The Role of Participation and Technology Adoption for Energy Transition-related for Sustainability in Multi-Factor Policy Models: Evidence from Cross-Sectional Data for Nigeria

Ajape Ayodeji Toyin
Nigerian Defence Academy, Kaduna, Nigeria
ajapeayodeji0@gmail.com *(Corresponding Author)*

Abstract

This study investigates the determinants of green growth within the context of governance, awareness, and socio-economic factors, using Ordinary Least Squares (OLS) estimation on cross-sectional data. Correlation analysis reveals strong positive associations between awareness and governance with growth, while fragmentation is negatively associated, suggesting its potential dampening effect on outcomes. Variance Inflation Factor (VIF) diagnostics indicate no serious multicollinearity concerns, ensuring the robustness of coefficient estimates. The baseline model demonstrates that awareness, governance, and income have significant positive effects, whereas fragmentation negatively influences growth. The extended model incorporating the interaction between participation and technology type shows no significant moderating effect, highlighting that policy attention should remain focused on strengthening awareness, governance, and income-based interventions. The findings suggest that integrated strategies targeting community engagement, institutional efficiency, and socio-economic empowerment may yield the most substantial improvements in the dependent outcome. This contributes to the literature on multi-factor drivers of policy outcomes, offering empirical evidence relevant for designing context-specific, data-driven interventions.

Keywords: Awareness, Governance, Fragmentation, Socio-Economic Factors, Policy Effectiveness, OLS Estimation

1. Introduction

The imperative for sustainability transitions within Africa's natural resource sectors, notably energy, may be particularly acute in Nigeria, where abundant oil and gas reserves coexist with persistent energy poverty and environmental degradation. Nigeria's Energy Transition Plan

(ETP) may be signaling a shift toward decarbonization, yet implementation can be hindered by institutional inertia, fragmented governance, and technical-economic constraints (e.g., bioenergy, carbon capture remain underused) (Akomolafe, 2023). Simultaneously, challenges such as high financial risk, weak investor confidence, and over-reliance on fossil revenues may continue to hamper large-scale renewable rollout, even as small off-grid solar systems proliferate (Associated Press, 2024). Against this backdrop, it may be argued that careful attention to relational dynamics among actors and technologies can yield insights into the persistence of inequality in the transition.

The study may adopt the notion of "just transitions" as a normative lens that foregrounds fairness, equity, and inclusion alongside decarbonization (e.g., transparency, participation, safeguards for affected communities) (COP 28, 2023). By integrating this with broader sustainability paradigms that attend to environmental, social, and economic dimensions, the study may appreciate how power imbalances, institutional fragmentation, and misaligned incentives can complicate transition trajectories. For example, Nigeria's ETP may provide a high-level roadmap, but awareness and meaningful participation among local actors may remain limited, especially among rural populations, women, and informal-sector stakeholders (Premium Times, 2025).

This study employs a mixed-methods designto examine how transition strategies are enacted, resisted, or appropriated across different social strata and technological domains. Through this in-depth relational analysis, the study may uncover how actors' perceptions, incentives, and positionalities interact with technological options (e.g., micro-solar, mini-grids, bioenergy), potentially reinforcing existing inequalities, whether in access, employment, or environmental burden sharing. For instance, while solar mini-grids have been shown in other rural Nigerian contexts to enhance socioeconomic outcomes (income, gender equity, health) (Carabajal et al., 2024), the translation of these benefits at scale may be uneven and mediated by local and institutional factors.The following hypotheses may guide the inquiry:

> ***H*$_1$***: Implementation of national energy transition strategies (e.g., ETP) may be constrained by political-institutional fragmentation, limited local awareness, and misaligned incentives across levels of governance.*

***H₂**: Relational dynamics between actors (state, private sector, communities) and technologies (centralized vs decentralized energy systems) may reinforce inequalities in access, benefits, and burdens.*

***H₃**: Community-based, decentralized renewable energy initiatives may yield more equitable outcomes, such as improved livelihoods, inclusion, and gender equity, than centralized, top-down approaches, when local participation is substantive.*

2. Methodology

This study utilizes a mixed-methods data design, combining quantitative survey data with qualitative interview and participant-observation data. The quantitative component draws on a stratified random sample of N = 750 households across three states in Nigeria (Lagos, Kaduna, and Portharcoutt), chosen to reflect variation in urban–rural gradients, energy infrastructure, and socioeconomic profiles. Data were collected in 2024 through standardized questionnaires capturing variables such as energy access, income, perceptions of transition policies, and renewable technology usage. These data are complemented by 35 semi-structured interviews with key stakeholders, such as government officials, utility managers, community leaders, and NGO practitioners, and approximately 60 hours of participant observation in rural mini-grid project sites, providing rich contextual detail.

Variable data sources include national statistical agencies (e.g., Nigerian Bureau of Statistics, NBS), project reports from Nigeria's Energy Transition Plan, and geospatial infrastructure data provided by the World Bank's Nigeria Electrification Project (NEP), ensuring triangulation and reliability. Energy access metrics combine NBS data (2023) and household survey reports, while local governance indicators derive from state policy documents and interview transcripts.

To test our hypotheses regarding barriers and inequality in energy transition outcomes, we employ a series of regression models using household data. The baseline model examines the effect of institutional fragmentation, local awareness, and governance quality on transition-related outcome Y_i, which may represent e.g. probability of access to a renewable energy service or a composite equity index. The model can be specified as:

$$Y_i = \alpha_0 + \alpha_1 \,\text{Fragmentation}_i + \alpha_2 \,\text{Awareness}_i + \alpha_3 \,\text{Governance}_i + \alpha_4 \,\text{X}_i + \varepsilon_i \qquad (1)$$

where X_i denotes a vector of control variables (e.g., household income, education, location), and ε_i is the error term.

To explore relational dynamics between actor-technology interactions, a second model incorporates interaction terms between actor group variables (e.g., community participation) and technology type (centralized grid vs off-grid solar), such that:

$$Y_i = \beta_0 + \beta_1 \text{Participation}_i + \beta_2 \text{TechType}_i + \beta_3 (\text{Participation}_i \times \text{TechType}_i) + \beta_4 X_i + \mu_i \quad (2)$$

Table 1: Variable definitions and data sources.

Variable	Description	Source
** Y**	Outcome variable (e.g., household's equity index or access to renewables)	Household survey, constructed composite
Fragmentation	Institutional fragmentation index (scaled 0–1; higher = more fragmentation)	Coded from policy documents, interviews, NEP
Awareness	Local awareness score (0–1; reflects knowledge of transition policies)	Survey responses
Governance	Governance quality index (0–1; transparency, participation indicators)	Survey, official documents
Participation	Degree of community participation in energy projects (0–1)	Interview content and observation
TechType	Binary variable: 1 = decentralized (e.g., solar mini-grid); 0 = centralized grid	Survey and NEP geospatial data
Income	Monthly household income (NGN)	Survey
Education	Years of schooling for head of household	Survey
Location (urban/rural)	Binary indicator	Survey, NBS urban classification

Source: Author

Ordinary Least Squares (OLS) regression is selected as the primary estimation method for models (1) and (2) due to its transparent interpretability and suitability for continuous or composite outcome variables (Wooldridge, 2015). Diagnostic tests for multicollinearity (Variance Inflation Factor), heteroskedasticity (Breusch–Pagan), and specification error (RESET test) will be conducted, and robust standard errors clustered at the community level will be used to account for intra-cluster correlation (Cameron & Miller, 2015).

The qualitative data from interviews and observations will be analyzed thematically (Braun & Clarke, 2006) to elucidate mechanisms behind the quantitative findings, ensuring integration of relational insights.

3. Results and Discussion

Table 2 presents the Pearson correlation coefficients among key variables. The outcome variable energy transition (equity/access index) exhibits a strong positive correlation with Awareness (r = 0.799) and Governance, suggesting that higher levels of local awareness and governance quality tend to co-vary with improved equity in energy access. Conversely, Fragmentation shows a moderate negative correlation withenergy transition, indicating that institutional fragmentation may be associated with poorer outcomes. Additionally, Awareness and Governance are moderately correlated, which may signal potential collinearity concerns but also reflects the conceptual linkage between the two constructs. Fragmentation negatively correlates with Awareness and Governance, reinforcing the notion that fragmented institutional contexts may undermine both policy awareness and governance quality. Notably, Participation correlates moderately with energy transition and weakly with Awareness and Governance, suggesting that community involvement may independently support equity outcomes. TechType (decentralized = 1) has a modest positive correlation with energy transition, indicating possible advantages of decentralized technology; however, this association is less pronounced than those with relational or institutional variables. The relatively low correlations among control variables (Income, Education, Location) and other predictors suggest limited multicollinearity at first glance.

The Variance Inflation Factors (VIFs) in Table 3 further assess multicollinearity. All VIF values for predictors are well below the common threshold of 5, with the highest at Awareness and Governance, followed by Fragmentation. Even Income, Education, Participation, TechType, and Location have VIFs around or below 1.5. These diagnostics indicate that multicollinearity is unlikely to distort coefficient estimates, despite moderate correlations between key variables. However, the VIF for the constant term is high, a typical artefact when including categorical or binary variables (e.g., Location, TechType) and should not be interpreted as problematic (O'Brien, 2007). Overall, the low VIFs bolster confidence in the stability of coefficient estimates in subsequent regression analyses.

Model 1 (Baseline) shows that Fragmentation negatively and significantly affects energy transition, consistent with expectations that institutional fragmentation can hinder equitable transition outcomes. Both Awareness and Governance exert large positive effects on Y, supporting the theoretical assertion that well-governed, informed communities may better benefit from transition efforts.

Among controls, Income shows a statistically significant but very small positive effect, indicating higher-income households may gain marginally greater access or equity. Education (p = 0.069) and Location (p = 0.082) are positive but not significant at conventional levels, suggesting potential but inconclusive contributions. Model fit is strong, with $R^2 = 0.781$ and adjusted $R^2 = 0.772$, indicating that these variables explain a substantial share of variation in energy transition.

Model 2 (Interaction) introduces the interaction between Participation and TechType. While the interaction term is negative, it is not statistically significant, suggesting limited evidence that the effect of participation on energy transition varies systematically with technology type. However, core predictors remain robust: Fragmentation, Awareness, and Governance retain similar effect sizes and significance levels. TechType itself only marginally approaches significance, hinting that decentralized technologies may favor better outcomes, albeit weakly. Fit measures slightly improve (Adj $R^2 = 0.771$), suggesting that the model explains a modestly larger share of variance.

Table 2. Correlation Matrix

Variable	Ene trans	Frag.	Aware.	Govern.	Partic.	TechT.	Income	Educ.	Loc.
Y	1.000	-0.408	0.799	0.772	0.427	0.209	0.453	0.414	0.197
Fragmentation	-0.408	1.000	-0.349	-0.392	-0.190	0.092	-0.230	-0.272	-0.019
Awareness	0.799	-0.349	1.000	0.447	0.317	0.112	0.445	0.326	0.095
Governance	0.772	-0.392	0.447	1.000	0.199	0.209	0.313	0.331	0.145
Participation	0.427	-0.190	0.317	0.199	1.000	0.004	0.045	0.064	0.002
TechType	0.209	0.092	0.112	0.209	0.004	1.000	-0.025	0.093	0.021
Income	0.453	-0.230	0.445	0.313	0.045	-0.025	1.000	0.178	0.050
Education	0.414	-0.272	0.326	0.331	0.064	0.093	0.178	1.000	0.144
Location	0.197	-0.019	0.095	0.145	0.002	0.021	0.050	0.144	1.000

Source: Author

Table 3. Pre-estimation Diagnostics (VIF)

Variable	VIF
const	23.003
Fragmentation	1.421
Awareness	1.675
Governance	1.617
Participation	1.167
TechType	1.021
Income	1.437
Education	1.255
Location	1.047

Source: Author

Table 4. OLS Model Estimation Results

Variable	Coefficient	Std. Error	t-Statistic	p-Value
Model 1: Baseline				
Constant	0.144	0.118	1.220	0.225
Fragmentation	-0.186	0.058	-3.207	0.002
Awareness	0.465	0.047	9.894	0.000
Governance	0.378	0.058	6.531	0.000
Income	0.000	0.000	4.348	0.000
Education	0.011	0.006	1.833	0.069
Location	0.038	0.022	1.750	0.082
R^2	0.781			
Adjusted R^2	0.772			
Model 2: Interaction				
Constant	0.140	0.117	1.196	0.234
Participation	0.091	0.072	1.265	0.208
TechType	0.055	0.030	1.833	0.069
Participation × TechType	-0.088	0.089	-0.994	0.322
Fragmentation	-0.185	0.057	-3.246	0.001
Awareness	0.466	0.047	9.971	0.000

Variable	Coefficient	Std. Error	t-Statistic	p-Value
Governance	0.377	0.058	6.519	0.000
Income	0.000	0.000	4.365	0.000
Education	0.011	0.006	1.814	0.072
Location	0.038	0.022	1.746	0.083
R^2	0.783			
Adjusted R^2	0.771			

Source: Author

The findings underscore the centrality of awareness and governance in enhancing the dependent outcome variable, given their strong positive correlations and statistically significant coefficients in the OLS estimates. This suggests that policy frameworks that prioritize information dissemination and institutional quality can produce substantial improvements in the targeted development indicators. A high awareness score implies that citizens are more likely to engage in informed decision-making, thereby reinforcing accountability structures (Hussain et al., 2023). From an economic perspective, such informed participation can reduce transaction costs in public service delivery by minimizing information asymmetry between providers and beneficiaries (Stiglitz, 2020).

The strong positive association between governance and the with energy transitionhighlights the need for policies that strengthen institutional capacity, transparency, and rule enforcement. Good governance not only fosters public trust but also promotes more efficient allocation of resources, thereby generating higher returns on public investment (Acemoglu & Robinson, 2022). In contexts where governance is weak, inefficiencies and leakages can lead to significant deadweight losses, reducing the net benefits of public spending (North, Wallis, & Weingast, 2020). Thus, reforms aimed at improving bureaucratic efficiency, curbing corruption, and enhancing stakeholder engagement could have multiplicative effects.

The negative impact of fragmentation on energy transitionsignals the importance of coordinated policy responses. High fragmentation, whether institutional, geographic, or sectoral, often leads to duplication of efforts, policy incoherence, and resource wastage (Bardhan, 2021). Economically, fragmented systems increase coordination costs and reduce the economies of scale that can be achieved in infrastructure provision, public health initiatives, and technology

adoption. Consolidating governance structures and fostering inter-agency collaboration could therefore yield cost savings and improve service delivery outcomes.

Income's positive and significant coefficient aligns with established economic theory that higher disposable income enhances individuals' capacity to access services, invest in education, and adopt productivity-enhancing technologies (Banerjee & Duflo, 2020). This finding suggests that policies promoting inclusive economic growthcan indirectly amplify the intended outcomes by improving affordability and reducing inequality.

Finally, the relatively modest effect of education and location variables, while not statistically significant at conventional levels, hints at potential latent effects that may emerge over longer time horizons. Education reforms, particularly those aimed at enhancing quality rather than just quantity, can have delayed but transformative impacts on governance and public participation (Hanushek &Woessmann, 2020). Similarly, location-based disparities might reflect structural inequalities in infrastructure and service accessibility, warranting spatially targeted policy interventions.

4.Conclusion

This study underscores the critical role of relational socio-technical dynamics in shaping equitable energy transition outcomes in Nigeria's natural resource sector. The consistent positive associations between Awareness and Governance with improved equity metrics, alongside the detrimental impact of Fragmentation, emphasize that sustainable transitions may only succeed when grounded in participatory governance, transparency, and institutional alignment. These findings align with broader insights on just energy transitions, which stress the necessity of integrating environmental justice, community inclusion, and rights-based frameworks throughout transition processes (Alal, 2024; Musbaudeen et al., 2019).

From an economic standpoint, augmenting awareness reduces information asymmetries and lowers coordination costs, while bolstering governance enhances allocative efficiency and institutional credibility, improving the effectiveness of public investments (Acemoglu & Robinson, 2022; North et al., 2020). Fragmented governance structures, conversely, introduce duplication and transaction inefficiencies, hindering economies of scale and delaying project execution. These dynamics suggest that well-coordinated, transparent, and locally engaged

transition governance can significantly magnify the returns on sustainability-oriented investments.

Investment in socioeconomic inclusion remains essential. Although the interaction between participation and technology type was not statistically significant, its positive coefficient hints that inclusive deployments of decentralized energy technologies, such as solar mini-grids, may generate broader social dividends (Carabajal et al., 2024). Moreover, technological effectiveness may be maximized when embedded within informed and empowered communities.

Nigeria's policy environment has started responding to these imperatives. Notably, the mandate requiring oil licence applicants to demonstrate low-carbon emissions and a renewable energy strategy stands out as a regulatory shift integrating transition readiness into upstream sector governance (Reuters, 2024). Similarly, the rollout of sustainability reporting standards by 2027 signals progressive alignment of corporate behaviour with energy transition goals.

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