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Renewable Energy Integration as a Catalyst for Agribusiness Sustainability and Green Enterprise Development: Empirical Evidence from Agricultural Education and Agribusiness stakeholders in Nigeria

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Received: 2 June 2026, Revised: 23 June 2026, Accepted: 26 June 2026, Published: 30 June 2026

Abstract

The growing demand for sustainable agricultural production has increased interest in renewable energy as a means of improving agribusiness sustainability and promoting green enterprise development. Despite advances in renewable energy technologies, their adoption within agribusiness and agricultural education systems in developing countries remains limited. This study investigated renewable energy integration as a catalyst for agribusiness sustainability and green enterprise development among agricultural education stakeholders in Nigeria. The study examined existing renewable energy integration practices, barriers to adoption, the effectiveness of educational initiatives, and strategies for strengthening renewable energy integration. Four research questions and four null hypotheses guided the study. A descriptive survey design was adopted. The population consisted of agricultural education lecturers in Nigerian universities. A sample of 172 respondents was selected through stratified random sampling, while 155 valid responses were used for analysis. Data were collected using a structured questionnaire with an overall Cronbach Alpha reliability coefficient of 0.81. Mean and standard deviation answered the research questions, while multiple regression analysis tested the hypotheses at the 0.05 level of significance. The findings revealed moderate implementation of renewable energy integration practices. Major barriers included inadequate funding, poor infrastructure, low stakeholder awareness, and insufficient technical expertise. Educational initiatives were effective only to a limited extent. Curriculum reform, industry partnerships, practical training opportunities, and supportive policies were identified as key strategies for strengthening renewable energy integration. The study concludes that stronger renewable energy integration can enhance agribusiness sustainability and stimulate green enterprise development in Nigeria.

Keywords: renewable energy integration, agribusiness sustainability, green enterprise development, agricultural education

1. INTRODUCTION

The drive for sustainable agricultural transformation has intensified due to climate change, environmental degradation, energy insecurity, and rising food demand. Agriculture remains highly energy-dependent, requiring substantial inputs for production and value addition activities. Dependence on fossil fuels has increased costs and environmental pressures on agricultural systems [1]. Renewable energy technologies offer sustainable alternatives for improving efficiency and environmental performance [2]. Their adoption is increasingly viewed as essential for achieving global goals related to food security, clean

energy, and climate action [3].

Renewable energy integration involves incorporating technologies such as solar, wind, biomass, biogas, and hydropower into agricultural production and agribusiness operations. These technologies enhance productivity through improved irrigation, processing, and climate-smart farming systems [4]. They also improve enterprise resilience and environmental sustainability [5]. Studies indicate that renewable energy utilization reduces operating costs and improves profitability across agricultural value chains [6]. Consequently, renewable energy integration has become a key driver of sustainable agribusiness development.

Agribusiness sustainability refers to the ability of agricultural enterprises to remain economically viable while preserving environmental resources and supporting social well-being. Sustainable agribusiness systems emphasize efficiency, innovation, environmental stewardship, and competitiveness [7]. Rising environmental concerns have increased the need for renewable energy technologies that support sustainable production and value addition [8]. Evidence shows that sustainability-oriented enterprises are often more innovative and resilient than conventional businesses [9]. Renewable energy integration therefore provides an important pathway for strengthening agribusiness sustainability.

The sustainability agenda has also encouraged the emergence of green enterprises within agriculture. These enterprises provide products, services, and technologies that support environmental conservation and sustainable resource use. Examples include renewable energy providers, climate-smart farming ventures, and sustainable food-processing businesses [10]. Green enterprises contribute to innovation, employment, and rural development [11]. Countries with stronger renewable energy ecosystems generally experience greater green enterprise growth [12].

Nigeria possesses significant potential for renewable energy-driven agribusiness development due to its abundant renewable resources and large agricultural sector. Agriculture remains a major source of employment and food security [13]. However, persistent energy challenges continue to undermine productivity and competitiveness. Inadequate electricity supply increases operating costs and constrains innovation among agribusiness operators [14]. Renewable energy technologies provide practical solutions for improving agricultural performance and enterprise growth [15].

Educational institutions play a critical role in promoting renewable energy adoption and sustainable agribusiness development. Universities are expected to generate knowledge and prepare graduates with competencies required for sustainability transitions. Integrating renewable energy concepts into agricultural education can improve stakeholders' understanding of sustainable production systems and green entrepreneurship [16]. Nwakile, Izuakor, Onogu and Ali [17] emphasized the importance of innovation-oriented educational systems for sustainability transformation. Likewise, Umeh et al. [18] highlighted the growing importance of green skills for sustainable agribusiness employment.

Renewable energy adoption is influenced by economic, technological, institutional, and human factors. Financial limitations remain a major challenge, particularly in developing economies [19]. Inadequate infrastructure and limited technical expertise also constrain renewable energy utilization [20]. Furthermore, low awareness of renewable energy benefits reduces stakeholders' willingness to adopt sustainable technologies [21]. Addressing these constraints requires coordinated interventions involving governments, educational institutions, and industry stakeholders.

Several studies have highlighted the importance of sustainability oriented agricultural education for supporting the green economy. Evidence indicates that deficiencies in green skills development and sustainability competencies continue to constrain the adoption of environmentally responsible agricultural practices and renewable energy technologies [11]. Research has also shown that mismatches between educational outcomes and labour market requirements reduce the capacity of educational institutions to support sustainable enterprise development [7]. Furthermore, UNESCO [16] emphasized the need for curriculum innovation and practical learning approaches that equip learners with competencies required for emerging green economies. These findings suggest that stronger renewable energy integration within

agricultural education may enhance innovation, employability, and enterprise development within the agricultural sector.

Despite growing recognition of the importance of renewable energy, empirical evidence on its contribution to agribusiness sustainability and green enterprise development remains limited in Nigeria. Most existing studies have examined renewable energy adoption, sustainability practices, agricultural education, and green skills development separately. As a result, little is known about how renewable energy integration influences agribusiness sustainability and green enterprise development simultaneously. This gap limits the availability of evidence needed by policymakers, educators, and industry stakeholders to support sustainable agricultural transformation. Therefore, this study investigates renewable energy integration as a catalyst for agribusiness sustainability and green enterprise development among agricultural education stakeholders in Nigeria.

Objectives of the Study

The main objective of this study was to investigate renewable energy integration as a catalyst for agribusiness sustainability and green enterprise development among agricultural education stakeholders in Nigeria. Specifically, the study sought to:

1. Examine existing renewable energy integration practices that support agribusiness sustainability and green enterprise development in Nigeria.
2. Identify barriers limiting renewable energy adoption among agricultural education stakeholders.
3. Assess the effectiveness of educational initiatives in promoting renewable energy awareness and utilization for sustainable agribusiness development.
4. Determine strategies for strengthening renewable energy integration to enhance agribusiness sustainability and green enterprise development.

Research Questions

The following research questions guided the study:

1. What renewable energy integration practices currently support agribusiness sustainability and green enterprise development in Nigeria?
2. What barriers limit renewable energy adoption among agricultural education and agribusiness stakeholders?
3. To what extent are educational initiatives effective in promoting renewable energy awareness and utilization?
4. What strategies can strengthen renewable energy integration to enhance agribusiness sustainability and green enterprise development?

Research Hypotheses

The following hypotheses were tested at 0.05 level of significance.

H01: Renewable energy integration practices have no significant influence on agribusiness sustainability among agricultural education stakeholders in Nigeria.

H02: Barriers to renewable energy adoption have no significant influence on green enterprise development among agricultural education stakeholders in Nigeria.

H03: Educational initiatives promoting renewable energy awareness have no significant influence on agribusiness sustainability among agricultural education stakeholders in Nigeria.

H04: Strategies for renewable energy integration have no significant influence on green enterprise development among agricultural education stakeholders in Nigeria.

2. LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Renewable Energy Integration and Agribusiness Sustainability

Renewable energy integration has emerged as a critical strategy for improving the sustainability of agribusiness systems across the world. The increasing cost of conventional energy sources, coupled with growing concerns about environmental degradation, has compelled agricultural enterprises to adopt cleaner and more sustainable energy alternatives. Renewable energy technologies such as solar photovoltaic systems, biomass energy, wind power, and biogas digesters have demonstrated significant potential for reducing production costs, enhancing resource-use efficiency, and improving environmental performance within agricultural value chains [1]. The deployment of renewable energy systems also contributes to reduced greenhouse gas emissions and strengthens the resilience of agribusiness enterprises against energy-related disruptions [2]. Furthermore, renewable energy adoption supports the transition towards climate-smart agricultural systems capable of sustaining productivity under changing environmental conditions [5].

Agribusiness sustainability encompasses the economic, environmental, and social dimensions of agricultural enterprise performance. Sustainable agribusinesses are characterized by efficient resource management, environmental stewardship, profitability, and long-term competitiveness. Renewable energy integration contributes directly to these dimensions by lowering energy expenditures, minimizing environmental impacts, and improving operational efficiency [4]. Studies conducted in both developed and developing economies have shown that agribusinesses that utilize renewable energy technologies often experience higher levels of productivity and sustainability than those dependent on fossil fuel-based energy systems [9]. Similarly, renewable energy technologies facilitate value addition, processing efficiency, and market expansion, thereby strengthening the economic viability of agricultural enterprises [6].

Within the Nigerian context, renewable energy integration remains an important but underutilized mechanism for promoting sustainable agricultural transformation. The agricultural sector continues to experience severe energy constraints that affect production, storage, processing, and distribution activities. Inadequate access to reliable electricity has limited the growth of agribusiness enterprises and constrained opportunities for technological innovation [14]. Renewable energy technologies offer practical alternatives capable of supporting irrigation systems, cold storage facilities, agro-processing centres, and other agribusiness operations [15]. Consequently, increasing renewable energy integration may enhance the sustainability and competitiveness of agribusiness enterprises in Nigeria.

The relationship between renewable energy integration and agribusiness sustainability is supported by emerging empirical evidence. Research indicates that renewable energy technologies improve environmental sustainability while simultaneously enhancing economic performance through reduced operating costs and increased productivity [12]. Nwakile, Izuakor, Onogu and Ali [17] further emphasized that sustainability-oriented innovation systems are essential for transforming agribusiness education and enterprise development. These findings suggest that renewable energy integration has the potential to serve as a catalyst for sustainable agribusiness growth.

Recent empirical studies from other Sub-Saharan African countries provide additional evidence regarding the importance of renewable energy adoption for sustainable agribusiness development. In Kenya, Mungai and Ndiritu [22] found that access to solar powered irrigation systems improved farm productivity and reduced production costs among smallholder farmers. Similarly, Nyarko and Mensah [23] reported that renewable energy utilisation enhanced agribusiness competitiveness and environmental sustainability among agricultural enterprises in Ghana. In Uganda, Kato et al. [24] identified inadequate financing, limited technical expertise, and weak infrastructure as major barriers to renewable energy adoption within agricultural value chains. These studies suggest that the opportunities and constraints associated with renewable energy integration are not unique to Nigeria but reflect broader trends across Sub Saharan Africa. Based on this evidence, the following hypothesis was formulated:

H01: Renewable energy integration practices have no significant influence on agribusiness sustainability among agricultural education stakeholders in Nigeria.

Renewable Energy Adoption Barriers and Green Enterprise Development

The development of green enterprises depends largely on the availability and utilization of sustainable technologies, including renewable energy systems. Green enterprises promote environmentally responsible production practices while generating economic value and employment opportunities. Within the agricultural sector, green enterprises include renewable energy service providers, climate-smart farming ventures, sustainable food processing businesses, and environmentally friendly agricultural technology firms [7]. These enterprises play an important role in promoting environmental sustainability and stimulating rural economic development [11]. However, the successful establishment and growth of green enterprises often depend on favourable institutional, technological, and financial conditions.

Several barriers continue to constrain renewable energy adoption among agricultural stakeholders. Financial limitations remain one of the most significant obstacles, particularly in developing countries where access to investment capital is often restricted. The high initial cost of renewable energy technologies discourages many potential users despite their long-term economic benefits [19]. Inadequate infrastructure also limits renewable energy deployment, especially in rural communities where many agricultural activities are concentrated [20]. Additionally, insufficient technical expertise and limited access to maintenance services frequently hinder the effective utilization of renewable energy technologies [21].

Low awareness levels among stakeholders further constrain renewable energy adoption and green enterprise development. Many agricultural entrepreneurs lack adequate knowledge regarding the economic and environmental benefits associated with renewable energy technologies. This information gap often reduces willingness to invest in sustainable energy systems and limits opportunities for green enterprise creation [25]. Regulatory uncertainties and weak policy support mechanisms have also been identified as factors affecting renewable energy adoption in many developing economies [19]. Collectively, these barriers restrict the capacity of agricultural stakeholders to establish and expand environmentally sustainable enterprises.

Empirical evidence suggests that reducing renewable energy adoption barriers can significantly stimulate green enterprise development. Improved access to financing, supportive policy frameworks, technical training programmes, and infrastructure development have been associated with increased renewable energy utilization and entrepreneurial growth [10]. Nwachukwu et al. [26] similarly reported that inadequate access to green-job competencies and sustainability-related skills constrains employment and enterprise opportunities within the agricultural sector. Therefore, addressing barriers to renewable energy adoption may facilitate the growth of green enterprises and strengthen sustainable economic development. Consequently, the following hypothesis was formulated:

H02: Barriers to renewable energy adoption have no significant influence on green enterprise development among agricultural education stakeholders in Nigeria.

Educational Initiatives and Sustainable Agribusiness Development

Educational initiatives play a vital role in promoting renewable energy awareness, knowledge acquisition, and technology adoption among agricultural stakeholders. Universities, training institutions, extension agencies, and professional development programmes serve as key channels for disseminating information on sustainable agriculture and renewable energy technologies. Through education and training, stakeholders acquire competencies needed to adopt and utilize renewable energy systems effectively in agricultural production and enterprise activities [16]. Consequently, educational interventions have become essential for supporting sustainability transitions within agricultural sectors.

The effectiveness of educational initiatives depends on curriculum relevance, instructional quality, practical learning opportunities, and stakeholder engagement. Programmes that combine theoretical instruction with experiential learning generally produce better outcomes in technology adoption and innovation [1]. Industry partnerships, demonstration projects, field-based training, and internships expose learners to renewable energy applications and improve their readiness for sustainable agribusiness activities [4]. Such initiatives are particularly valuable in developing countries where technological awareness remains limited.

Studies in Nigeria have emphasized the role of sustainability-oriented agricultural education in promoting innovation and enterprise development. Okoli et al. [27] advocated curriculum reforms to address emerging sustainability challenges. Umeh et al. [18] highlighted the increasing demand for green skills required in precision agriculture and sustainable agribusiness sectors. Likewise, Ekenta et al. [28] reported that improving curriculum relevance can enhance graduate employability and enterprise development. These findings underscore the importance of educational interventions in achieving sustainability outcomes.

Research consistently demonstrates positive relationships between educational initiatives and sustainable agricultural development. Educational programmes improve awareness, strengthen competencies, encourage innovation, and promote environmentally responsible practices [7]. Stakeholders exposed to sustainability-focused training are more likely to adopt renewable energy technologies and contribute to sustainable agribusiness development [12]. Consequently, the following hypothesis was formulated:

H03: Educational initiatives promoting renewable energy awareness have no significant influence on agribusiness sustainability among agricultural education stakeholders in Nigeria.

Strategies for Renewable Energy Integration and Green Enterprise Development

The successful integration of renewable energy technologies into agribusiness systems requires coordinated institutional, educational, technological, and policy interventions. These strategies are designed to improve awareness, adoption, utilization, and sustainability of clean energy technologies within agricultural systems. Their importance is particularly evident in developing economies where adoption is hindered by inadequate infrastructure, limited funding, and weak institutional support [19]. Effective integration strategies promote innovation, knowledge transfer, capacity development, and investment, thereby supporting sustainable agribusiness development [5].

Curriculum innovation remains a key strategy for renewable energy integration. Educational institutions are expected to equip future agricultural professionals and entrepreneurs with competencies required for sustainable enterprise development. Integrating renewable energy concepts into agricultural curricula enhances understanding of sustainable production systems and innovative agribusiness solutions [16]. Okoli et al. [27] emphasized the need for curriculum reforms that address sustainability challenges, while Nwakile, Izuakor, Onogu and Ali [17] highlighted the role of innovation-driven educational systems in promoting sustainability and institutional transformation.

Industry partnerships and interdisciplinary collaboration are also important for strengthening renewable energy adoption. Collaboration among educational institutions, renewable energy firms, agribusiness enterprises, government agencies, and development organizations facilitates knowledge exchange and access to technical expertise [4]. Such partnerships provide practical exposure to renewable energy applications and improve implementation capacity. Research has shown that collaborative innovation ecosystems support technological diffusion and entrepreneurial development in emerging economies [10].

Practical training opportunities enhance renewable energy integration by strengthening technical competence and confidence in using sustainable technologies. Internships, demonstration projects, workshops, field visits, and laboratory exercises provide opportunities to apply knowledge in real-world settings [1]. These experiences facilitate skill acquisition and encourage positive attitudes towards renewable energy technologies. Umeh et al. [18] emphasized the growing importance of green skills for sustainable agribusiness employment, while practical training has been linked to higher levels of technology adoption and innovation [6].

Supportive policies and financial incentives are equally critical for accelerating renewable energy integration and stimulating green enterprise development. Government interventions such as grants, subsidies, tax incentives, low-interest loans, and technical support services can reduce barriers to adoption [14]. Such measures encourage investment and private-sector participation in renewable energy projects. Evidence indicates that supportive policy frameworks significantly enhance renewable energy utilization and entrepreneurial activity within agricultural sectors [7].

Hence, the literature suggests that renewable energy integration strategies promote green enterprise development through improved innovation, sustainability performance, and entrepreneurial opportunities. Stakeholders with access to supportive educational programmes, collaborative networks, practical training opportunities, and enabling policy environments are more likely to establish and sustain environmentally responsible enterprises [12]. Consequently, the following hypothesis was formulated:

H04: Strategies for renewable energy integration have no significant influence on green enterprise development among agricultural education stakeholders in Nigeria.

Theoretical Framework

This study was anchored on the Diffusion of Innovation Theory developed by Everett Rogers in 1962. The theory explains how innovations are communicated and adopted over time among members of a social system. According to the theory, the adoption of innovations depends on factors such as relative advantage, compatibility, complexity, trialability, and observability. Individuals and organizations are more likely to adopt innovations when they perceive them as beneficial, compatible with existing practices, easy to understand, and capable of producing observable outcomes [29].

The theory is particularly relevant to renewable energy integration because renewable energy technologies represent innovations that require acceptance and adoption by agricultural stakeholders before their benefits can be fully realized. Agricultural education institutions, agribusiness operators, and policymakers serve as important actors within the innovation diffusion process. Educational initiatives increase awareness and knowledge, while practical demonstrations and collaborative partnerships enhance trialability and observability of renewable energy technologies [16]. Consequently, the theory provides a useful framework for understanding how renewable energy technologies can be adopted and integrated to promote agribusiness sustainability and green enterprise development.

The Diffusion of Innovation Theory further suggests that institutional support mechanisms and stakeholder perceptions influence adoption decisions. Barriers such as inadequate funding, insufficient infrastructure, and limited technical expertise may reduce the rate of innovation adoption, while supportive policies and educational programmes may accelerate diffusion processes [19]. The theory therefore provides a strong conceptual basis for examining the relationships among renewable energy integration practices, adoption barriers, educational initiatives, integration strategies, agribusiness sustainability, and green enterprise development.

Literature Gap

The reviewed literature demonstrates that renewable energy technologies contribute significantly to sustainable agricultural development, environmental protection, and enterprise growth. Existing studies have also established the importance of educational initiatives, institutional support systems, and green skills development in promoting sustainability-oriented innovation. However, most previous studies have examined renewable energy adoption, agricultural sustainability, educational interventions, and green enterprise development as separate constructs. Limited empirical evidence exists regarding how renewable energy integration simultaneously influences agribusiness sustainability and green enterprise development within the Nigerian context.

Furthermore, previous Nigerian studies have largely focused on renewable energy awareness, agricultural education, or sustainability practices without providing an integrated assessment of renewable energy integration as a catalyst for sustainable agribusiness development. Although studies have contributed valuable insights regarding sustainability, green skills, and agribusiness education, there remains a paucity of empirical evidence linking renewable energy integration to agribusiness sustainability and green enterprise development. This study therefore fills this gap by investigating the influence of renewable energy integration practices, adoption barriers, educational initiatives, and integration strategies on sustainable agribusiness outcomes among agricultural education stakeholders in Nigeria.

3. METHODOLOGY

Research Design

This study adopted a descriptive survey research design. The design was considered appropriate because it enabled the researchers to collect data from respondents regarding renewable energy integration practices, barriers to adoption, educational initiatives, integration strategies, and their perceived contributions to agribusiness sustainability and green enterprise development. Descriptive survey research is widely used in social science and educational research to obtain information from a representative sample of a population and describe existing conditions, relationships, attitudes, and practices.

Area of the Study

The study was conducted in Nigerian universities offering agricultural education programmes. Nigeria comprises six geopolitical zones with universities providing agricultural education and agribusiness-related programmes. These institutions play important roles in developing human capital, promoting innovation, and supporting sustainable agricultural transformation through teaching, research, and community engagement activities.

Population of the Study

The population of the study comprised all lecturers teaching agricultural education and agribusiness related courses in Nigerian universities offering agricultural education programmes. These lecturers were considered appropriate respondents because they possess specialised knowledge of agricultural systems, sustainability education, agribusiness development, renewable energy applications, and workforce preparation. Their academic and professional responsibilities place them in a unique position to evaluate renewable energy integration practices, educational initiatives, barriers to adoption, and strategies for promoting sustainable agribusiness development.

Sample and Sampling Technique

A sample size of 172 lecturers was selected for the study using a stratified random sampling technique. The six geopolitical zones of Nigeria served as strata. Two universities offering agricultural education programmes were selected from each geopolitical zone, resulting in twelve participating universities.

The selection criterion was not whether a university was exclusively agricultural in orientation but whether it offered accredited agricultural education or agribusiness related programmes. This criterion ensured that respondents possessed relevant expertise in agricultural education, sustainable agriculture, agribusiness development, and emerging agricultural technologies. Consequently, both specialised agricultural universities and conventional universities offering agricultural education programmes were included in the study.

The number of lecturers selected from each university varied because the sampling adopted a proportionate approach based on the actual number of agricultural education lecturers available in each institution at the time of the study. Universities with larger numbers of eligible lecturers contributed more respondents than institutions with smaller academic staff strength. This approach enhanced representativeness and ensured adequate coverage of the target population across the six geopolitical zones.

The sample comprised 15 lecturers from the University of Ilorin and 20 lecturers from the Federal University of Agriculture, Makurdi, representing the North Central zone. Ten lecturers from Adamawa State University and 18 lecturers from Modibbo Adama University participated from the North East zone. The North West zone was represented by 12 lecturers from Usmanu Danfodiyo University and 16 lecturers from the Federal University of Agriculture, Dutsin Ma. Fourteen lecturers from Michael Okpara University of Agriculture and eight lecturers from Ebonyi State University participated from the South East zone. Eleven lecturers from the University of Calabar and nine lecturers from Delta State University represented the South South zone. The South West zone comprised 17 lecturers from Obafemi Awolowo University and 22 lecturers from the Federal University of Agriculture, Abeokuta.

A total of 172 questionnaires were distributed to the selected respondents. Of these, 155 questionnaires were properly completed and returned, representing a response rate of 90.1 percent. The non response rate of

9.9 percent was considered minimal and unlikely to introduce substantial bias because responses were obtained from all six geopolitical zones and from all selected institutions. Furthermore, the achieved response rate exceeded the minimum threshold commonly regarded as acceptable for survey research, thereby supporting the representativeness of the data used for analysis.

Instrument for Data Collection

Data were collected using a structured questionnaire titled Renewable Energy Integration, Agribusiness Sustainability and Green Enterprise Development Questionnaire (REIASGEDQ). The instrument was developed from the literature reviewed and consisted of two sections. Section A elicited information on the demographic characteristics of the respondents. Section B consisted of four clusters corresponding to the four study objectives and predictor variables investigated in the study.

Cluster I contained items on renewable energy integration practices supporting agribusiness sustainability and green enterprise development.

Cluster II contained items on barriers limiting renewable energy adoption among agricultural education and agribusiness stakeholders.

Cluster III contained items on the effectiveness of educational initiatives promoting renewable energy awareness and utilization.

Cluster IV contained items on strategies for strengthening renewable energy integration for sustainable agribusiness development.

Clusters I, II, and IV were structured on a four-point Likert scale of Strongly Agree (4), Agree (3), Disagree (2), and Strongly Disagree (1). Cluster III was structured on a four-point scale of High Extent (4), Moderate Extent (3), Low Extent (2), and Very Low Extent (1).

Validity of the Instrument

The instrument was subjected to face and content validation by five experts. Three experts were drawn from the Department of Agricultural Education, University of Nigeria, Nsukka, while two experts were drawn from the fields of agribusiness management and sustainable agriculture. The validators examined the instrument in terms of clarity of items, relevance to the study objectives, appropriateness of language, and adequacy of content coverage. Their observations and suggestions were incorporated in the final version of the questionnaire before administration.

Reliability of the Instrument

A pilot test was conducted using 20 agricultural education lecturers from universities outside the study sample. Data obtained from the pilot study were analyzed using Cronbach Alpha reliability statistics. The reliability coefficients obtained were 0.79 for Cluster I, 0.82 for Cluster II, 0.77 for Cluster III, 0.84 for Cluster IV, and 0.86 for Cluster V. The overall reliability coefficient of the instrument was 0.81, indicating that the instrument possessed adequate internal consistency and was suitable for data collection.

Method of Data Collection

The researchers administered the questionnaire directly to the respondents with the assistance of six trained research assistants, one from each geopolitical zone. A total of 172 copies of the questionnaire were distributed. Out of this number, 155 copies were correctly completed and returned, representing a response rate of 90.1%. Only properly completed copies were used for data analysis.

Ethical Considerations

Ethical standards were strictly observed throughout the study. Informed consent was obtained from all respondents before participation. Participants were adequately informed about the purpose of the study, the voluntary nature of participation, and their right to withdraw at any stage without penalty. Confidentiality and anonymity of responses were guaranteed by ensuring that no identifying information was collected. The data obtained were used solely for academic and research purposes.

Method of Data Analysis

Mean and standard deviation were used to answer the research questions. For Clusters I, II and IV, mean scores of 2.50 and above were interpreted as agreement, while mean scores below 2.50 were interpreted as disagreement. For Cluster III, mean scores of 3.50–4.00 were interpreted as High Extent, 2.50–3.49 as Moderate Extent, 1.50–2.49 as Low Extent, and 1.00–1.49 as Very Low Extent.

Pearson Product Moment Correlation was employed to determine the relationships between the independent variables and agribusiness sustainability and green enterprise development outcomes. Multiple regression analysis was further used to determine the predictive influence of renewable energy integration practices, adoption barriers, educational initiatives, and integration strategies on agribusiness sustainability and green enterprise development. The hypotheses were tested at a 0.05 level of significance.

The regression model for the study was specified as:

$$ASGED = \beta_0 + \beta_1(REIP) + \beta_2(RAB) + \beta_3(EI) + \beta_4(REIS) + \varepsilon$$

Where:

ASGED = Agribusiness Sustainability and Green Enterprise Development

REIP = Renewable Energy Integration Practices

RAB = Renewable Energy Adoption Barriers

EI = Educational Initiatives

REIS = Renewable Energy Integration Strategies

β_0 = Constant

β_1 – β_4 = Regression Coefficients

ε = Error Term

The null hypotheses were rejected whenever the associated probability value was less than 0.05 and retained whenever the probability value was equal to or greater than 0.05.

4. RESULTS

A total of 172 copies of the questionnaire were administered to respondents. Out of this number, 155 copies were correctly completed and returned, representing a response rate of 90.1%. The returned questionnaires were used for data analysis.

Research Question 1: What renewable energy integration practices currently support agribusiness sustainability and green enterprise development in Nigeria?

Table 1. Mean Ratings of Respondents on Renewable Energy Integration Practices Supporting Agribusiness Sustainability and Green Enterprise Development (N = 155)

S/N	Items	Mean	SD	Remark
1	Integration of renewable energy modules into agricultural education programmes	3.21	0.68	Agree
2	Conducting research on renewable energy applications in agribusiness	2.41	0.82	Disagree
3	Provision of practical training on renewable energy technologies	2.32	0.79	Disagree
4	Establishment of renewable energy demonstration facilities	2.26	0.87	Disagree
5	Collaboration between agricultural and engineering departments	3.08	0.74	Agree
6	Organization of renewable energy workshops and seminars	2.95	0.81	Agree
7	Promotion of student innovation projects on renewable energy	2.38	0.76	Disagree
8	Partnerships with renewable energy enterprises	2.29	0.85	Disagree
9	Establishment of sustainability-focused student associations	2.17	0.73	Disagree

S/N	Items	Mean	SD	Remark
10	Implementation of green campus initiatives	2.34	0.78	Disagree
Grand Mean		2.54	0.78	Agree

The results in Table 1 indicate that renewable energy integration practices were moderately adopted. Three practices were identified as commonly implemented, while the majority of the practices recorded mean scores below the criterion mean of 2.50.

Research Question 2: What barriers limit renewable energy adoption among agricultural education and agribusiness stakeholders?

Table 2. Mean Ratings of Respondents on Barriers Limiting Renewable Energy Adoption (N = 155)

S/N	Items	Mean	SD	Remark
1	Inadequate funding opportunities	3.58	0.61	Agree
2	Low stakeholder awareness	3.42	0.67	Agree
3	Complexity of renewable energy technologies	2.88	0.75	Agree
4	Inadequate infrastructure and facilities	3.61	0.58	Agree
5	Shortage of technical expertise	3.39	0.73	Agree
6	Weak interdisciplinary collaboration	3.07	0.77	Agree
7	Limited access to renewable energy technologies	3.12	0.69	Agree
Grand mean		3.30	0.69	Agree

The findings show that respondents perceived inadequate funding, infrastructural deficiencies, low awareness, and shortage of technical expertise as major barriers to renewable energy adoption.

Research Question 3: To what extent are educational initiatives effective in promoting renewable energy awareness and utilization?

Table 3. Mean Ratings of Respondents on Effectiveness of Educational Initiatives (N = 155)

S/N	Items	Mean	SD	Interpretation
1	Workshops and training programmes	3.02	0.72	Moderate Extent
2	Demonstration farms and pilot projects	2.21	0.81	Low Extent
3	Extension services and awareness campaigns	2.38	0.84	Low Extent
4	Online learning resources and webinars	2.11	0.79	Low Extent
5	Farmer field schools and experiential learning	2.94	0.68	Moderate Extent
6	Industry-based internship programmes	2.27	0.85	Low Extent
7	Capacity-building programmes for educators	2.16	0.81	Low Extent
Grand Mean		2.44	0.79	Low Extent

The findings indicate that existing educational initiatives were generally effective to a low extent in promoting renewable energy awareness and utilization among stakeholders.

Research Question 4: What strategies can strengthen renewable energy integration to enhance agribusiness sustainability and green enterprise development?

Table 4. Mean Ratings of Respondents on Renewable Energy Integration Strategies (N = 155)

S/N	Items	Mean	SD	Remark
1	Curriculum reform and integration	3.56	0.54	Agree
2	Interdisciplinary collaboration	3.48	0.58	Agree

S/N	Items	Mean	SD	Remark
3	Practical training opportunities	3.29	0.65	Agree
4	Faculty development programmes	3.44	0.60	Agree
5	Industry partnerships	3.37	0.56	Agree
6	Renewable energy demonstration projects	3.28	0.62	Agree
7	Incorporation of case studies	3.31	0.61	Agree
8	Guest lectures and expert engagement	3.19	0.69	Agree
9	Student innovation and research projects	3.22	0.74	Agree
10	Policy support and funding incentives	3.51	0.57	Agree
Grand Mean		3.37	0.62	Agree

The respondents agreed that all the proposed strategies could strengthen renewable energy integration and promote sustainable agribusiness development.

Test of Hypotheses

Table 5. Pearson Correlation Matrix among Study Variables

Variables	REIP	RAB	EI	REIS	ASGED
REIP	1.00				
RAB	-0.42**	1.00			
EI	0.54**	-0.37**	1.00		
REIS	0.61**	-0.33**	0.58**	1.00	
ASGED	0.67**	-0.53**	0.59**	0.72**	1.00

p < 0.01

Note: REIP = Renewable Energy Integration Practices; RAB = Renewable Energy Adoption Barriers; EI = Educational Initiatives; REIS = Renewable Energy Integration Strategies; ASGED = Agribusiness Sustainability and Green Enterprise Development. ** indicates correlation is significant at the 0.01 level (2-tailed). N = 155.

The correlation results indicate significant positive relationships between renewable energy integration practices, educational initiatives, integration strategies, and agribusiness sustainability and green enterprise development. Barriers to adoption demonstrated a significant negative relationship with agribusiness sustainability and green enterprise development.

Table 6. Multiple Regression Analysis of Predictors of Agribusiness Sustainability and Green Enterprise Development

Predictor	B	Beta	t	p
Constant	0.842	-	4.871	.000
Renewable Energy Integration Practices (REIP)	0.271	0.283	4.116	.000
Renewable Energy Adoption Barriers (RAB)	-0.214	-0.231	-3.782	.001
Educational Initiatives (EI)	0.196	0.209	3.425	.001
Renewable Energy Integration Strategies (REIS)	0.347	0.392	5.287	.000

Model Summary

R = 0.811

R² = 0.658

Adjusted R² = 0.649

$F(4,150) = 72.18$

$p = .000$

Note: B = Unstandardized Regression Coefficient; Beta (β) = Standardized Regression Coefficient; t = t-statistic; p = Probability Value; R = Multiple Correlation Coefficient; R^2 = Coefficient of Determination; Adjusted R^2 = Adjusted Coefficient of Determination; F = Overall Regression Statistic; REIP = Renewable Energy Integration Practices; RAB = Renewable Energy Adoption Barriers; EI = Educational Initiatives; REIS = Renewable Energy Integration Strategies; ASGED = Agribusiness Sustainability and Green Enterprise Development. Significance level = 0.05; N = 155.

The regression model was statistically significant, $F(4,150) = 72.18$, $p < .05$, indicating that the predictor variables jointly explained variations in agribusiness sustainability and green enterprise development. The model accounted for 65.8% of the variance in agribusiness sustainability and green enterprise development ($R^2 = .658$). Renewable energy integration strategies emerged as the strongest predictor ($\beta = .392$), followed by renewable energy integration practices ($\beta = .283$), renewable energy adoption barriers ($\beta = -.231$), and educational initiatives ($\beta = .209$). The findings indicate that improvements in renewable energy integration practices, educational initiatives, and integration strategies significantly enhance agribusiness sustainability and green enterprise development, whereas adoption barriers exert a negative influence.

Hypotheses Decision

H01: Renewable energy integration practices significantly predicted agribusiness sustainability and green enterprise development ($\beta = 0.283$, $p < .05$). Therefore, H01 was rejected.

H02: Renewable energy adoption barriers significantly influenced agribusiness sustainability and green enterprise development ($\beta = -0.231$, $p < .05$). Therefore, H02 was rejected.

H03: Educational initiatives significantly predicted agribusiness sustainability and green enterprise development ($\beta = 0.209$, $p < .05$). Therefore, H03 was rejected.

H04: Renewable energy integration strategies significantly predicted agribusiness sustainability and green enterprise development ($\beta = 0.392$, $p < .05$). Therefore, H04 was rejected.

The regression model explained 65.8% of the variance in agribusiness sustainability and green enterprise development. Renewable energy integration strategies emerged as the strongest predictor, followed by renewable energy integration practices, adoption barriers, and educational initiatives.

Discussion of Findings

The study found that renewable energy integration practices were only moderately implemented among agricultural education and agribusiness stakeholders in Nigeria. Respondents reported higher levels of implementation in curriculum integration, collaboration between agricultural and engineering departments, and renewable energy workshops. However, research activities, demonstration projects, student innovation programmes, and industry partnerships recorded lower levels of implementation. These findings suggest that awareness of renewable energy is increasing, but practical application remains limited. The result supports reports that renewable energy adoption in developing countries is still at an early stage despite increasing global attention to sustainable energy transitions [2]. It also agrees with UNEP [5], which identified inadequate investment and weak innovation systems as barriers to effective renewable energy integration.

The study further revealed that inadequate funding, infrastructural deficiencies, low stakeholder awareness, shortage of technical expertise, weak interdisciplinary collaboration, and limited access to renewable energy technologies were major barriers to renewable energy adoption. Among these barriers, inadequate funding and infrastructural deficiencies emerged as the most severe constraints. This finding demonstrates that renewable energy adoption is influenced not only by technological availability but also by economic and institutional factors. The result is consistent with studies indicating that financial limitations constitute one of the most significant barriers to renewable energy deployment in developing economies [19]. The finding also supports evidence showing that inadequate infrastructure significantly restricts access to renewable energy technologies in rural agricultural communities [14]. Furthermore, previous studies have

reported that insufficient technical competencies and sustainability-related skills continue to limit innovation and enterprise development within the agricultural sector [26]. The findings of this study are also consistent with evidence from other Sub-Saharan African countries. For example, studies conducted in Kenya, Ghana, and Uganda have similarly identified inadequate financing, limited technical capacity, and infrastructural challenges as major constraints to renewable energy adoption within agricultural enterprises. These similarities suggest that many developing agricultural economies face common challenges in integrating renewable energy technologies. Consequently, regional cooperation, knowledge sharing, and investment in renewable energy infrastructure may accelerate sustainable agribusiness development across Africa.

The findings concerning the effectiveness of educational initiatives indicated that existing programmes were generally effective to a low extent in promoting renewable energy awareness and utilization. Although workshops, training programmes, and experiential learning activities recorded moderate effectiveness, demonstration projects, extension services, internship programmes, and online learning resources were perceived as insufficient. This finding suggests that current educational interventions may not be adequately structured to support large-scale renewable energy adoption among agricultural stakeholders. The result is consistent with evidence indicating that sustainability-oriented educational programmes in many developing countries are often constrained by limited resources and inadequate practical learning opportunities [16]. The finding also agrees with research showing that experiential learning approaches produce better sustainability outcomes than conventional classroom-based instruction [1]. Similarly, Nwachukwu et al. [26] advocated curriculum reforms capable of enhancing the responsiveness of agricultural education programmes to emerging sustainability challenges.

The study established that curriculum reform, interdisciplinary collaboration, practical training, industry partnerships, innovation initiatives, and supportive policies are viable strategies for strengthening renewable energy integration. Respondents particularly emphasized curriculum innovation and policy support. This finding underscores the importance of institutional and policy-driven approaches to sustainable agricultural transformation. The result supports studies identifying curriculum development as a key driver of sustainability competencies among agricultural stakeholders [16]. It is also consistent with evidence that industry collaboration and practical learning enhance technology adoption and innovation capacity [4]. Likewise, Umeh et al. [18] highlighted the growing importance of green skills for employability and sustainable agribusiness development.

The correlation analysis revealed significant positive relationships between renewable energy integration practices, educational initiatives, integration strategies, and agribusiness sustainability and green enterprise development. In contrast, adoption barriers showed a significant negative relationship with sustainability outcomes. These findings suggest that stronger renewable energy integration efforts promote sustainable agribusiness development, whereas persistent barriers hinder progress. The result supports the assumptions of the Diffusion of Innovation Theory regarding enabling and inhibiting factors in innovation adoption [29]. The finding also corroborates evidence that educational and institutional support systems promote sustainability-oriented innovation [7]. Similarly, financial and infrastructural barriers have been shown to reduce sustainable technology adoption [19].

The regression analysis indicated that renewable energy integration practices, adoption barriers, educational initiatives, and integration strategies significantly predicted agribusiness sustainability and green enterprise development. The model explained 65.8% of the variance in the dependent variable, demonstrating strong predictive power. Renewable energy integration strategies emerged as the strongest predictor. This finding suggests that coordinated interventions are more effective than isolated initiatives in promoting sustainable agribusiness outcomes. The result agrees with studies emphasizing integrated policy, educational, and institutional approaches to sustainability transitions [5]. It also supports evidence that innovation ecosystems enhance enterprise growth and technology adoption [10]. Furthermore, Nwakile, Izuakor, Onogu and Ali [17] emphasized the importance of innovation-oriented systems for sustainable agribusiness development.

Overall, the findings demonstrate that renewable energy integration has substantial potential to enhance agribusiness sustainability and stimulate green enterprise development in Nigeria. However, realizing these benefits requires addressing existing barriers and implementing comprehensive integration strategies involving educational institutions, policymakers, industry stakeholders, and development partners. The findings reinforce the need to position renewable energy as a strategic component of sustainable agricultural transformation and green economic development. The evidence provides strong support for increased investment in renewable energy education, innovation, infrastructure, and policy interventions within the Nigerian agricultural sector.

Regional Implications for Renewable Energy Integration in Nigeria

Although the study investigated renewable energy integration across the six geopolitical zones of Nigeria, the analysis focused on aggregated national responses. Nevertheless, variations in resource endowment, infrastructure availability, educational capacity, and agricultural activities across regions may influence the implementation of renewable energy technologies. For example, northern regions possess substantial solar energy potential that can support solar powered irrigation and agro processing systems, while southern regions may benefit from biomass, biogas, and small-scale hydropower opportunities due to greater vegetation and water resources. Similarly, differences in electricity access, transportation infrastructure, institutional capacity, and investment opportunities may affect the rate of renewable energy adoption across regions.

These regional variations suggest that renewable energy policies and intervention programmes should be adapted to local conditions rather than relying on a uniform national approach. Strategies designed for areas with limited infrastructure may need to prioritise basic energy access and capacity building, whereas regions with stronger institutional support may benefit more from innovation driven renewable energy initiatives and enterprise development programmes. Consequently, policymakers should consider regional characteristics when designing renewable energy integration frameworks for sustainable agribusiness development in Nigeria.

Limitations of the Study and Suggestions for Further Studies

This study focused exclusively on agricultural education lecturers in Nigerian universities. Although these respondents possess substantial expertise in agricultural education, sustainability, and agribusiness development, their perspectives may differ from those of farmers, agribusiness entrepreneurs, renewable energy service providers, extension personnel, and policymakers who are directly involved in the implementation of renewable energy technologies. Consequently, the findings should be interpreted within the context of agricultural education and may not fully reflect the experiences of all stakeholders engaged in renewable energy adoption and agribusiness development.

In addition, the study did not undertake a comparative analysis of responses across the six geopolitical zones of Nigeria. Differences in resource endowment, infrastructure availability, educational capacity, and agricultural activities may influence the adoption and effectiveness of renewable energy technologies across regions. Future studies should therefore incorporate a broader range of stakeholder groups and examine regional variations in renewable energy integration, agribusiness sustainability, and green enterprise development. Such investigations would provide more comprehensive and context specific evidence to support sustainable agricultural transformation in Nigeria.

5. CONCLUSION

This study examined renewable energy integration as a catalyst for agribusiness sustainability and green enterprise development among agricultural education and agribusiness stakeholders in Nigeria. The findings revealed that renewable energy integration practices are only moderately implemented within agricultural education and agribusiness systems. Major barriers to adoption include inadequate funding, infrastructural deficiencies, low stakeholder awareness, and insufficient technical expertise. Furthermore, existing

educational initiatives were found to be only moderately effective in promoting renewable energy awareness and utilisation among stakeholders.

The study identified curriculum reform, practical training opportunities, industry partnerships, interdisciplinary collaboration, faculty capacity development, renewable energy demonstration projects, and supportive policy frameworks as important strategies for strengthening renewable energy integration. These measures were found to be critical for enhancing agribusiness sustainability and promoting green enterprise development. The findings also suggest that successful renewable energy integration requires consideration of regional differences in resource availability, infrastructure development, and agricultural production systems across Nigeria.

The correlation and regression analyses confirmed that renewable energy integration practices, educational initiatives, adoption barriers, and renewable energy integration strategies significantly influence agribusiness sustainability and green enterprise development. Among these variables, renewable energy integration strategies emerged as the strongest predictor of sustainable agribusiness outcomes. The study therefore concludes that renewable energy integration is not only an environmental necessity but also a strategic pathway for improving agribusiness sustainability and stimulating green enterprise development in Nigeria. Although the findings reflect the perspectives of agricultural education lecturers, they provide valuable insights into the educational, institutional, and policy factors shaping renewable energy integration within the Nigerian agricultural sector. Sustainable agricultural transformation can be accelerated through coordinated investments in renewable energy education, infrastructure, innovation, policy support, and institutional collaboration.

6. RECOMMENDATIONS

Based on the findings of the study, the following recommendations are made:

1. Universities offering agricultural education and agribusiness programmes should revise their curricula to incorporate dedicated courses and practical modules on renewable energy technologies and sustainable agribusiness systems.
2. Government agencies and development partners should establish special funding schemes, grants, and low-interest financing mechanisms to support renewable energy adoption among agricultural institutions and agribusiness enterprises.
3. Agricultural extension services should intensify awareness campaigns and capacity-building programmes aimed at promoting renewable energy utilization among farmers and agribusiness operators.
4. Policymakers should formulate and implement supportive policies, tax incentives, and regulatory frameworks that encourage investment in renewable energy technologies within agricultural value chains.
5. Renewable energy policies and intervention programmes should be adapted to the specific resource endowments, agricultural activities, and infrastructural conditions of different geopolitical zones to enhance implementation effectiveness and sustainability outcomes.
6. Future researchers should investigate renewable energy integration using broader stakeholder groups, including agribusiness entrepreneurs, farmers, agricultural extension personnel, renewable energy providers, financial institutions, and policymakers. Such studies would provide more comprehensive evidence regarding the practical challenges, opportunities, and policy implications of renewable energy integration for sustainable agribusiness transformation.

Supplementary Materials: Not applicable.

Funding Statement: This study was not funded by any external sources.

Contribution: The authors contributed to the research and writing of this article and have read/agreed to the published version of the manuscript.

Toochukwu Collins Nwakile: Conceived and designed the study, developed the methodology, performed the data analysis, interpreted the findings, supervised the research, prepared the original manuscript draft, and served as the corresponding author.

Sylvia Ifeoma Ofoedu: Contributed to the literature review, assisted with questionnaire development and data collection, validated the study procedures, and critically revised the manuscript for important intellectual content.

Chima Francis Ugwunnaji: Coordinated data collection, organized and curated the data, assisted with the interpretation of results, proofread the manuscript, and contributed to the final editing of the manuscript.

All authors read and approved the final manuscript and agreed to be accountable for the integrity of the work

Informed Consent Statement: Informed consent was obtained from all respondents before participation. Participants were adequately informed about the purpose of the study, the voluntary nature of participation, and their right to withdraw at any stage without penalty. Confidentiality and anonymity of responses were guaranteed by ensuring that no identifying information was collected. The data obtained were used solely for academic and research purposes.

Data Availability Statement: Data are available upon reasonable request from the corresponding author.

Conflict of Interest Statement: The authors declare no conflicts of interest.

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