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Adoption and Challenges of Zero-Carbon Energy among Rural Smallholder Farmers in Southeast Nigeria

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Abstract

This study investigated the adoption, energy productivity and challenges of zero-carbon energy (ZCE) among rural smallholder farmers in southeast Nigeria. A multistage sampling procedure was used to select 378 respondents. Data were analysed using percentages, mean, ranking statistics, and a single-factor productivity model. Findings show that the majority (97.4%) of the respondents were aware that ZCE could be used for farming activities, 15.0% knew about wind power, 6.0% were aware of hydropower, and 2.7% were not aware of any types of ZCE. Also, 90.0% of the farmers were aware of the major benefits of ZCE. Only 28.6% use photovoltaic solar energy, while major farming activities powered by ZCE were the lighting of the farmhouses (89.8%) and water supply (15.7%). The energy productivity of ZCE (4.1%) was higher than fossil fuel (1.8%). High installation costs and lack of credit/ subsidy for ZCE ranked 1st and 2nd as challenges to the adoption of ZCE. Extension officers should do more to educate farmers to use the ZCE options since they have higher energy productivity than fossil fuels.

Introduction

Climate change caused by the accumulation of carbon into the environment, primarily from the use of fossil fuels, is an existential threat to life on earth (Intergovernmental Plan on Climate Change [IPCC], 2023), impacting food production and human security in Nigeria (Ani, Anyika & Mutambara (2022). Agriculture contributes to the emission of methane, nitrous oxide, and carbon (iv) oxide in the environmental carbon pool. At the same time, climate change affects agriculture through temperature rise, affecting crop and animal production, rising sea levels, which cause farmland salinisation and flooding, and pests/ diseases infestation (Kumar, Chhogyel, Gopalakrishnan, Hasan, Jayasinghe, Kariyawasam, Kogo, & Ratnayake 2022).

To combat the magnitude of the crises, both urban and rural dwellers are expected to be involved in a deliberate decarbonisation process to limit global warming to 1.5°C, as decided in the Paris Agreement (IPCC, 2023). According to the Climate Change Performance Index (2024), Nigeria is one of the developing countries in Africa to have set an economy-wide decarbonisation target for an unconditional contribution of 20% below business-as-usual by 2030 and a 47% contribution conditional on international support to achieve a net-zero target of 2060. To achieve these targets, decarbonisation in the rural economies must not be left out, especially in Nigeria, where over 70% of the rural population is engaged in the agriculture sector, mainly at a subsistence level (Food and Agriculture Organisation, 2024). These rural farmers depend largely on human labour and motorised farm equipment for agricultural production, processing, and transportation, contributing to carbon emissions.

Rural smallholder farmers have great potential to contribute to the decarbonisation targets in Nigeria through the adoption of zero-carbon energy, of which sources are incidentally abundant in the rural areas. Zero-carbon energy (ZCE) is a type of renewable energy produced without emitting any carbon into the environment from its production process (Omeje et al., 2024). Zero-carbon energy has economic and environmental advantages, making it the most suitable clean and sustainable energy for Nigeria and other developing countries to achieve the seventh sustainable development goal of the United Nations (Ghosh, 2023). Nevertheless, ZCE is grossly underutilised in Nigeria despite the availability of low-carbon energy sources (Omeje et al., 2024).

Smallholder farmers are great agents of change, contributing significantly to global agriculture (Kapari, Hlophe-Ginindza, Nhamo, & Mpandeli (2023), also, in Nigeria, where over 70% of Nigerian farmers are small-holders, mainly at a subsistence level (FAO, 2024). These smallholder farmers contribute about 90% of the food output in the country (Chiaka, Yunfeng, Xiao, Muhirwa, & Lang, 2022). Small-holder farmers, therefore, could play a significant role in the decarbonisation targets in Nigeria if the right policies are made to encourage them to use ZCE for motorised farming activities. Despite their contributions, research has shown that rural smallholder farmers are often faced with enormous challenges due to their socioeconomic characteristics. For example, Chiaka et al. (2022) emphasised that rural farmers lack access to critical resources such as credit, education, information, and innovation. However, there is little information on whether these same challenges are also responsible for the gross underutilisation of ZCE among rural smallholder farmers in Southeast Nigeria.

Most often, good policies fail because of the high aggregation of distinct sub-sectors, thereby making a blanket policy that cannot work efficiently across different sub-sectors of the economy (Baron, 2000). Rural smallholder farmers have significantly distinct socioeconomic characteristics from the rest of the actors in Nigeria’s economy. Nevertheless, most national decarbonisation policies are based on an economy-wide approach. Policy formulation must consider these peculiarities to have an efficient problem-solving policy for specific sub-sectors and regions with distinct characteristics. Therefore, there is a need to focus research on the decarbonisation of ZCE among rural smallholder farmers in Southeast Nigeria.

Furthermore, although there exists related literature on the awareness of farmers (Izuogu et al., 2023), the adoption of innovations among farmers (Adeleke, Fadairo, & Camara, 2024), challenges faced by farmers (Isaac & Nkosi, 2020) and low-carbon energy among farmers (Majeed, et al., 2023), and the use of low-carbon/ renewable energies (Omeje et al., 2024), none of these studies examined the awareness, adoption, and challenges of zero-carbon energy among rural smallholder farmers in Southeast Nigeria. In addition, this study also compared the energy productivity of using both ZCE and fossil. Closing these research gaps would be a veritable tool for formulating energy policies and modelling Nigeria's path to the net-zero carbon target by 2060. This study, therefore:

- investigated the extent of awareness of ZCE options usable for household farming,
- examined the degree of adoption of ZCE among rural farmers,
- compared the energy-factor productivity between ZCE and fossil users, and;
- identified the socio-economic challenges of using ZCE in Southeast Nigeria.

Methodology

The study area was Southeast Nigeria, which comprises five states: Abia, Anambra, Ebonyi, Enugu, and Imo. According to the National Population Census (NPC, 2020), the population of Southeast was over 22,012,828, 18% of Nigeria's population. The rural areas of the region are predominantly agrarian and rain-fed, with two distinct seasons in a year—the rainy and the dry seasons (Climate Change Knowledge Portal, 2024).

The study population comprised all rural smallholder farmers. A multi-stage sampling procedure was used in the selection of respondents. The first stage involved the purposive selection of three states – Anambra, Ebonyi, and Enugu that were considered due to their predominance in the decarbonisation programme. In the second stage, to ensure that predominantly rural areas were selected, two Local Government Areas (LGAs) were purposively selected from each of the three states, making a total of six LGAs. In the third stage, two (distinctive rural and agrarian) autonomous communities were purposively selected from each of the six LGAs, making a total of 12 rural agrarian communities. Finally, in line with the Cochran formula for infinite sample size (Uakarn, Chaokromthong, & Sintao, 2021), 32 respondents were randomly selected from each of the communities, making a total of 384 respondents. The Cochran formula used to determine the sample size is given as: $n = \frac{z^2}{4e^2}$ where n = sample size, z = z-score at 95% confidence level (z=1.96), e = error term (e = 0.05). Out of the 384 questionnaires distributed, 378 were retrieved and validated successfully. Table 1 presents the description of the variables used for the analysis.

Table 1: Descriptions of variables

Variables	Descriptions of variables
Energy productivity (E)	an indicator of the amount of economic output that is derived from each unit of energy consumed

energy productivity of ZCE (E_1)	an indicator of the amount of economic output that is derived from each unit of ZCE used
Energy productivity of Fossil option (E_2)	an indicator of the amount of economic output that is derived from each unit of fossil energy used
Energy input value (EIV)	The value of the unit of energy consumed (in Naira)
output value (OV)	the amount of economic output derived from the energy option (in Naira)

Awareness of ZCE options, degree of adoption of ZCE and the challenges facing the adoption of ZCE were analysed with percentages and Likert scales, while energy productivity differentials between ZCE and fossil options were analysed with a single-factor productivity model. The single-factor productivity of energy(E) among the farmers is given as:

$$E = \frac{\text{OV}}{\text{EIV}} \qquad --- \; equation\ 1$$

This single-factor energy productivity (E) is analysed here in monetary value as the amount of economic output that is derived from each set of energy (zero-carbon or fossil energy) used by the farmer, measured by taking the ratio of the economic output (OV) derived from the energy used and the value of energy consumed in the process (EIV) (Australian Alliance for Energy Productivity, 2017). To further compare the single-factor productivity of both ZCE (E_1) and fossil energy (E_2), the two energy options (E_1 & E_2) are built into equation 2, given as:

$$E_1/E_2 = (OV)_1 + (EIV)_1/(OV)_2 + (EIV)_2 \qquad \text{--- equation 2.}$$

Results and Discussion

Awareness of ZCE among Rural Farmers

The awareness of ZCE among rural farmers was measured in two categories. Table 2 presents the awareness of ZCE types, and Table 3 presents the awareness of ZCE benefits. the major highlight in Table 2 shows that the majority (97.4%) of the respondents were aware that solar energy could be used for various farming activities.

Table 2: Awareness of ZCE types

Types of ZCE known to the respondents	%
solar power	97.4
wind power	15.1
hydropower	05.6
None	02.6

Source: Field Survey, 2024

Table 3 shows that the majority of the respondents were aware that ZCE has less operational cost than fossil fuel and that ZCE sources are sustainable and renewable. This implies that the awareness of solar energy as a zero-emission option is high among farmers, suggesting that the efforts being put in place in recent years are yielding great results. This also suggests that resources (policymakers, energy and agriculture stakeholders) need to channel more resources towards the adoption of ZCE instead of spending more of their limited resources on the creation of awareness among the farmers. These findings are in line with Ling, Xue, Yang, and Zhang (2023), who also found that awareness of low-carbon energy among different groups of farmers is significantly high.

Table 3: Awareness of ZCE benefits

Benefits of ZCE known to the respondents	%
does not produce poisonous elements	60.1
reduces labour due to the absence of toxic waste	73.6
leads to decarbonization	78.2
sources are sustainable/ renewable	91.6
has less operational cost	98.1

Source: Field Survey, 2024

Adoption of ZCE among Rural Farmers

The adoption of ZCE among rural farmers was measured in two categories. A psychometric evaluation of the multiple responses was scaled using a 4-point Likert-type technique to select significant responses from the farmers. Table 4 presents the adoption of ZCE types, and Table 5 presents the adoption of ZCE for specific farming activities.

Table 4 shows that 28.6% of the respondents were using solar energy for various farming activities, while none of the farmers used hydropower or wind power sources. One reason the respondents did not use either hydropower or wind power could be that investing in hydropower and wind turbines requires much more capital than solar power and may also need to meet certain location specifics, such as a waterfall or strong wind direction, to function properly.

Table 4: Adoption of ZCE types by rural farmers

Types of ZCE adopted by the farmers	%
Solar power (photovoltaic)	28.6
Wind power	0.0
Hydropower	0.0

Source: Field Survey, 2024

Table 5 further shows that 90.8% of the respondents indicated using thermal heat to sun-dry various farm inputs and outputs, but the study's focus was on photovoltaic solar energy. The table also shows that the majority (89.8%) of the respondents indicated that the adoption of photovoltaic solar energy was mainly for lighting up the farmhouse and its environment. In comparison, 9.2% represents other activities on the farm. The reason for using photovoltaic solar, mostly for lighting farmhouses and the environment, could be linked to the high cost of installation for motorised equipment on the farm. These findings are in line with the observations of Ling et al. (2023) and Omeje et al. (2024), who also discovered that despite high awareness among farmers, the usage of renewable or low-carbon energy for farm operations was low and below expectations. The remedies for this continued low adoption of ZCE among farmers could come from increased campaigns and incentives for the use of ZCE and the promotion of credit programmes, especially for farmers who are willing to adopt but are constrained by high initial capital requirements.

Table 5: Adoption of ZCE for specific farm activities by the farmers

Specific Farm activities done with the ZCE	%
lighting the farmhouse/environment	89.8
water supply	15.7
transportation	4.6
drying farm produce/by-products (photovoltaic)	3.7
making feeds for animals	2.8
heating of pen	1.9
Others (cutting, bagging, cracking, etc.)	1.8
drying farm produce/by-products (thermal heat)	90.7***

Source: Field Survey, 2024 (**Thermal solar use, which is not the focus of the study).

Comparing the Energy Productivity of ZCE and Fossil Fuels Used for major Farm Activities

An evaluation of the multiple responses by the farmers using a 4-point Likert-type technique was used to rank the farm activities done with the ZCE. The result further reveals (Table 6) that water supply and lighting of farmhouses were the most common farm activities done with ZCE and fossil energy. A further breakdown of the single-factor productivity analysis shows that the energy productivity of using ZCE for water supply in the farm was higher (2.8%) than the use of fossil energy (1.8%). Also, the energy productivity of using ZCE for lighting up the farmhouse was higher (5.4%) than the use of fossil energy (1.8%). On average, the energy productivity of the farm activities executed with ZCE was higher than fossil energy on the ratio of 2:1. The high productivity attributed to ZCE could be a result of the low cost of production achievable in the long run despite its high cost of installation. This increased productivity is a big incentive for more farmers to start using ZCE, and stakeholders could encourage rural farmers to achieve this goal. These findings align with that of Kata, et al. (2021), who showed that the use of low-carbon or renewable energies for agricultural production is more efficient than the use of high-carbon energies.

Table 6: Comparing the energy productivity of ZCE and fossil fuels

Major farm activities	Energy-factor productivities	
	Solar (photovoltaic)	Fossil fuel
Water supply	2.8	1.8
Lighting of farmhouse	5.4	1.8
Mean	4.1	1.8

Source: Field Survey, 2024

Challenges Faced in Using ZCE among Rural Farmers

The major challenges faced in the use of ZCE among rural farmers are shown in Table 7. The most severe challenge was the high initial/ installation cost (82.0%). This was followed by a lack of credit/ subsidy for the installation of ZCE (77.0%) and illiteracy/ lack of training on the use of ZCE (76.0%). This result implies that the most critical challenges facing the farmers are related to funding the adoption of zero-carbon equipment meant to generate electricity. It appears that the farmers are generally constrained by a lack of adequate capital spurred by the high inflation rate in Nigeria and inadequate access to credit facilities. This research findings corroborate with Adeleke et al., (2024), who found that insufficient loans and inadequate extension contacts were challenges to adoption among rice farmers.

Table 7: Challenges facing the use of ZCE among rural farmers

Challenges (multiple responses)	%
Cultural attachment to the use of fossil fuels	38.0
Poor extension service education	45.0
Illiteracy/ lack of training on the use of ZCE	76.0
Lack of credit/ subsidy for installation of ZCE	77.0
Seasonality of farm activities	34.4
High initial/ installation cost of ZCE	82.0
Fear/ uncertainty about the safety/durability of ZCE	29.4
Lack of supportive policies	42.3

Source: Field Survey, 2024

Conclusion and Recommendations

The majority of the rural smallholder farmers in Nigeria are aware that ZCE is better than fossil fuels and that such a zero-carbon option could be used for various farming activities. The farmers who are using innovative photovoltaic solar energy have higher energy productivity than those who depend on traditional fossils. The most severe challenge of adopting ZCE among the farmers is the lack of capital. The study, therefore, recommends that extension officers could do more to educate farmers to use the ZCE options and that governments at all levels should promote ZCE by formulating supportive policies such as reduced taxation for users of ZCE, zero-carbon grants, carbon loans, and incentives.

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