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Determinant and Impact of Renewable Energy Utilization on Farm Productivity in South-South Nigeria

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Abstract

Nigeria is endowed with abundant renewable and non-renewable energy resources but despite this abundance, the country is currently facing inadequate supply and widening demand for energy. In this study, we examine how farmers' use of renewable energy is related to their productivity in Nigeria. Since not all farmers are using renewable energy in the study area, it is important to separate them into 2 groups, "Users" and "Non-users" in order to estimate the productivity level of each group. Primary data was analyzed using an endogenous switching regression model (ESRM) with a sample size of 313 farm households. The result of the study indicates that renewable energy use increased agricultural productivity by 39%. The study also reveals that of the farmers surveyed, 75% are willing to use renewable energy. These results provide knowledge to stakeholders on the need to protect agricultural land and increase agricultural production and productivity through continuous use of renewable energy.

Keywords: Agricultural productivity; Endogenous switching regression; Renewable energy; Willingness to use.

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1. Introduction

Energy demand for agricultural production is increasing due to growing population, high food demand and supply, inevitable industrialization, and research on improvement in agricultural productivity [1]. As time passes and agriculture advances, the need for energy in agricultural production will rise intensively as the conventional, low-energy agriculture becomes replaced by modern systems, which require more energy to carry out the various agricultural operations [2]. Agricultural production processes rely on and use energy in one form or another, either in form of electricity for pumping water for irrigation, drying of crops, powering/lighting of farm houses, heating/cooling farm houses etcetera. These agricultural activities rely mostly on energy which is mainly provided by fossil resources which however is unsafe for agricultural lands [3].

Energy is grouped into renewable and non-renewable. Renewable energy is energy from nature's resources and can easily be replenished by nature; for example; hydro energy, solar energy, wind energy, and bio-energy are renewable energy sources, while non-renewable energy are energy from fossil fuels and cannot be replenished by natural processes. Crude oil, natural gas and coal are forms of non-renewable energy [4]. These energy resources provide energy for various sectors of the economy, including the Nigeria agricultural sector.

In Nigeria, the geographical distribution of fossil deposits is more clustered in the South-South region due to the large amount of crude oil in the region, leading to emission of carbon dioxide and other greenhouse gases which is a contributor to climate change, global warming, environmental pollution as well as pollution on lands used for agricultural activities [5]. Emission of greenhouse gases has a negative effect on man, agriculture and the environment, which on the long run is capable of reducing productivity [6]. Food produced in polluted land are unsafe for human consumption and can lead to food poisoning due to traces of heavy metals contained in the food produce. Hash weather condition also poses a threat to agricultural production and meeting the growing demand for food [7].

The United Nations in their report on climate change stated that an increase in global temperature by 3°C would have a negative impact on outbreak of pest and diseases, food availability and supply as well as planting and harvest time [8]. This however will reduce crop yield, resulting in low production and in turn lead to failure in meeting food demand and supply [9]. Thus the use of renewable energy in agriculture is considered a better alternative as it is a clean source of energy, environmentally friendly, safe and can help reduce climate change [10].

Solar energy is the most commonly used renewable energy application by farmers in most part of the country including the South-south region for drying agricultural products [11]. The region experiences high sunlight and produces a large amount of agricultural waste which is renewable and can be tapped to reduce the negative effect of fossil fuel in the agricultural sector [12]. However, its energy production is inefficient, compared to the constant availability of energy-generating resources, which may be due to farmers poor knowledge of the benefits associated with renewable energy use, especially in rural areas that are composed mainly of smallholder farmers with limited resources and who lack basic knowledge on the application of modern farm methods [13].

Previous studies in Nigeria [14-16] focused on the application of renewable energy in poultry production but did not look at the relationship between the use of renewable energy and productivity. Others focused on identifying factors that influence farmers in developing energy efficiency and use of renewable energy [17-20]. In addition, [21-27] focused on the potential benefits and challenges in the utilization of renewable energy in agriculture but these however were not an empirical study. We improve on these studies by approaching it empirically and identify factors that influence the decision to use renewable energy and assess how the decision to use renewable energy influences farmers' productivity.

2. Study Area

2.1. Materials and Methods

The study was carried out in South-South Nigeria. The region is bordered to the south by the Atlantic Ocean and Cameroon to the east. The South-South states occupy 85,303 square kilometers of land and are composed of six states. These states are Nigeria's top oil producing states and they include Akwa-Ibom, Bayelsa, Cross River, Delta, Edo and Rivers and are divided into 18 agricultural zones [28]. According to the National Population Commission (NPC, 2006), the population of the South-South States as of 2006 was 21,014, 655. The region is blessed with abundant crude oil reserves and provide about 90 percent of the nation's foreign earning [29].

Farming is the most common occupation in the zone, which includes fish farming, palm culture, yam cultivation, cassava cultivation, cocoyam cultivation, and so on. Despite contamination from oil drilling in the region, agriculture remains the people's major source of income due to the rich soil and suitable climate. Farmers in the area also engage in various off-farm activities ranging from clay pot making, basket making, local broom making, mat making and petty trading on various non-farm produce, especially during the off-farm season. Farmers dominate the population of the state thus making food production, processing and marketing the major occupation in the area. Also, renewable energy have not fully penetrated the energy scene in the region however, solar energy is the popular renewable energy commonly used by farmers for various farm operations.

A proportionate random sampling method was used at 95% confidence level. Out of 400 copies of the questionnaire administered, 313 copies were used for the analysis. The remaining 87 were not used due to insufficient data provided and Covid19 restrictions at the time of data collection.

Table-1. Sample size per Stratum

State	Population	Percentage	Sample Size by State
Delta	179,256	43	172
Edo	167,540	41	164
Bayelsa	66,337	16	64
Total	**413,133**	**100**	**400**

Author's computation 2020

2.2. Endogenous Switching Regression Model (ESRM)

This paper examines the relationship of farmers' use of renewable energy and agricultural productivity. An ESRM which accounts for selection bias was used for the estimation. The ESRM is an economic system that describes a choice making process and the regression models related to each choice alternative. It is often used to overcome the difficulties of self-selection [30]. It allows us to estimate the direction and degree of non-random response of farmers' use of renewable energy, as well as the selection biases embedded in the ordinary least squares (OLS) estimates of the effects of renewable energy use. The ESRM model employed in this study was derived from [30-32]. First, we stipulate the binary decision choice of respondents' users of renewable energy conditional on the observable covariates through the use of a Probit model as follows:

$$P_i^* = \beta Z_i + \varepsilon_i \ldots \ldots (1)$$

$$P_i = 1 \; if \; P_i^* > 0 \ldots \ldots (2)$$

$$P_i = 0 \; if \; P_i^* \leq 0 \ldots \ldots (3)$$

Because of the selection bias, farmers are assumed to encounter two regimes as follows:

Regime 1 (Users): $P_{1i} = \lambda_1 Q_i + \phi_1 C_{1i} + v_{1i} \ldots \ldots (4)$

Regime 2 (Non-users): $P_{2i} = \lambda_2 Q_i + \phi_2 C_{2i} + v_{2i} \ldots \ldots (5)$

Where P1i and P2i represents productivity of respondents in regimes 1 and 2. Qi denotes a vector of exogenous variables that are hypothetically presumed to be driving the farmer's productivity function. ϕ1 and ϕ2 are the estimated parameters v1 and v2 the error terms. Lastly, the error terms are assumed to have a trivariate normal distribution, with zero mean and a non-singular covariance matrix stated as follows:

$$cov(\varepsilon_i, v_1, v_2)\begin{bmatrix}\sigma_1^2 & \sigma_{12} & \sigma_{1\varepsilon}\\ \sigma_{12} & \sigma_2^2 & \sigma_{2\varepsilon}\\ \sigma_{1\varepsilon} & \sigma_{2\varepsilon} & \sigma^2\end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ldots(6)$$

Where,

$\sigma_1^2 = var(v_1)$; $\sigma_2^2 = var(v_2)$; $\sigma^2 = var(\varepsilon_i)$; $\sigma_{12} = cov(v_1, v_2)$; $\sigma_{1\varepsilon} = cov(v_1, \varepsilon_i)$; $\sigma_{2\varepsilon} = cov(v_2, \varepsilon_i)$; σ^2 Represents variance of the error term in the selection equation and σ_1^2, σ_2^2 represents variance of the error term in the outcome equations. The key relevance of the error structure, according to Feder, *et al.* [31], where there are non-observable elements related to selection bias, it is based on the fact that the error term (ε_i) of the selection equation (1 to 3) are correlated with the error terms (v_1, v_2) of the outcome functions (4) and (5), the expected values of v_{1i}, v_{2i} conditional on the sample selection are non-zero:

$$E(v_{1i}|P_i = 1) = E(v_{1i}|\varepsilon_i > -Z_i\beta) = \sigma_{1\varepsilon}\left[\frac{\theta(Z_i\beta|\sigma)}{\varphi(Z_i\beta|\sigma)}\right] \equiv \beta_{1\varepsilon}\gamma_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$E(v_{2i}|P = 0_i) = E(v_{2i}|\varepsilon_i \le -Z_i\beta) = \sigma_{2\varepsilon}\left[\frac{-\theta(Z_i\beta|\sigma)}{1 - \varphi(Z_i\beta|\sigma)}\right] \equiv \beta_{2\varepsilon}\gamma_2 \ldots\ldots\ldots\ldots\ldots (8)$$

Here, θ and φ represent the probability density and cumulative distribution functions of the standard normal distribution. The ratio of θ and φ assessed atβZ_i, denoted by γ_1 and γ_2 in equations 7 and 8, is termed the Inverse Mills Ratio (IMR), which signifies the selection bias terms.

The IMR provides the correlation between use of renewable energy and productivity. The endogenous switching model has previously been estimated using a two-stage technique [31]. In the first step, the IMRs are determined by the probit model of the criterion equation and the terms in equations 7 and 8. Those forecasted variables are then joined to the corresponding equations in Equations 4 and 5 to produce the following sets of equations in the second step.

$$P_{1i} = \mathcal{J}_1 Q_i + \beta_{1e}\phi_1 P_{1i} + \eta_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

$$P_{2i} = \mathcal{J}_2 Q_i + \beta_{2e}\phi_2 P_{2i} + \eta_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

The coefficient of the variables $\mathcal{J}_1$and $\mathcal{J}_2$ show estimates of the covariance terms β_{1e} and β_{2e} respectively. Since the variables $\mathcal{J}_1$and $\mathcal{J}_2$ have been estimated, the residuals η_1 and η_2 cannot be used to estimate the standard errors of the two-stage estimates. While Lee [33] proposed a strategy for calculating coherent standard errors, especially for the two-step procedure, Maddala [34] argues that such a process requires a possibly long and sophisticated procedure that most research has not employed. The endogeneity of the use decision is therefore accounted for by employing Full Information Maximum Likelihood (FIML) to estimate a simultaneous equation model with endogenous switching. The FIML evaluates the entire system of equations and estimates all of the parameters at the same time. The FIML estimators have all of the qualities of maximum likelihood estimators. They are evenly distributed and asymptotically normal. The FIML fit the selection (equations 1 to 3) and outcomes (4 and 5) equations simultaneously to deliver consistent standard errors, thus making $\gamma_1$and $\gamma_2$in equation 9 and 10, homoscedastic respectively.

The average treatment effect on treated individuals (ATT) of farmers who do not use renewable energy can be computed as follows:

$$ATT = E(G_{1i} - G_{2i}|P_1 = 1) = H_i(\lambda_1 - \lambda_2) + (\sigma_{1\mu} - \sigma_{2\mu})\gamma_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

In equation 4 and 5, $E(G_{1i}|P_i = 1) = H_i\lambda_1 - \sigma_{1\mu}\gamma_1$ represents the expected output of farmers for farm households who use renewable energy, if they had chosen not to use renewable energy. The above equations will be estimated with the STATA software program, which was built specifically for this sort of endogenous switching regression model and was written by Lokshin and Sajaia [35]. The renewable energy use function which is a Probit regression and a farmers' production function, is the empirical ESRM equation to be calculated. The decision equation for the use of renewable energy, which is equivalent to equations 1 to 3, is given as follows:

$$use = f\,(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

The dependent variable is in binary form and takes the form of 1 if the farmers use renewable energy and 0 if otherwise. The alternative productivity function for farmers who use renewable energy and those who do not use renewable energy is similar to equations 9 and 10 and is as follows:

$$Ln\,(PRODUCTIVITY = f\,(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11} \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

Where;

ln is a natural logarithm,

X_1 = sex (1 = male, 0 = female)

X_2 = marital status (married =1, otherwise =0)

X_3 = age of the famer in years

X_4 = level of education in years

X_5 = household size in numbers

X_6 = farm size in hectare

X_7 = farming experience in years

X_8 = membership of a cooperative society (1 = yes, 0 = no)

X_9 = access to credit (1 = yes 0 = otherwise)

X_{10} = extension visit (number of visit)

X_{11} = monthly off farm income in Naira

Credit access and use decision can be made together, which could lead to endogeneity issues in an Endogenous Switching Regression Model. If potential endogeneity issues are not taken into consideration, estimates may be biased because the dependent variable is dichotomous. The endogeneity issue is addressed using Blundell and Smith [36] two-stage technique. As seen in equation 1, the first stage involved specifying a possibly endogenous variable (credit access) as a function of all other independent variables, including a set of instruments.

$$Pr[Vi = 1] = Gi + \tau' Ti + e \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

Where Vi is a vector of the potential endogeneity

Variable Gi is a vector of independent variables,

While Ti is a vector of instruments that are correlated with the given endogenous variable, but uncorrelated with the error terms in equation 14. A variable that effects credit assess but not the outcome variables was included in equation 14. The credit constraint definition uses renewable energy awareness as an instrument, which affects credit constraint but not the result variable. The ESR model second step however, required the addition of credit access values as well as their related residuals from equation 14. As a result, in the presence of a potential endogenous variation in Ti, consistent parameter estimation is conceivable. The endogeneity of these variables is tested using a simple t-test [37].

3. Results

3.1. Summary of Statistics

Table 2 shows the statistical summary of users and non-users of renewable energy. The t-test values indicate the differences between the two groups (users and non-users). Farm households who use renewable energy obtained an output of 3,554 kg, while those who did not use renewable energy realized 2223.84 kg of output. Also, a significant difference was seen among the age of RE users and non-users with 41.70 years and 44.21 years respectively. Furthermore, users spent about 13.70 years in school, while non-users spent about 11.50 years in school. The respondents were asked during the fieldwork to determine if they utilize renewable energy on a Yes or No scale. The result shows that majority (172) of respondents did not use renewable energy while (141) of the respondents use renewable energy to carry out different farm operations. The high level of non-users could be due to the high cost of acquiring renewable energy as well as poor knowledge of the uses and benefits of renewable energy utilization. The p-values indicates a significant difference between renewable energy users and non-users showing that the impact analysis is necessary in order to evaluate the real impact that the use of renewable energy utilization has on productivity.

Table-2. Definition of variables and mean differences between users and non-users of renewable energy

Variable	Users	Non-users	Difference	Statistical Significance
Age	41.70	44.21	-2.52	**
Educational level	13.70	11.50	0.31	***
Farm experience	19.45	14.37	5.0	***
Household size	1.65	1.47	0.18	***
farm size	8.65	5.84	2.81	
Off farm income	103,878	78,436	25,552	**
Energy use Cost per farming season	30000	128005.8	-98,005	***
Farm output (kg)	3554.468	2223.837	1330.631	**
Use of RE 1 for users and 0 for non-users	141	172		
Number of observation	141	172		

Author's computation 2020

From the sample of "not use" respondents in table 2 above, it important to check respondent's willingness to use renewable energy and the result is presented in Table 3.

Table-3. Willingness to Use Renewable energy

Willingness	Frequency	Percentage
Willing	129	75.00
Without willingness	43	25.00
Total	**172**	**100**

Author's computation 2020

Result presented in Table 3 showed respondents with willingness and without willingness to use renewable energy. From the result, (75%) of the respondents indicated willingness to use renewable energy, while (25%) were not willing.

3.2. Full Information Maximum Likelihood Estimates of Endogenous Switching Regression Model for Farm Productivity

The determinants of the use of renewable energy and its impact on productivity are reported in Table 4. As indicated earlier, the full information maximum likelihood technique was used to estimate the use and outcome equation simultaneously. Given the use of crop output in the study, the value of output (kg) per hectare was used to capture productivity. The logarithm of the value of output per hectare was taken and used as productivity in the analysis. The result of the estimations is in three parts, the selection equation represents the determinants of the use of renewable energy. In addition, due to variances in use decisions, two separate sets of productivity functions were constructed for users and non-users. The coefficients in the use equation were used as regular probit coefficients. As noted in the empirical model, identification requires the absence of at least one variable from the selection equation in the outcome equations. In the ESR specification, the variable representing renewable energy awareness is used as an identification tool. Farmers' awareness of renewable energy is expected to influence their use decisions, but not directly on production.

Selection model incorporates the expected residual (credit residual) from the binary models for credit access. The results show that the extrapolated residual for credit access (credit residual) was not significant, suggesting that all potential endogeneity issues as a result of credit limits have been addressed. The final log likelihood is - 450.077 and is significant at 1% level, indicating that the model is a good fit. The statistically significant covariance term for users (/1ns1 = -0.320) in Table 4 implies self-selection into the use of RE by farmers in the South-South region of Nigeria. This also means that non-users may be affected differently if they decide to use renewable energy. The negative sign of the covariance term also implies the presence of positive selection bias and that farmers with higher-than-average yields are more inclined to use renewable energy. The correlation coefficients r1 and r2 are both statistically significant at 1% and 5% respectively, indicating that there was an occurrence of selection bias in the credit status due to unobservable factors.

Table-4. Full information maximum likelihood estimates of endogenous switching regression model for farm productivity

Selection			Non-users		users	
Variables	**Coefficient**	**T-value**	**Coefficient**	**T-value**	**Coefficient**	**T-value**
Constant	1.471	0.91	5.523	1.35	6.322***	9.80
Gender	0.282***	11.96	0.217	0.57	0.203**	1.99
Age	-0.011	-1.05	0.017	0.66	-0.003	-0.69
Educational level	0.092***	3.78	0.053***	2.99	0.041***	3.37
Household size	0.014	0.34	0.045	0.67	0.031**	2.04
Farm size	0.0210	0.39	-0.031	-0.46	-0.021	-0.95
Farm experience	0.118***	9.47	-0.012	-0.67	-0.009***	-1.43
Cooperative membership	-0.098	-0.13	0.268***	2.43	-0.021	-0.22
Credit access	0.535***	3.29	0.248**	1.98	0.078	0.69
Extension visit	0.101	0.78	0.213***	3.52	-0. -0.003	-0.06
Lnofffarm income	-0.137*	-0.98	0.104	0.29	0.105*	1.91
RE awareness	0.548**	1.95				
Creditres	-0.030	-0.04				
/1ns1	-0.320***	-6.92				
/1ns2	0.944***	3.35				
/r1	-0.807***	-3.75				
/r2	0.559**	2.00				
Log likelihood	-450.077					

Source: field survey 2020

Note: *, ** and *** represent significance at 10%, 5% and 1% levels respectively

Therefore, an endogenous switching regression (ESR) model that includes both observable and unobservable components is appropriate for this study [35].Since r1 is positive and r2 is negative, this means that renewable energy users have greater output (lesser probability of output loss) than a random person from the sample. Non-renewable energy users, on the other hand, had lesser output (greater probability of output failure) than a random person from the sample.

3.3. Determinants of Renewable Energy Use

The findings of the selection equation are presented in Table 4. As is interpreted as a normal probit coefficient. It is worth noting that estimates for variables in the selection equation with the same name (probability of using renewable energy) have identical impact on the dependent variable. The gender coefficient showed a strong beneficial effect on renewable energy usage. This finding shows that men farmers are more likely than female farmers to use renewable energy. This is not surprising since, in South-South Nigeria, men were more involved in agriculture. This is in agreement with the findings of Bello, *et al.* [38] whose result showed a significant difference between men and women who used improved rice variety. The coefficient of educational level is positive and statistically significant at the 1% level of significance, implying that the more educated and aware farmers are, the more likely they are to use renewable energy in their farms. This result is consistent with the findings of Abdulai [39] who arrived at the same conclusion that education is important in farmers' use decision in employing new farming methods.

Farm experience had a positive and significant impact on RE usage. This showed that increase in a farm experience increases farmer's motivation to use renewable energy. A more experienced farmer would have a better understanding of the best strategies to improve productivity and the negative effect of fossil fuel on agricultural lands. This result is in line with that of Ali, *et al.* [40] whose study found that a farmer's level of experience increases motivation to adopt best farming methods capable of improving productivity. The coefficient of credit access was positive and statistically significant at 1% level. This implies that having access to agricultural credit would increase farmers' chance of utilizing renewable energy in the study area. This result agrees with the findings of Ali and Awade [41] who highlight the importance of having access to credit in enhancing use of modern farm methods. Awareness had a positive and significant effect with renewable energy usage which implies that awareness of renewable energy tends to enhance the likelihood of using renewable energy.

3.4. Impacts of Determinants

In the second and third columns of Table 4, the estimates in the outcome equation, which is the second stage switching regression model for farm productivity (output per hectare), are shown. The findings of productivity regressions among farmers who use renewable energy are presented as users while productivity among farmers who do not use renewable energy is presented as non-users. The impact estimates suggest that the educational level of the respondent positively and significantly influenced farm productivity among users and non-users of renewable energy. This means that higher levels of education tend to contribute to greater farm output. The positive and significant relationship between education level and farm productivity reported in this study is consistent with the findings of Abdulai and Huffman [42] who found that good knowledge and solid understanding of new farming methods acquired through education can increase the yield of rice farmers in northern Ghana.

Cooperative membership and extension visits showed a positive and significant relationship with agricultural productivity, implying that cooperative membership and extension visits increase agricultural productivity for non-RE users. These results are in line with the findings of Donkor, *et al.* [43] who reported that access to extension services significantly promotes rice yield for non-users of row planting technology. Similarly, Manda, *et al.* [44] also reported that membership in a cooperative enhances the probability of adoption of improved maize varieties in Zambia. Gender of respondents had a positive and significant influence on productivity under RE users, this shows that being male has the probability of increasing agricultural productivity. This is in agreement with Oparinde [45] who reported a positive and significant influence of gender on productivity. The coefficient household size had a significant positive effect on productivity for renewable energy users, showing that larger household size contributes to increase in farm productivity.

The variable farming experience had a significant negative effect on RE utilization for users. This finding suggests that farmers' level of experience is less likely to increase productivity. The traditional nature of some experienced farmers may explain the negative relationship between farming experience and productivity. Some farmers tend to be so comfortable with their conventional approach to farming that they find it more difficult to adopt improved farm methods, which enhances farm productivity. This findings agrees with that of Ojo, *et al.* [46] who found a negative relationship between farming experience and rice yield among rice farmers in South Western Nigeria.

3.5. Farm Productivity Impacts

Table-5. Impacts of Determinants

Variable	Non-users constrained	users constrained	ATT
Productivity (kg)	7.411	10.171	2.760***

Note: *** represent significance at 1% levels
Source: field survey 2020

Table 5 presents the impact of the use of renewable energy on productivity from the average treatment effects on the treated (ATT) estimates of the endogenous switching regression (ESR). The ATT on the expected results are assessed to investigate the influence of renewable energy utilization on productivity. The result from the analysis indicates that on the average, renewable energy utilization significantly increases farm productivity. To be specific, the expected farm productivity from renewable energy users is on the average of 10.17kg compared with 7.31 kg from renewable energy non-users. This difference represents an increase in causal effect in farm productivity from renewable energy utilization by 39%. This is consistent with earlier research that show that using new agricultural methods is capable of increasing farm productivity [42, 47].

4. Conclusion and Policy Recommendation

This study was conducted to estimate the determinants of the use of renewable energy (RE) and its impact on agricultural productivity in south-south Nigeria. The estimates of renewable energy use and its influence on productivity were obtained using the full information maximum likelihood technique of the endogenous switching regression model, which jointly evaluated the use and outcome equations.

The result showed that gender, educational level, farm experience and credit access had a significant positive effect on RE utilization at the 1% and 5% level respectively. Educational level, cooperative membership, access to credit and extension visits positively and significantly influenced agricultural productivity among non-RE users while gender, educational level, household size and farm experience positively and significantly influenced agricultural productivity of RE users. The impact of RE use on productivity from the average treatment effects on the treated (ATT) estimates indicate that renewable energy (RE) utilization increases agricultural productivity by 39%.

Since the use of RE from the findings was found to improve farm productivity, it is necessary to recommend that government at all levels should encourage the use of RE among farmers, especially in rural areas by installing the technology and subsidizing cost of use. This will allow for mass adoption and in turn improve productivity, food security and agricultural lands. Furthermore, there is need for both governmental and non-governmental authorities to promote the use of renewable energy among farmers through public campaigns in order to create RE awareness for sustainable agriculture.

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Statement of Human and Animal Rights

This study did not collect any confidential information about the farmers. All individual respondents in the study provided informed consent. This article does not include any animal studies conducted by any of the authors.

Data Availability Statement

The data sets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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