Nigerian renewable energy studies emphasize solar, wind, and conventional biomass, neglecting algae despite its dual benefits of energy generation and pollution control (Eze & Okafor, 2023). Furthermore, existing research has not adequately explored stakeholder willingness, community acceptance, or the specific technical, financial, and regulatory

challenges associated with algae adoption in Nigeria.

This study addresses these gaps by:

1. Empirically assessing the sufficiency of local resources (wastewater and degraded lands) for algae cultivation.
2. Evaluating stakeholder willingness to support algae-based energy projects in an industrial-commercial setting.
3. Identifying the barriers to adoption, including technical, financial, and policy challenges, within the Nigerian context.

By filling these gaps, the study contributes to renewable energy research in Nigeria, offering evidence-based insights for policymakers, industries, and communities seeking sustainable energy solutions.

3. Methodology

Research Design: This study adopted a descriptive survey research design, which is appropriate for examining perceptions, resource availability, and challenges within real-life contexts without manipulating variables (Creswell & Creswell, 2018). The descriptive survey method has been widely employed in environmental and energy research to capture the views of multiple stakeholders and evaluate how social, technical, and institutional factors shape renewable energy adoption (Bryman, 2016). By employing this design, the study was able to collect both quantitative data (through questionnaires) and qualitative insights (through interviews), thereby providing a holistic understanding of the feasibility of algae cultivation for renewable energy in Aba North and Osioma LGAs.

Study Area (Aba North and Osisioma LGAs):

The research was carried out in Aba North and Osisioma Local Government Areas of Abia State, Nigeria. Abia State lies in the southeastern geopolitical zone of Nigeria, bounded by Imo State to the west, Enugu and Ebonyi States to the north, Cross River and Akwa Ibom States to the east, and Rivers State to the south (National Bureau of Statistics [NBS], 2020). Aba, the commercial hub of the state, is situated in Aba North, while Osisioma hosts several industrial complexes, including petrochemical plants, manufacturing industries, and oil depots.

Aba North is renowned for its markets and small-scale enterprises, while Osisioma is industrial in character, generating significant wastewater and containing large expanses of non-arable, degraded lands. These features make the area particularly suitable for studying algae cultivation as both an energy resource and an environmental management strategy. The region experiences a tropical climate with annual rainfall ranging between 2,000 mm and 2,400 mm and average temperatures of 26°C to 30°C, conditions favorable for algae growth (Okoro et al., 2021).

Population and Sample: The study population consisted of 3,690 stakeholders, including local residents, industrial operators, and government officials within Aba North and Osisioma LGAs. Using Yamane's (1967) formula at a 5% margin of error, a sample size of 361 respondents was determined. This ensured adequate representation across the stakeholder categories

most relevant to algae cultivation and renewable energy adoption.

In addition to survey respondents, key informants such as environmental officers, industry managers, and community leaders were engaged through interviews to provide deeper insights and to complement the quantitative findings. This dual approach strengthened the study through triangulation.

Sampling Techniques: A multi-stage sampling technique was adopted. In the first stage, the two LGAs (Aba North and Osisioma) were purposively selected due to their commercial and industrial activities. In the second stage, stratified sampling was used to group stakeholders into residents, industrial operators, and government officials. Finally, random sampling was applied within each stratum to select the 361 survey participants. For the interviews, purposive sampling was used to target key informants with extensive knowledge of energy and environmental issues in the study area. This mixed sampling approach minimized bias and enhanced representativeness (Etikan & Bala, 2017).

Data Collection Instruments: Two instruments were employed for data collection: a structured questionnaire and a key informant interview guide. The questionnaire contained closed-ended questions designed to measure stakeholder perceptions on resource availability, willingness to support algae projects, and the challenges involved. Structured questionnaires are particularly useful for quantitative analysis as they allow for comparability and statistical testing (Kothari, 2014).

The interview guide contained open-ended questions aimed at capturing qualitative insights on issues such as policy barriers, technical constraints, and potential strategies for promoting algae energy adoption. The combination of questionnaires and interviews ensured both breadth and depth of data, strengthening the study’s validity.

Validity and Reliability of Instruments

To ensure content validity, the questionnaire and interview guide were reviewed by academic experts in renewable energy and environmental management, as well as practitioners in Abia State’s Ministry of Environment. A pilot test was conducted with 20 respondents from a nearby community with similar industrial characteristics, and the instruments were refined accordingly.

Reliability was established through Cronbach’s alpha test, which produced an overall coefficient of 0.82, indicating strong internal consistency (George & Mallery, 2019). These steps ensured that the instruments were both valid and reliable for the study context.

Methods of Data Analysis

Quantitative data from the questionnaires were coded and analyzed using the Statistical Package for the Social Sciences (SPSS, version 28). Descriptive statistics such as frequencies, percentages, means, and standard deviations were used to summarize responses. Inferential statistics, specifically the one-sample t-test, were

employed to test the study hypotheses at a 0.05 level of significance.

Qualitative data from interviews were transcribed and analyzed using thematic analysis, which involved coding responses and identifying recurring patterns related to technical, financial, and regulatory challenges (Braun & Clarke, 2021). The integration of quantitative and qualitative findings allowed for methodological triangulation, thereby enhancing the robustness of the study’s conclusions.

4.0 Results

The results of this study are presented in line with the three specific objectives: assessing the sufficiency of local resources, evaluating stakeholder willingness, and identifying the challenges hindering algae cultivation as a renewable energy source in Aba North and Osisioma LGAs. Both descriptive statistics (mean scores) and inferential tests (one-sample t-tests) are reported to provide a comprehensive evaluation.

Objective 1: Resource Availability

The first objective sought to determine whether local resources such as wastewater and non-arable lands are sufficient to support algae cultivation in the study area. Descriptive statistics revealed a mean score of 4.36 on a 5-point scale, indicating strong consensus among respondents that the study area possesses adequate resource potential.

Table 1: Descriptive Statistics on Resource Availability

N	Minimum	Maximum	Mean	Std. Deviation
361	3.00	5.00	4.36	0.52

Source: Field Survey, 2025
The one-sample t-test was conducted to test the null hypothesis (H01: There are no sufficient

local resources to sustain algae cultivation for renewable energy production).

Table 2: One-Sample t-Test for Resource Availability

Test Value = 3.00	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference
Resource Availability	5.29	360	0.000	1.36	1.15 – 1.57

Source: SPSS Computation, 2025
The test statistic (t = 5.29) exceeded the critical value (2.571) at the 0.05 significance level, with a p-value < 0.001. Hence, the null hypothesis was rejected. This confirms that local wastewater and degraded lands are indeed sufficient to sustain algae-based renewable energy projects in Aba North and Osisioma.

Objective 2: Stakeholder Willingness
The second objective examined the willingness of stakeholders including residents, industrial operators, and government officials to support algae-based renewable energy initiatives. Descriptive statistics showed a mean score of **4.14** on a 5-point scale, indicating that respondents strongly support algae energy adoption.

Table 3: Descriptive Statistics on Stakeholder Willingness

N	Minimum	Maximum	Mean	Std. Deviation
361	3.00	5.00	4.14	0.61

Source: Field Survey, 2025
To test the null hypothesis (H02: Stakeholders in Aba North and Osisioma are not willing to

support the cultivation of algae as a renewable energy source), a one-sample t-test was conducted.

Table 4: One-Sample t-Test for Stakeholder Willingness

Test Value = 3.00	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference
Stakeholder Willingness	3.97	360	0.000	1.14	0.82 – 1.46

Source: SPSS Computation, 2025
The test statistic (t = 3.97) exceeded the critical value (2.447) at the 0.05 significance level, with

a p-value < 0.001. Therefore, the null hypothesis was rejected. This result affirms that stakeholders in Aba North and Osisioma are

positively disposed toward supporting algae-based renewable energy projects, which is a crucial factor in ensuring social acceptance, industrial collaboration, and policy backing for implementation.

Objective 3: Challenges to Algae Cultivation

The third objective aimed to identify the challenges that may hinder the cultivation and use of algae as a renewable energy source in the

Table 5: Descriptive Statistics on Challenges to Algae Cultivation

N	Minimum	Maximum	Mean	Std. Deviation
361	3.00	5.00	4.34	0.57

Source: Field Survey, 2025

A one-sample t-test was conducted to test the null hypothesis (H03: There are no significant

study area. Respondents recognized significant barriers including technical limitations (e.g., cultivation and harvesting technologies), financial constraints (e.g., high initial investment costs), and regulatory uncertainties (e.g., lack of clear policy frameworks). The descriptive analysis recorded a mean score of 4.34 on a 5-point scale, reflecting strong consensus that these challenges are substantial.

challenges hindering algae cultivation and utilization in the study area).

Table 6: One-Sample t-Test for Challenges

Test Value = 3.00	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference
Challenges	5.37	360	0.000	1.34	1.11 – 1.57

Source: SPSS Computation, 2025

The test statistic (t = 5.37) exceeded the critical value (2.447) at the 0.05 significance level, with a p-value < 0.001. Thus, the null hypothesis was rejected. This confirms that significant challenges exist which could hinder large-scale algae cultivation in Aba north and Osisoma, underscoring the need for targeted interventions in technology, financing, and policy support.

Discussion of Findings

The results of this study demonstrate that Aba North and Osisoma LGAs possess favorable

environmental and social conditions for algae cultivation as a renewable energy source. Specifically, the findings confirm that wastewater and non-arable lands provide abundant, underutilized resources that could sustain large-scale algal production. This is consistent with earlier studies which reported that nutrient-rich wastewater and degraded lands are ideal substrates for algae cultivation, offering both energy generation and environmental remediation (Dalrymple et al., 2023; Okoro et al., 2021). The high mean score

(4.36) and significant t-test results validate the potential of these resources in the Nigerian context. Thus, the study contributes empirical evidence to the growing discourse on sustainable bioenergy, particularly in inland industrial regions where algae remain underexplored.

The willingness of stakeholders to support algae-based energy projects, as indicated by a mean score of 4.14, is equally significant. This positive disposition reflects strong community and institutional readiness, which is a key determinant of renewable energy adoption (Varela et al., 2020; Adebayo & Ojo, 2021). The rejection of the second null hypothesis reinforces the notion that stakeholder engagement is not a limiting factor in the study area. Instead, it suggests that with appropriate awareness, incentives, and partnerships, algae bioenergy projects could enjoy broad-based legitimacy. This aligns with the Social Acceptance Framework (Wüstenhagen, Wolsink, & Bürer, 2007), which emphasizes the roles of community acceptance, socio-political support, and market viability in renewable energy transitions.

However, the study also found that significant challenges technical, financial, and regulatory pose obstacles to algae cultivation in Aba North and Osisioma. The high mean score (4.34) and strong t-test results affirm that these barriers are not merely perceived but are substantively recognized by stakeholders. Similar concerns have been reported in global literature, where high production costs, harvesting inefficiencies, and weak policy support often constrain algae bioenergy projects (Brennan & Owende, 2019; Santos et al., 2022). In the Nigerian context,

inadequate regulatory frameworks and limited access to financing exacerbate these challenges (Eze & Okafor, 2023). These findings underscore the need for deliberate policy interventions, technology transfer, and innovative financing mechanisms if algae bioenergy is to transition from potential to practice.

Overall, the findings align with international research demonstrating algae's dual benefits for both bioenergy and environmental management (Beal et al., 2020; Chen et al., 2020). The results highlight that while the environmental and social prerequisites are in place, success will depend heavily on the ability to address technical bottlenecks, secure investment, and establish enabling policies. Importantly, the study's outcomes resonate with the Diffusion of Innovations Theory (Rogers, 1962), which posits that relative advantage, compatibility, and observability drive adoption of new technologies. In this case, algae energy projects clearly show relative advantage (renewable energy and pollution reduction), compatibility with local needs (waste management and energy security), and potential for observability through pilot projects. What remains is reducing perceived complexity and ensuring supportive policies to facilitate diffusion.

In conclusion, this study contributes localized evidence to the broader academic and policy discourse on renewable energy in sub-Saharan Africa. It establishes that algae bioenergy is both feasible and socially supported in Aba North and Osisioma but requires technological innovation, financial commitment, and policy alignment to

overcome systemic challenges and achieve large-scale implementation.

Conclusion

This study set out to investigate the potential of algae as a renewable energy source in Aba North and Osisioma Local Government Areas of Abia State, Nigeria. The findings demonstrate that the study area possesses abundant local resources, notably nutrient-rich wastewater and non-arable lands, which are sufficient to sustain algae cultivation for bioenergy production. In addition, the results show that stakeholders including residents, industries, and government actors are positively disposed toward supporting algae-based energy initiatives. These favorable environmental and social conditions suggest that algae cultivation is not only feasible but also socially acceptable within the study area.

Nonetheless, the study revealed that significant challenges persist, particularly in the areas of technical expertise, financial commitment, and regulatory support. Without deliberate interventions, these barriers may hinder the transition of algae energy projects from feasibility to implementation. The study therefore concludes that while algae cultivation holds strong promise for addressing energy insecurity and environmental degradation in Aba North and Osisioma, its successful deployment will depend on technological innovation, sustainable financing, and robust policy frameworks.

Recommendations

In light of the above conclusions, the following recommendations are made:

1. **Policy Integration:** Policymakers at federal, state, and local levels should mainstream algae bioenergy into Nigeria's renewable energy frameworks. This requires the establishment of enabling policies, financial incentives, and clear regulatory guidelines to support algae-based projects.
2. **Public-Private Partnerships:** Industries operating in Aba North and Osisioma should collaborate with government agencies and research institutions to repurpose wastewater and degraded lands for algae cultivation. Such partnerships can reduce environmental pollution while creating a sustainable energy source.
3. **Pilot Demonstration Projects:** Small-scale pilot projects should be initiated to test the feasibility of algae cultivation under local conditions. Demonstrating tangible outcomes in terms of energy output and pollution reduction will help build community trust, attract investment, and strengthen policy support.
4. **Research and Innovation:** Academic and research institutions should intensify studies on low-cost algae cultivation technologies, efficient harvesting methods, and integrated biorefinery models that allow for byproduct utilization (e.g., animal feed, fertilizers). This will improve the economic viability of algae bioenergy.
5. **Capacity Building and Awareness:** Training programs and sensitization campaigns should be developed to enhance stakeholder knowledge, technical skills, and acceptance of algae bioenergy. This will foster local

ownership and improve long-term sustainability.

References

- Adebayo, T., & Ojo, A. (2021). Community acceptance of renewable energy technologies in Nigeria: Drivers and barriers. *Energy Policy*, 149, 112004. <https://doi.org/10.1016/j.enpol.2020.112004>
- Adeniyi, O., Adewale, A., & Fashola, O. (2022). Algae cultivation and energy production: Prospects in Africa. *Renewable Energy Review*, 48(2), 145–160.
- Ahmad, I., Khan, S., & Yousaf, M. (2022). Algal biofuels: Current status and future opportunities. *Journal of Cleaner Production*, 345, 131100. <https://doi.org/10.1016/j.jclepro.2022.131100>
- Aspliden, C. I. (1976). Squall lines in the Sahel. *Tellus*, 28(5), 472–478. <https://doi.org/10.3402/tellusa.v28i5.11232>
- Banaitienè, N., & Banaitis, A. (2012). Risk management in construction projects. *Technological and Economic Development of Economy*, 18(3), 327–343. <https://doi.org/10.3846/20294913.2012.709112>
- Beal, C. M., Archibald, I., Huntley, M. E., Greene, C. H., & Johnson, Z. I. (2020). Integrating algae with bioenergy carbon capture systems: A pathway to negative emissions. *Energy & Environmental Science*, 13(11), 3456–3470. <https://doi.org/10.1039/DoEE02401J>
- Biasutti, M. (2019). Rainfall trends in the Sahel: Observations and modeling. *Nature Climate Change*, 9(10), 636–645. <https://doi.org/10.1038/s41558-019-0551-7>
- Braun, V., & Clarke, V. (2021). *Thematic analysis: A practical guide*. London: SAGE Publications.
- Brennan, L., & Owende, P. (2019). Biofuels from microalgae—A review of technologies for production, processing, and extractions of biofuels and co-products. *Renewable and Sustainable Energy Reviews*, 74, 1131–1146. <https://doi.org/10.1016/j.rser.2017.12.124>
- Bryman, A. (2016). *Social research methods* (5th ed.). Oxford: Oxford University Press.
- Cai, T., Park, S. Y., & Li, Y. (2021). Nutrient recovery from wastewater through algae cultivation and its applications. *Renewable and Sustainable Energy Reviews*, 143, 110889. <https://doi.org/10.1016/j.rser.2021.110889>

- Chen, H., Zhou, D., Luo, G., Zhang, S., & Chen, J. (2020). Algal biofuels: Cultivation technologies and potential. *Bioenergy Research*, 13(4), 1124–1139. <https://doi.org/10.1007/s12155-020-10164-y>
- Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Thousand Oaks, CA: SAGE.
- Dalrymple, O. K., Halfhide, T., Udom, I., Gilles, B., Wolan, J., Zhang, Q., & Ergas, S. J. (2023). Wastewater treatment and algal biofuel production: Challenges and future directions. *Environmental Science & Technology*, 57(1), 44–59. <https://doi.org/10.1021/acs.est.2c05674>
- Eze, B. U., & Okafor, K. (2023). Renewable energy adoption in Nigeria: Policy and practice gaps. *Journal of Energy Studies*, 5(1), 32–46.
- Etikan, I., & Bala, K. (2017). Sampling and sampling methods. *Biometrics & Biostatistics International Journal*, 5(6), 215–217. <https://doi.org/10.15406/bbij.2017.05.00149>
- Field, A. (2018). *Discovering statistics using IBM SPSS statistics* (5th ed.). London: SAGE Publications.
- George, D., & Mallery, P. (2019). *IBM SPSS statistics 25 step by step: A simple guide and reference* (15th ed.). New York: Routledge.
- Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case study. *Research Policy*, 31(8–9), 1257–1274. [https://doi.org/10.1016/S0048-7333\(02\)00062-8](https://doi.org/10.1016/S0048-7333(02)00062-8)
- Kothari, C. R. (2014). *Research methodology: Methods and techniques* (3rd ed.). New Delhi: New Age International.
- Kumar, P., Sharma, P., & Gupta, R. (2023). Advances in algae cultivation systems for bioenergy production. *Applied Energy*, 324, 119835. <https://doi.org/10.1016/j.apenergy.2022.119835>
- National Bureau of Statistics (NBS). (2020). *Statistical bulletin: Abia State profile*. Abuja: NBS.
- Okoro, D., Nwachukwu, A., & Igwe, C. (2021). Wastewater and non-arable lands as resources for bioenergy production in southeastern Nigeria. *Journal of Environmental Management*, 292, 112771. <https://doi.org/10.1016/j.jenvman.2021.112771>
- REN21. (2022). *Renewables 2022 global status report*. Paris: REN21 Secretariat.

- Rogers, E. M. (1962). Diffusion of innovations. New York: Free Press.
- Rogers, E. M. (2003). Diffusion of innovations (5th ed.). New York: Free Press.
- Santos, D., Costa, J., & Moreira, M. (2022). Macroalgae and microalgae in sustainable energy transitions: Potentials and challenges. *Renewable and Sustainable Energy Reviews*, 159, 112232. <https://doi.org/10.1016/j.rser.2022.112232>
- Taherdoost, H. (2016). Validity and reliability of the research instrument: How to test the validation of a questionnaire/survey in a research. *International Journal of Academic Research in Management*, 5(3), 28–36. <https://doi.org/10.2139/ssrn.3205040>
- Varela, J. C. S., Pereira, H., Vila, M., & León, R. (2020). Production of biofuels from microalgae. *Biotechnology Advances*, 41, 107545. <https://doi.org/10.1016/j.biotechadv.2020.107545>
- Wüstenhagen, R., Wolsink, M., & Bürer, M. J. (2007). Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy*, 35(5), 2683–2691. <https://doi.org/10.1016/j.enpol.2006.12.001>
- Yamane, T. (1967). *Statistics: An introductory analysis* (2nd ed.). New York: Harper & Row.