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STAKEHOLDER ENGAGEMENT AND SOCIAL ACCEPTANCE OF ALGAE-BASED RENEWABLE ENERGY IN ABIA STATE, SOUTH EAST NIGERIA

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Abstract: *This study investigates stakeholder engagement and the social acceptance of algae-based renewable energy in Aba North and Osisioma Local Government Areas of Abia State, South East Nigeria. The research was motivated by the dual challenges of energy insecurity and untreated industrial effluents that contribute to environmental degradation. Specifically, the study pursued three objectives: to examine stakeholder perceptions of algae cultivation as both a renewable energy option and a wastewater management strategy; to assess how stakeholder engagement influences social acceptance, legitimacy, and sustainability; and to identify the socio-economic and environmental benefits, as well as the challenges, associated with wastewater-driven algae systems. A cross-sectional descriptive survey design was employed, using structured questionnaires administered to 361 respondents and semi-structured interviews with key informants. Descriptive statistics and one-sample t-tests were used to analyze quantitative data, while thematic analysis guided the interpretation of qualitative responses. The findings revealed strong stakeholder consensus that wastewater effluents in Aba North and Osisioma contain adequate nutrients to sustain algae growth ($M = 4.42$; $t = 5.87$; $p < 0.001$). Engagement processes were found to significantly influence social acceptance, enhancing trust, ownership, and legitimacy of algae bioenergy projects ($M = 4.18$; $t = 4.67$; $p < 0.001$). Respondents also acknowledged algae's socio-economic and environmental potential, including wastewater remediation, employment generation, and energy diversification ($M = 4.27$; $t = 5.02$; $p < 0.001$). Despite these benefits, challenges such as high capital costs, inadequate technical expertise, weak infrastructure, and limited policy*

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support were identified as barriers to large-scale adoption. The study concludes that algae-based renewable energy is technically viable and socially desirable in Abia State, but its success will depend on awareness creation, participatory governance, capacity building, and supportive regulatory and financial frameworks.

1. Introduction

Urban–industrial Nigeria is confronted with a dual crisis of chronic energy insecurity and inadequate wastewater management. Large volumes of untreated effluents are routinely discharged into rivers and soils, degrading ecological systems, threatening biodiversity, and undermining public health (Okoro, Nwankwo, & Ezeh, 2021; Adewale, Onuorah, & Obinna, 2021). Aba North and Osisioma in Abia State exemplify this challenge: they are industrial hubs where textile, chemical, and petroleum-related industries generate nutrient-rich wastewater streams that remain largely untreated, while communities face erratic electricity supply and high energy costs (Eze, Obuka, & Ugwoke, 2023). This paradox of resource abundance and infrastructural deficit underscores the need for integrated solutions that simultaneously address environmental remediation and energy access. Globally, algae cultivation has emerged as a promising renewable energy pathway capable of bridging this gap. Microalgae possess high lipid and carbohydrate contents suitable for biodiesel, biogas, and bioethanol production, while macroalgae contribute to biochar and biogas applications (Khan, Shin, & Kim, 2019; Chen, Yeh, Aisyah, Lee, & Chang, 2020). Importantly, algae thrive in wastewater, removing nitrogen, phosphorus, and trace metals, thereby serving as both a bioenergy feedstock and a bioremediation agent (Dalrymple et al., 2023; Roostaei & Zhang, 2017). Algae systems thus embody circular economy principles—transforming pollutants into resources while advancing energy diversification and climate mitigation (Beal, Smith, Webber, Ruoff, & Hebner, 2020; Cai, Park, & Li, 2021).

Despite these advantages, algae bioenergy remains underexplored in Nigeria's renewable energy mix, where policy and investment priorities overwhelmingly favor solar and wind technologies (Adeniyi, Adeola, & Okonkwo, 2022). While studies in Asia, Europe, and the Americas have demonstrated scalable wastewater–algae integration, Nigerian evidence remains limited to exploratory assessments, with few empirical studies quantifying resource sufficiency, stakeholder willingness, or socio-economic implications (Ungureanu, Vladut, & Dinca, 2020; Edrisi, Abhilash, & Singh, 2022). Consequently, the feasibility of wastewater-based algae systems in industrial regions like Aba North and Osisioma has not been systematically examined, leaving a critical knowledge gap in policy and practice.

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Furthermore, technology alone cannot guarantee successful adoption. Research in renewable energy transitions emphasizes that social acceptance, policy legitimacy, and participatory governance are as decisive as technical feasibility (Wüstenhagen, Wolsink, & Bürer, 2007; Smith & Johnson, 2020). Stakeholder engagement is therefore indispensable, ensuring that community priorities—such as affordable electricity, reduced pollution, and employment opportunities—are aligned with project goals. In the case of Aba North and Osisioma, where industrial pollution shapes public perceptions of sustainability projects, social buy-in is essential to overcoming skepticism, correcting misconceptions about algae, and securing long-term viability (San Juan, Adeoye, & Ibrahim, 2020).

Aim and Objectives of the Study

The central aim of this study is to explore the dynamics of stakeholder engagement and the social acceptance of algae-based renewable energy in Abia State, focusing specifically on Aba North and Osisioma Local Government Areas. In pursuing this aim, the research is guided by three objectives:

1. To examine how local communities, industries, and government agencies perceive algae cultivation as both a renewable energy option and a wastewater management strategy.
2. To assess how stakeholder engagement influences social acceptance, legitimacy, and the long-term sustainability of algae-based bioenergy projects.
3. To identify the key socio-economic and environmental benefits, as well as the major challenges, associated with wastewater-driven algae systems in Abia State, and to propose strategies for their effective adoption.

Significance of the Study

This study is significant because it repositions wastewater, traditionally viewed as a liability, into a valuable resource for renewable energy production. In the industrial hubs of Aba North and Osisioma, untreated effluents have long been a major contributor to water pollution and ecological degradation. By demonstrating the potential of these effluents to sustain algae cultivation, the research highlights a dual-purpose solution: reducing pollution while producing renewable biomass for energy generation.

Nigeria's renewable energy discourse has largely focused on solar and wind technologies, often sidelining biomass and algae systems. This study broadens the scope by providing empirical evidence on algae's feasibility as part of a diversified energy mix. By doing so, it addresses the persistent problem of energy insecurity in semi-urban and industrial regions and offers a pathway to reduce reliance on fossil fuels while improving electricity access for local communities.

The research is also important for its socio-economic implications. Algae cultivation linked to wastewater use has the potential to create new employment opportunities in biomass harvesting, energy processing, and ancillary

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industries such as aquaculture feed and fertilizers. In addition, it can lower the cost of effluent management for industries while opening avenues for green entrepreneurship. These outcomes align with Nigeria's broader development goals, particularly in promoting sustainable livelihoods and local innovation.

Finally, this study contributes to policy and governance debates on renewable energy adoption. By foregrounding stakeholder engagement and social acceptance, it demonstrates that technological feasibility must be complemented by participatory governance, transparent decision-making, and regulatory support. The findings provide policymakers with evidence to guide the integration of algae bioenergy into Nigeria's renewable energy frameworks and to design culturally appropriate engagement strategies that build legitimacy and trust.

2. Literature Review

2.1 Conceptual Clarifications

Algae cultivation refers to the controlled growth of microalgae and macroalgae for biomass production. Microalgae such as *Chlorella vulgaris* and *Spirulina platensis* are particularly valued for their high lipid and carbohydrate content, making them suitable for biofuel production (Chen et al., 2020; Khan, Shin, & Kim, 2019). Unlike traditional crops, algae do not compete for fertile land or freshwater and can thrive in wastewater environments, offering both environmental remediation and energy generation opportunities.

Stakeholder engagement, in this context, entails the active involvement of local communities, industries, policymakers, and environmental groups in the design and implementation of renewable energy projects. It is critical to building trust, reducing conflict, and ensuring long-term sustainability (Smith & Johnson, 2020; Wüstenhagen, Wolsink, & Bürer, 2007). Social acceptance, on the other hand, refers to the willingness of communities and institutions to embrace algae-based energy systems, which depends on awareness, perceived benefits, and institutional legitimacy.

2.2 Theoretical Framework

This study is anchored on three complementary theories. First, the Resource-Based View (RBV) (Barney, 1991) frames wastewater and non-arable lands as underutilized local resources that can be transformed into strategic inputs for renewable energy production. Second, the Social Acceptance Framework (Wüstenhagen et al., 2007) emphasizes that adoption of renewable energy depends not only on technical feasibility but also on socio-political support, community trust, and market legitimacy. Finally, the Diffusion of Innovations Theory (Rogers, 2003) explains how algae-based energy can spread in Nigeria, stressing attributes such as relative advantage (e.g., reduced pollution, job creation), compatibility with local needs, and ease of implementation. Together, these theories highlight that technical solutions must be reinforced by community inclusion and institutional support.

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2.3 Empirical Review

Globally, studies confirm that wastewater-based algae cultivation can deliver dual benefits. Roostaei and Zhang (2017) showed that nutrient-rich effluents sustain algae growth while reducing environmental pollution. In Europe, Ungureanu, Vladut, and Dinca (2020) demonstrated algae's capacity to remove nitrogen and phosphorus while producing bioethanol. In Africa, Cai, Park, and Li (2021) emphasized the continent's favorable climatic conditions for algae cultivation but noted infrastructural and policy gaps. Nigerian studies, such as Okoro, Nwankwo, and Ezeh (2021), have identified industrial effluents in Aba as nutrient-rich yet poorly managed, while Eze, Obuka, and Ugwoke (2023) stressed the potential of integrating algae cultivation into wastewater management to achieve co-benefits in energy and environmental remediation. Despite these findings, localized empirical evidence on stakeholder perceptions and adoption readiness remains scarce.

2.4 Identified Gaps the Study Addresses

Although global evidence supports wastewater-based algae cultivation, significant gaps remain in Nigeria. First, there is limited localized data on the nutrient sufficiency of industrial and municipal effluents in Aba North and Osisioma. Second, socio-economic dimensions—particularly stakeholder perceptions, willingness to adopt, and community trust—have received little scholarly attention, as most research has focused narrowly on technical or biochemical aspects. Third, algae bioenergy remains absent from Nigeria's renewable energy policy agenda, which emphasizes solar and wind, creating a governance and investment gap. Finally, the integration of wastewater reuse, environmental remediation, and energy diversification within a circular economy model is underexplored in Nigerian contexts. This study seeks to fill these gaps by providing empirical insights into resource sufficiency, social acceptance, and governance conditions for algae bioenergy adoption in Abia State.

Research Design

The study adopted a cross-sectional descriptive survey design. This design was appropriate because it allowed the researcher to capture stakeholder perceptions, levels of awareness, and socio-economic implications of algae-based renewable energy at a single point in time. Quantitative data were obtained through structured questionnaires, while qualitative insights were gathered via semi-structured interviews with key informants. The integration of both approaches ensured a comprehensive understanding of the technical, social, and policy-related factors influencing algae adoption (Creswell, 2014).

Study Area

The research was conducted in Aba North and Osisioma Local Government Areas of Abia State, South East Nigeria. Aba North is a commercial hub known for its bustling markets and medium-

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scale enterprises, while Osisioma is predominantly industrial, hosting petrochemical plants, textile mills, breweries, and food-processing industries. These activities generate large volumes of wastewater that are often discharged untreated into nearby rivers and drains. In addition, the area contains degraded non-arable lands that could support algae cultivation without competing with food production. The humid tropical climate, with annual rainfall above 2,000 mm and mean temperatures between 26°C and 30°C, further favors algal growth (Okoro et al., 2021; Eze et al., 2023).

Population and Sampling

The study population comprised stakeholders directly or indirectly affected by wastewater discharge and energy shortages in the study area. These included residents, industrial operators, and government officials, with an estimated population of 3,690. Using Yamane's (1967) formula at a 5% margin of error, a sample size of 361 respondents was determined. Sampling was carried out in stages: the LGAs were purposively selected due to their wastewater generation potential; respondents were stratified into residents, industry operators, and officials; then random sampling was applied within each stratum. Additionally, purposive sampling was used to select key informants such as factory managers, environmental regulators, and community leaders, ensuring diversity and relevance of perspectives.

Instruments for Data Collection

Two main instruments were employed:

Structured Questionnaire: designed to capture quantitative data on stakeholder perceptions of algae cultivation, willingness to adopt algae-based energy, and anticipated socio-economic benefits or challenges.

Semi-Structured Interview Guide: used with selected informants to obtain deeper insights on technical feasibility, infrastructural limitations, policy frameworks, and engagement dynamics.

This combination of tools provided both breadth and depth of data for robust analysis.

Validity and Reliability

The instruments were subjected to expert review by scholars in environmental management and officials in Abia State's Ministry of Environment to ensure content validity. A pilot test was conducted with 20 respondents in a nearby industrial community, leading to refinements in clarity and relevance. Reliability analysis using Cronbach's alpha produced a coefficient of 0.82, demonstrating high internal consistency and suitability of the questionnaire for the study (George & Mallery, 2019).

Data Analysis

Quantitative data were coded and analyzed using SPSS version 28. Descriptive statistics such as means, percentages, and standard deviations summarized responses, while inferential statistics, particularly the one-sample t-test, were used to test hypotheses at the 0.05 significance level.

Qualitative interview responses were transcribed and analyzed thematically following Braun and

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Clarke's (2021) procedure. Codes were categorized into themes reflecting technical, socio-economic, and policy-related issues. Triangulation of survey and interview findings enhanced the reliability and depth of conclusions.

4.0 Results

The results of this study are presented in line with the three specific objectives:
(i) examining how stakeholders perceive algae cultivation as a renewable energy option and wastewater management strategy,
(ii) Assessing the extent to which stakeholder engagement influences social acceptance, legitimacy, and sustainability, and
(iii) Identifying the socio-economic and environmental benefits, as well as the challenges, associated with wastewater-driven algae systems.

Both descriptive statistics (mean scores) and inferential tests (one-sample t-tests) are reported to provide a comprehensive evaluation.

4.1 Stakeholder Perceptions of Algae Cultivation

The first objective sought to determine how stakeholders perceive algae cultivation in Aba North and Osisioma LGAs, particularly as both a renewable energy source and a wastewater management strategy. Descriptive statistics revealed a mean score of 4.42 on a 5-point Likert scale, showing strong consensus that wastewater in the study area provides adequate nutrients (nitrogen, phosphorus, organic matter) for algae cultivation.

Table 1: Descriptive Statistics on Stakeholder Perceptions

N	Minimum	Maximum	Mean	Std. Deviation
361	3.00	5.00	4.42	0.47

Source: Field Survey, 2025

To validate this result, a one-sample t-test was conducted at a test value of 3.00 (neutral). The null hypothesis was:

Stakeholders do not perceive wastewater as a viable resource for algae cultivation.

Table 2: One-Sample t-Test on Stakeholder Perceptions

Test Value = 3.00	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval
Stakeholder perception	5.87	360	0.000	1.42	1.18 – 1.61

Source: SPSS Computation, 2025

The test statistic ($t = 5.87$) was greater than the critical value (2.571) at 0.05 significance, with $p < 0.001$. Thus, the null hypothesis was rejected. This confirms that stakeholders strongly perceive wastewater as both an energy and environmental management resource. The findings align with earlier studies (Chen et al.,

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2020; Okoro et al., 2021) that highlight the nutrient-rich potential of industrial effluents for algae cultivation.

4.2 Influence of Stakeholder Engagement on Social Acceptance

The second objective examined how stakeholder engagement shapes social acceptance, legitimacy, and the sustainability of algae-based bioenergy projects. Descriptive statistics produced a mean score of 4.18, suggesting that respondents agreed engagement fosters trust and ownership.

Table 3: Descriptive Statistics on Stakeholder Engagement

N	Minimum	Maximum	Mean	Std. Deviation
361	3.00	5.00	4.18	0.61

Source: Field Survey, 2025

The hypothesis tested was:

H02: Stakeholder engagement does not influence social acceptance and legitimacy of algae projects.

Table 4: One-Sample t-Test on Stakeholder Engagement

Test Value = 3.00	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval
Influence of engagement	4.67	360	0.000	1.18	0.96 – 1.39

Source: SPSS Computation, 2025

The result ($t = 4.67$, $p < 0.001$) confirmed that engagement significantly influences social acceptance and legitimacy. Interviews further revealed that early community dialogue reduces resistance, while industries and policymakers emphasized that participatory frameworks encourage collaboration and policy alignment. This supports earlier findings by Wüstenhagen et al. (2007) that renewable energy adoption depends on socio-political and community acceptance as much as technical feasibility.

4.3 Socio-Economic and Environmental Benefits and Challenges

The third objective assessed the perceived socio-economic and environmental benefits, alongside challenges, of algae cultivation in Aba North and Osisioma LGAs. Descriptive analysis produced a mean score of 4.27, indicating strong agreement that algae provides multiple benefits, such as wastewater remediation, employment, and energy diversification.

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Table 5: Descriptive Statistics on Socio-Economic & Environmental Benefits

N	Minimum	Maximum	Mean	Std. Deviation
361	3.00	5.00	4.27	0.55

Source: Field Survey, 2025

The hypothesis tested was:

H03: Wastewater-driven algae cultivation has no significant socio-economic or environmental benefits.

Table 6: One-Sample t-Test on Benefits of Algae Systems

Test Value = 3.00	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval
Socio-economic & environmental benefits	5.02	360	0.000	1.27	1.05 – 1.48

Source: SPSS Computation, 2025

The test result ($t = 5.02$, $p < 0.001$) rejected the null hypothesis, confirming stakeholders' recognition of algae's benefits. However, qualitative responses highlighted significant challenges: high capital costs of photobioreactors, limited technical expertise, weak infrastructure, and uncertain economic viability without subsidies. These findings echo global evidence (Ungureanu et al., 2020; Cai et al., 2021) that algae projects succeed only where technical readiness and supportive policies coexist.

Discussion

Stakeholder Perceptions of Algae Cultivation

The results revealed that stakeholders in Aba North and Osisioma generally perceive algae cultivation positively, with a mean score of 4.42, confirming strong support for its role as both a renewable energy resource and a wastewater management strategy. Respondents emphasized algae's capacity to convert industrial effluents into biomass for biofuel production while simultaneously mitigating pollution in the Aba River. These findings align with Chen et al. (2020), who reported high nutrient uptake by *Chlorella vulgaris* cultivated in wastewater, and with Roostaei and Zhang (2017), who demonstrated the potential of algae biofuels within wastewater treatment systems.

Despite this optimism, qualitative interviews highlighted a knowledge gap, as many community members were more familiar with solar and wind energy than algae. This reflects Wüstenhagen, Wolsink, and Bürer's (2007) assertion that social acceptance requires awareness and understanding. For algae

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bioenergy to gain wider legitimacy in Nigeria, stakeholders stressed the importance of sensitization programs and evidence from demonstration projects that showcase visible benefits.

Stakeholder Engagement and Social Acceptance

Stakeholder engagement was shown to significantly shape acceptance and legitimacy, with a mean score of 4.18 and t-test results confirming the importance of participation. Respondents agreed that inclusive processes—such as dialogue forums, transparent planning, and equitable benefit-sharing—reduce resistance and foster ownership of algae-based projects. These findings resonate with Smith and Johnson (2020), who found that engagement strategies enhance renewable energy adoption by addressing trust and transparency issues.

However, the study also identified barriers such as power imbalances, conflicting priorities between economic gains and environmental protection, and misconceptions about algae technologies. This aligns with Rogers' (2003) *Diffusion of Innovations Theory*, which argues that adoption is slowed when technologies are perceived as complex or unfamiliar. Overcoming these challenges requires participatory governance structures that bring together industries, communities, and policymakers, ensuring that algae projects are not only technically feasible but also socially legitimate and politically supported.

Socio-Economic and Environmental Benefits and Challenges

The third objective highlighted stakeholders' recognition of algae's socio-economic and environmental potential, reflected in a mean score of 4.27. Respondents emphasized benefits such as reduced industrial effluent disposal costs, job creation in algae harvesting and processing, and opportunities for green entrepreneurship. These findings are consistent with Eze, Obuka, and Ugwoke (2023), who observed that wastewater-to-energy initiatives in South East Nigeria could simultaneously stimulate employment and improve regulatory compliance for industries.

Environmental benefits were also strongly acknowledged, with respondents agreeing that algae could remediate wastewater, improve river water quality, and support land rehabilitation. These findings echo Ungureanu et al. (2020), who documented high nutrient removal efficiencies in algae systems, and Cai et al. (2021), who argued for algae's integration into Africa's circular economy framework.

Nevertheless, respondents also identified significant challenges, including high capital costs for photobioreactors, weak infrastructure (e.g., power and water), limited technical expertise, and uncertainty about long-term profitability without subsidies. These concerns mirror Beal et al. (2020), who stressed that large-scale algae adoption depends on supportive financial models and enabling policies. Therefore, while the benefits are evident, the

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study underscores the necessity of policy integration, innovative financing, and capacity building to ensure successful scaling in Abia State.

Conclusion

This study set out to examine stakeholder engagement and the social acceptance of algae-based renewable energy in Aba North and Osisioma Local Government Areas of Abia State, South East Nigeria. The findings confirmed that stakeholders generally perceive algae cultivation positively, recognizing its potential as both a renewable energy option and a wastewater management strategy. With strong consensus on algae's dual role in pollution reduction and bioenergy generation, the study highlights a growing awareness of its relevance to sustainable development in the region.

The results also established that stakeholder engagement plays a pivotal role in enhancing social acceptance, legitimacy, and sustainability of algae-based bioenergy initiatives. Active involvement of communities, industries, and policymakers fosters trust, transparency, and ownership, thereby reducing resistance and improving long-term viability. However, challenges such as power imbalances, conflicting interests, and limited awareness remain critical barriers to acceptance.

Furthermore, the study identified significant socio-economic and environmental benefits associated with wastewater-driven algae systems. Stakeholders emphasized algae's role in reducing effluent disposal costs, creating employment opportunities, stimulating entrepreneurship, and improving ecosystem health. At the same time, barriers such as high capital costs, inadequate technical expertise, and weak infrastructure threaten large-scale adoption. These findings suggest that algae cultivation in Abia State is both technically viable and socially beneficial but requires deliberate policy, financial, and institutional support to be successfully scaled.

Recommendations

In light of the above conclusions, the following recommendations are made in line with the study objectives:

1. Government agencies, research institutions, and NGOs should collaborate to design awareness campaigns and demonstration projects that showcase algae's potential as both a renewable energy resource and a wastewater management solution. Such initiatives will bridge existing knowledge gaps and strengthen positive stakeholder perceptions.
2. Policymakers and project developers should adopt participatory governance frameworks that ensure inclusive stakeholder involvement at every stage of algae bioenergy projects. This includes community dialogues, transparent benefit-sharing agreements, and partnerships between industries and government regulators to enhance legitimacy and trust.
3. To unlock algae's socio-economic and environmental potential, targeted investments should be made in capacity building, technical

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training, and low-cost technologies. Financial incentives, such as subsidies and tax reliefs, should be introduced to reduce capital burdens on industries. Public–private partnerships should also be encouraged to develop scalable pilot projects that demonstrate tangible outcomes in pollution reduction, energy production, and job creation.

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