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Research Article

Stakeholder Readiness and Governance Barriers in Clean Technology Adoption: A Socio-Technical Mixed-Methods Study

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ABSTRACT: Clean technologies are critical for addressing resource depletion, energy insecurity, and environmental degradation, particularly in rapidly urbanizing regions of the Global South. However, their effective adoption depends not only on technological availability but also on stakeholder awareness, capacity, and governance contexts. This study examines stakeholder perspectives on clean technology adoption in Abuja, Federal Capital City, Nigeria, focusing on awareness, adoption readiness, perceived barriers, governance perceptions, and perceived benefits. Using a convergent mixed-methods approach - including structured surveys (n = 420), key informant interviews, and focus group discussions - the study captures insights from estate developers, development control managers, private businesses, governmental institutions, local traders, urban dwellers, and rural dwellers. Results reveal high awareness, adoption readiness, and benefit perception among professional and institutional stakeholders, whereas marginalized groups, particularly local traders and rural dwellers, face multidimensional constraints, including financial limitations, low technical capacity, weak governance engagement, and limited recognition of social and environmental benefits. Economic, institutional, social, and technical barriers were found to shape adoption in stakeholder-specific ways. The study highlights the importance of inclusive policy frameworks, targeted financial incentives, capacity-building programs, participatory governance, and tailored awareness campaigns to foster equitable and sustainable uptake of clean technologies. By integrating socio-technical and governance perspectives, the study offers actionable insights for advancing sustainable development and promoting stakeholder-specific strategies in urban clean technology transitions.

Keywords: Clean technology adoption, Stakeholder readiness, Socio-technical transitions, Urban sustainability governance, Inclusive energy and resource policy.

1. INTRODUCTION

Rapid urbanization, population growth, and escalating consumption pressures have intensified global challenges related to resource depletion, energy insecurity, and environmental degradation. Cities now account for over 70% of global energy consumption and a comparable share of greenhouse gas emissions, while also generating the bulk of solid waste and wastewater streams [1-3]. In response, clean technologies - defined as innovations that reduce environmental impacts while improving efficiency in resource and energy use - have emerged as central instruments for achieving sustainable development and climate mitigation goals [2,4,5].

Clean technologies encompass a wide range of solutions, including renewable energy systems, energy-efficient buildings, waste-to-energy processes, low-emission transport, water recycling, and environmentally sound

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construction practices. Empirical evidence shows that such technologies can significantly reduce carbon emissions, improve air and water quality, enhance resource efficiency, and stimulate green economic growth [1,6-8]. Consequently, clean technology adoption is closely aligned with the achievement of the Sustainable Development Goals (SDGs), particularly SDG 7 (affordable and clean energy), SDG 9 (industry, innovation, and infrastructure), SDG 11 (sustainable cities), SDG 12 (responsible consumption and production), and SDG 13 (climate action) [9-12].

Despite their proven benefits, the diffusion and effective implementation of clean technologies remain uneven, particularly in rapidly urbanizing regions of the Global South. Financial constraints, weak regulatory frameworks, limited technical capacity, and fragmented governance structures often hinder large-scale adoption [8,13]. Moreover, much of the existing literature has focused on technological performance and economic feasibility, with comparatively less attention devoted to the social, institutional, and governance dimensions that shape adoption outcomes [14]. This gap is critical, as sustainability transitions are not purely technical processes but socio-technical transformations involving multiple actors with divergent interests, capacities, and power relations.

Stakeholders - including estate developers, development control managers, private businesses, governmental institutions, local traders, urban residents, and rural dwellers - play distinct yet interconnected roles in shaping clean technology pathways [15]. Estate developers and private businesses influence adoption through investment decisions and construction practices, while development control managers and governmental institutions regulate standards, enforce compliance, and design incentives or disincentives [16]. At the same time, local traders, urban dwellers, and rural residents act as end-users whose awareness, affordability constraints, and behavioral responses directly affect long-term sustainability outcomes [5,17].

Emerging studies indicate that mismatches between policy design and stakeholder expectations can undermine clean technology initiatives, leading to low adoption rates, resistance, or unintended social inequities [18,19]. For example, top-down interventions often fail when they overlook informal economic activities, local livelihoods, or culturally embedded practices - particularly in developing urban and peri-urban contexts [20,21]. Conversely, inclusive and participatory approaches have been shown to enhance legitimacy, trust, and long-term effectiveness of sustainability transitions [22]. Despite this recognition, empirical studies that systematically compare perceptions across diverse stakeholder groups - especially between professional/institutional actors and marginalized communities, and across urban–rural divides - remain limited in Global South contexts.

This study addresses this gap and makes a novel contribution by providing a holistic, stakeholder-centered assessment of clean technology adoption in Abuja, Federal Capital City, Nigeria. Unlike prior studies that focus on single stakeholder groups or isolated dimensions, this research explicitly compares professional and institutional actors with marginalized community groups within a unified analytical framework. It integrates stakeholder awareness, adoption readiness, perceived benefits, multidimensional barriers (economic, technical, social, and institutional), and governance perceptions to reveal how structural inequalities and governance dynamics shape adoption outcomes. By bridging socio-technical and governance perspectives and grounding the analysis in a rapidly urbanizing African context, the study advances empirical understanding of inclusive clean technology transitions and offers policy-relevant insights for designing equitable, context-sensitive adoption strategies.

This study aims to examine stakeholder perspectives on the adoption of clean technologies for sustainable resource, energy, and environmental management, with a focus on identifying perceived benefits, barriers, and governance challenges across diverse stakeholder groups. The specific objectives of the study are to:

1. Assess stakeholder awareness and perceptions of clean technologies related to resource efficiency, energy use, and environmental protection.
2. Compare perspectives across key stakeholder groups, including estate developers, development control managers, private businesses, governmental institutions, local traders, urban dwellers, and rural dwellers.
3. Identify perceived economic, institutional, social, and technical barriers to clean technology adoption.
4. Examine the role of governance frameworks, regulations, and incentives in shaping clean technology uptake.
5. Evaluate perceived environmental, economic, and social benefits of clean technologies from different stakeholder viewpoints.

6. Generate policy-relevant insights to support inclusive, effective, and context-sensitive clean technology strategies for sustainable development.

This study makes a novel contribution by offering a comprehensive, stakeholder-centered analysis of clean technology adoption in a rapidly urbanizing Global South context. Unlike existing studies that emphasize technological or economic factors in isolation, this research integrates stakeholder awareness, adoption readiness, perceived benefits, multidimensional barriers, and governance perceptions within a single analytical framework. It explicitly compares professional and institutional actors with marginalized urban and rural communities, thereby revealing how structural inequalities, stakeholder capacities, and governance dynamics jointly shape adoption outcomes. By empirically bridging socio-technical transition theory and governance perspectives using evidence from Abuja, Nigeria, the study provides actionable insights for designing inclusive, context-sensitive clean technology policies and interventions.

2. CONCEPTUAL FRAMEWORK

This study adopts an integrated conceptual framework combining sustainability transitions theory and stakeholder theory to explain clean technology adoption as a multidimensional and actor-driven process. Rather than viewing clean technology uptake as a purely technical or market-based decision, the framework conceptualizes adoption as the outcome of dynamic interactions among economic, institutional, social, and technical factors, mediated by the roles, interests, and power relations of diverse stakeholders [8,18,23].

Sustainability transitions theory emphasizes that shifts toward clean technologies involve systemic transformations in production–consumption systems, governance arrangements, and societal practices [8,14]. In rapidly urbanizing contexts, these transitions are shaped by pressures from climate change, environmental degradation, and global sustainability agendas such as the SDGs [1,4]. Clean technologies - including renewable energy systems, green infrastructure, and resource-efficient innovations - are therefore embedded within broader socio-technical regimes that can either enable or constrain adoption depending on local conditions [6,9].

Economic considerations form a central pillar of the framework, as high upfront costs, limited access to finance, and uncertain returns remain critical barriers to clean technology adoption, particularly in developing and emerging economies [2,5]. While clean technologies promise long-term environmental and economic benefits, stakeholders often evaluate them through short-term cost–benefit lenses shaped by income levels, business models, and livelihood dependence [17]. Financial development and green investment mechanisms can mitigate these barriers, but uneven access to capital perpetuates adoption gaps between large developers, private firms, and smaller actors such as local traders or rural households [13,24].

Institutional conditions - including regulatory clarity, enforcement capacity, incentives, and policy coherence - strongly influence clean technology transitions [14,22]. Weak or fragmented governance frameworks often undermine investor confidence and stakeholder trust, while inconsistent enforcement can disadvantage compliant actors [16]. Conversely, well-designed incentives, participatory governance arrangements, and multi-level coordination enhance legitimacy and accelerate adoption [15,25]. Institutional effectiveness is therefore not only a regulatory issue but also a governance challenge tied to accountability, transparency, and stakeholder inclusion.

Social dimensions are critical in shaping perceptions, acceptance, and behavioral responses to clean technologies. Awareness, trust in institutions, cultural acceptance, and perceived fairness influence whether stakeholders view clean technologies as opportunities or risks [18,23]. Social inequalities—linked to gender, income, education, and spatial location—can result in uneven distribution of benefits and burdens, potentially reinforcing exclusion if not explicitly addressed [3,19]. From a justice perspective, clean technology transitions must therefore align with social inclusion and equity objectives embedded in SDG 11 and related sustainability goals [11,21].

Technical readiness, infrastructure availability, skills, and reliability constitute the operational foundation of clean technology adoption [7,10]. Even where economic incentives and supportive policies exist, inadequate infrastructure, limited technical capacity, and unreliable systems can impede effective deployment [20]. Digitalization and innovation ecosystems can enhance system performance and scalability, but they also require complementary investments in human capital and institutional learning [5,9].

Within this integrated framework, stakeholders - including estate developers, development control managers, private businesses, governmental institutions, local traders, urban dwellers, and rural dwellers - are positioned differently according to their roles in production, regulation, consumption, and livelihood systems. These positional differences shape how stakeholders perceive risk, benefit, responsibility, and urgency in clean technology transitions [23,24]. For example, developers and businesses may prioritize financial viability and regulatory certainty, while households and informal actors may emphasize affordability, reliability, and social impacts. Government institutions, in turn, mediate these interests through policy design, enforcement, and coordination [12,22].

Overall, the framework highlights that clean technology adoption is not a linear or uniform process but a negotiated outcome shaped by intersecting economic, institutional, social, and technical factors across stakeholder groups. By integrating sustainability transitions and stakeholder perspectives, the framework provides a comprehensive lens for analyzing both enabling conditions and persistent barriers to inclusive and equitable clean technology transitions.

Figure **1** presents an integrated conceptual framework that explains clean technology adoption as a socio-technical and stakeholder-driven process. It illustrates how system-level pressures, including urbanization, climate change, environmental degradation, and global sustainability agendas, interact with economic, institutional, social, and technical conditions to shape adoption pathways.

At the core of the framework, sustainability transitions theory and stakeholder theory converge to emphasize that adoption outcomes are influenced by the roles, capacities, and interactions of diverse stakeholder groups, such as government institutions, estate developers, development control managers, private businesses, local traders, urban dwellers, and rural dwellers. These interactions determine key adoption outcomes, including readiness, uptake levels, and the distribution of benefits. The framework further highlights a feedback loop whereby adoption outcomes inform governance learning and policy feedback, leading to institutional adjustments, capacity building, and more inclusive transition pathways across macro- and micro-levels, thereby reinforcing continuous improvement in clean technology governance and implementation.

3. STUDY AREA

Abuja Federal Capital City (FCC), located between 8°50′–9°20′ N and 7°20′–7°50′ E, was designated as Nigeria’s capital in the 1970s due to its central location, relative ethnic neutrality, and national accessibility. Since its establishment, Abuja has evolved into a rapidly expanding administrative and economic hub within the Guinea Savannah ecological zone. The city is characterized by undulating terrain, isolated inselbergs such as Aso Rock, and significant hydrological features, including the Usuma River and the Lower Usuma Dam, which support domestic water supply and urban development. Abuja experiences a tropical climate with a

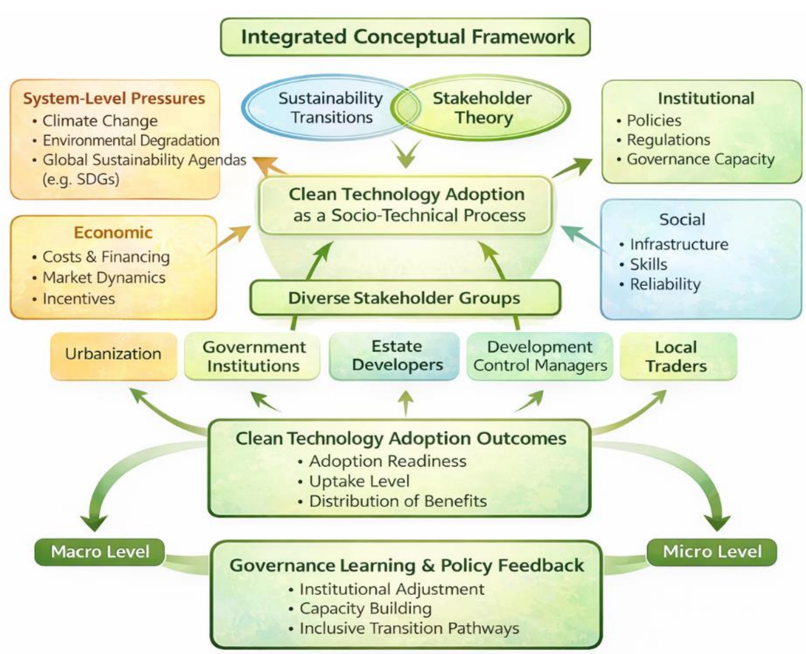

Figure 1. Integrated Framework for Clean Technology Adoption.

distinct rainy season (April–October) and dry season (November–March), annual rainfall ranging from 1,100 to 1,600 mm, and mean temperatures of 25–30 °C. Accelerated urbanization has substantially altered the city's natural savannah vegetation and ferruginous soils, driven by large-scale construction, infrastructure expansion, and rising energy and resource demand. Planned under the 1979 Abuja Master Plan, the FCC is spatially organized into four development phases and ten cadastral zones (A00–A09), encompassing residential, commercial, governmental, and institutional land uses (Figure **2**).

The population of Abuja FCC is estimated to exceed 3 million in the 2020s, fueled by rural–urban migration, administrative centralization, and private-sector growth. This rapid demographic expansion has intensified pressures on housing, transportation, energy systems, waste management, and public services, exposing gaps in infrastructure provision and regulatory capacity. While Abuja hosts a cosmopolitan population—including diplomats, civil servants, professionals, and an expanding middle class—significant socio-economic inequalities persist, with the continued growth of informal settlements and uneven access to services. These dynamics make Abuja FCC a compelling context for examining stakeholder perspectives on clean technology adoption, governance coordination, and sustainability transitions. The coexistence of formal planning structures with rapid, market-driven urban growth highlights the critical role of governmental institutions, private developers, businesses, and local communities in shaping pathways toward resource efficiency, energy transition, and environmental sustainability in rapidly urbanizing African cities.

The selection of Abuja as the study area is particularly justified because its governance structure and urbanization dynamics closely reflect the challenges and opportunities faced by rapidly growing cities across the Global South. As a planned capital experiencing accelerated population growth, spatial expansion, and increasing pressure on infrastructure and natural resources, Abuja exemplifies the complex intersection of formal planning institutions and informal urban development common in many developing regions. Its multi-tiered governance system—characterized by federal oversight, municipal authorities, development control agencies, and private-sector actors—mirrors governance arrangements in numerous Global South cities where policy coordination, regulatory enforcement, and stakeholder inclusion remain uneven. Furthermore, the coexistence of high-income estates, expanding commercial zones, informal settlements, and peri-urban and rural communities within the Federal Capital Territory provides a microcosm for examining socio-economic inequalities that shape access to, and perceptions of, clean technologies. Consequently, evidence from Abuja

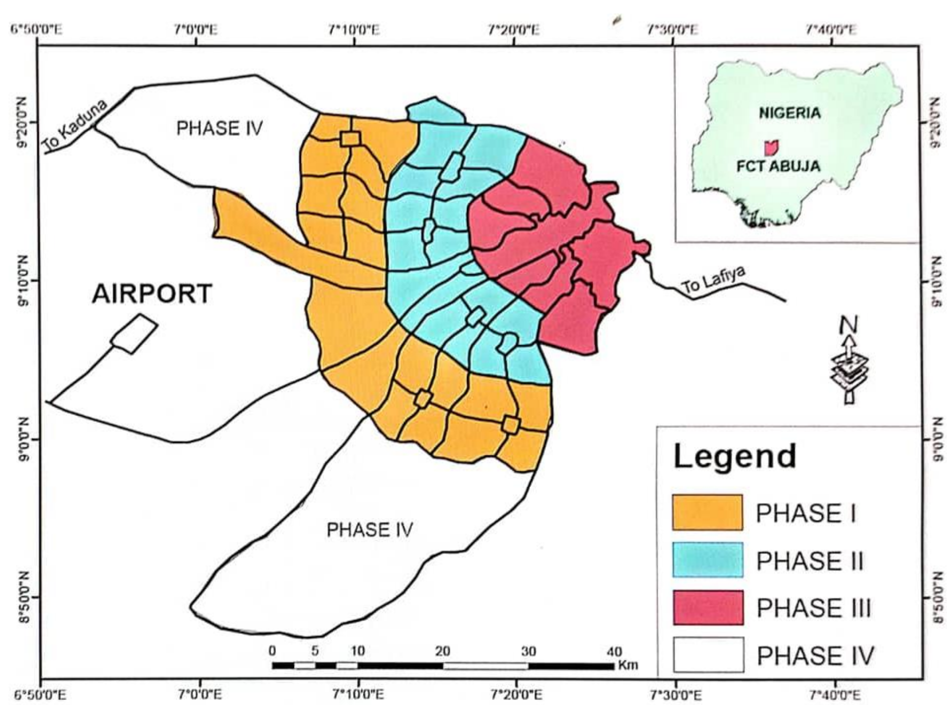

Figure 2: The major developmental phases of Abuja, Federal Capital City, Nigeria.

transcends the local scale, providing broader insights into how governance capacity, institutional trust, and entrenched urban–rural inequalities shape clean technology adoption across rapidly urbanizing cities in Africa and the wider Global South.

4. METHODS

4.1. Study Design

This study employed a convergent mixed-methods research design grounded in sustainability transitions theory and stakeholder theory to examine how economic, institutional, social, and technical factors jointly shape stakeholder perceptions and readiness for clean technology adoption. Consistent with the conceptual–empirical alignment (Table **1**), clean technology adoption is treated as a socio-technical transition outcome, emerging from interactions among actors positioned differently within production, regulation, consumption, and livelihood systems (Table **2**). The design integrates quantitative and qualitative strands to capture both structural drivers (e.g., regulation, markets, infrastructure) and actor-level perceptions (e.g., trust, fairness, risk), allowing systematic comparison across stakeholder groups and analytical triangulation (Table **3**). The quantitative component consisted of a structured stakeholder survey designed to operationalize the four dimensions of the conceptual framework and the outcome variable of adoption readiness, as mapped in Table **1**. Survey items captured standardized and comparable measures of:

- Economic factors, including perceived upfront costs, affordability, access to finance, expected returns, and willingness to invest;
- Institutional factors, such as regulatory clarity, enforcement effectiveness, availability of incentives, inter-agency coordination, and trust in governance institutions;
- Social factors, encompassing awareness of clean technologies, cultural acceptance, perceived fairness, inclusion in decision-making, and trust in implementing actors;
- Technical factors, including infrastructure availability, technical skills, reliability, maintenance capacity, and compatibility with existing systems.

All items were measured using Likert-scale formats to assess perceived barriers, benefits, and levels of readiness to adopt clean technologies. The dependent variable - adoption readiness - captured intention, perceived capability, and perceived responsibility for adoption, consistent with sustainability transitions literature emphasizing agency within structural constraints. Respondents were drawn from seven key stakeholder groups: estate developers, development control managers, private businesses, governmental institutions, local traders, urban dwellers, and rural

Table 1: Conceptual framework–empirical measurement alignment.

Framework Dimension	Core Constructs	Key Indicators/Survey Items	Primary Stakeholder Groups	Data Source
Economic factors	Cost, affordability, returns, finance	Upfront investment cost; access to credit/finance; payback period; perceived economic benefits; willingness to pay	Estate developers, private businesses, local traders, urban and rural dwellers	Structured survey; KIIs
Institutional factors	Regulation, enforcement, incentives, governance	Regulatory clarity; enforcement consistency; availability of incentives/subsidies; inter-agency coordination; trust in institutions	Governmental institutions, development control managers, and estate developers	Structured survey; KIIs
Social factors	Awareness, trust, acceptance, equity	Awareness of clean technologies; cultural acceptance; perceived fairness; trust in implementing actors; inclusion in decision-making	Urban dwellers, rural dwellers, local traders, civil society actors	Survey; FGDs
Technical factors	Infrastructure, skills, reliability	Availability of supporting infrastructure; technical skills and capacity; reliability and maintenance; compatibility with existing systems	Estate developers, private businesses, governmental institutions, and households	Survey; KIIs
Adoption readiness (Outcome)	Intent, capability, responsibility	Intention to adopt; perceived ability to adopt; perceived stakeholder responsibility; readiness timeframe	All stakeholder groups	Survey (dependent variable)

Table 2: Stakeholder positioning within the clean technology transition.

Stakeholder Group	Primary Role in Transition	Dominant Concerns	Framework Emphasis
Estate developers	Technology production and deployment	Capital cost, regulation, technical reliability	Economic; Institutional; Technical
Development control managers	Regulation and enforcement	Policy clarity, compliance, coordination	Institutional
Governmental institutions	Policy design and incentives	Governance capacity, equity, scaling	Institutional; Social
Private businesses	Market adoption and service provision	Return on investment, skills, infrastructure	Economic; Technical
Local traders	Livelihood-dependent users	Affordability, reliability, fairness	Economic; Social
Urban dwellers	End-users/consumers	Awareness, cost, service quality	Social; Economic
Rural dwellers	Marginalized end-users	Access, infrastructure gaps, inclusion	Social; Technical

Table 3: Analytical strategy linked to the conceptual framework.

Research Objective	Method	Analytical Technique	Framework Link
Compare perceptions across stakeholder groups	Quantitative survey	Descriptive statistics;	Stakeholder differentiation
Identify key drivers of adoption readiness	Quantitative survey	Descriptive statistics	Economic, institutional, social, and technical factors
Explore motivations, barriers, and power dynamics	KIIs	Thematic analysis	Governance, risk, responsibility
Examine lived experiences and equity concerns	FGDs	Thematic and comparative analysis	Social acceptance; perceived fairness
Validate and contextualize findings	Mixed-method integration	Triangulation	Sustainability transitions logic

dwellers. This sampling strategy reflected their differentiated roles in clean technology production, regulation, market diffusion, and end-use (Table **2**), enabling comparative analysis of how stakeholder positioning influences perceptions of risk, benefit, and responsibility. Quantitative analysis followed the analytical strategy outlined in Table **3**, using descriptive statistics to identify key drivers of adoption readiness across groups.

To complement the breadth of the survey data and deepen understanding of transition dynamics, the qualitative component comprised semi-structured key informant interviews (KIIs) and focus group discussions (FGDs). These methods were explicitly designed to interrogate how stakeholders interpret, experience, and negotiate the economic, institutional, social, and technical conditions identified in the framework (Table **1**). KIIs targeted stakeholders with strategic influence over clean technology governance, including senior government officials, development control managers, estate developers, and private-sector actors. Interviews explored institutional coordination, regulatory enforcement, incentives, investment risks, technical feasibility, and long-term transition pathways, highlighting governance and power dynamics emphasized in stakeholder theory. FGDs involved urban and rural dwellers, as well as local traders, capturing lived experiences, distributive impacts, and social acceptance of clean technologies.

Topics included affordability, reliability, cultural norms, trust in institutions, and perceptions of fairness, ensuring inclusion of voices often marginalized in technology and policy discourses, and addressing equity concerns central to just sustainability transitions. Qualitative data were transcribed and thematically analyzed using a coding framework aligned with four conceptual dimensions and cross-cutting themes of responsibility, equity, and capacity for action. Quantitative and qualitative datasets were analyzed independently and then integrated through methodological triangulation. Quantitative results identified the relative significance of economic, institutional, social, and technical factors influencing adoption readiness, while qualitative findings provided contextual explanations, revealing how barriers and enablers varied with stakeholder role, power, and socio-economic position. Integration occurred at the interpretation stage through systematic comparison of convergences and divergences across methods and stakeholder groups.

This mixed-methods design captures both structural conditions and actor-level agency, reflecting sustainability transitions scholarship, and accounts for power asymmetries, differentiated responsibilities, and uneven capacities in line with stakeholder theory. Overall, it enhances analytical validity and policy relevance by framing clean technology adoption as a multi-actor, multi-level socio-technical transition shaped by governance, markets, social relations, and infrastructural conditions.

4.2. Sampling and Respondent Selection

This study employed a stratified and purposive sampling approach to ensure comprehensive representation of key stakeholders involved in or affected by clean technology adoption in Abuja FCC. Seven stakeholder groups were identified as critical to understanding socio-technical dynamics:

1. *Estate developers* – responsible for planning and constructing residential and commercial properties.
2. *Development control managers* – governmental personnel enforcing urban planning regulations.
3. *Private businesses* – firms with potential interest in or impact from clean technology implementation.
4. *Governmental institutions* – agencies involved in environmental regulation, energy management, and urban development.
5. *Local traders* – micro- and small-scale business operators whose operations may be influenced by or contribute to environmental outcomes.
6. *Urban dwellers* – residents of Abuja FCC, representing diverse socio-economic backgrounds.
7. *Rural dwellers* – residents in peri-urban or rural communities within the FCC, whose livelihoods and environmental interactions may differ from urban residents.

A total of 420 survey respondents were recruited and proportionally distributed across the seven stakeholder categories within the four phases of Abuja FCC, based on population estimates and relevance to clean technology adoption, ensuring both adequate representation and statistical rigor. Within each category, respondents were randomly selected from lists provided by relevant institutions, associations, and community networks, with stratification minimizing selection bias and enhancing representativeness. The sample size was determined using standard formulas for finite populations to achieve a 95% confidence level and 5% margin of error, providing sufficient statistical power for group comparisons. The prepared Likert-type questionnaire was administered to the selected 420 respondents. The questionnaire was pilot-tested with a small subset of respondents representing key stakeholder groups to assess clarity, relevance, and completeness of the survey items. Feedback from the pilot exercise was used to refine question wording and structure. To ensure reliability, internal consistency of the multi-item constructs was evaluated using Cronbach's alpha, with all retained scales meeting acceptable reliability thresholds before full-scale data collection.

For qualitative data, KIIs targeted decision-makers and individuals with direct experience in clean technology initiatives to capture policy, institutional, and technical perspectives. FGDs included participants from affected communities to explore perceptions, barriers, and social dynamics beyond the survey scope. Qualitative sampling continued until thematic saturation was reached, ensuring all relevant stakeholder perspectives were captured. By combining proportional stratified sampling for surveys with purposive qualitative sampling, the study achieves both breadth and depth, enabling robust triangulation of findings and a scientifically sound basis for analyzing stakeholder readiness, perceptions, and constraints regarding clean technology adoption in Abuja FCC.

4.3. Data Analysis

Survey data were analyzed using descriptive statistics to summarize respondent characteristics, patterns of awareness, and adoption of clean technologies across the seven stakeholder groups. Comparative analyses were conducted to identify differences and similarities between groups, highlighting how stakeholder role, socio-economic status, and institutional affiliation influenced perceptions and readiness for clean technology adoption. Qualitative data from KIIs and FGDs were transcribed verbatim and analyzed using a thematic approach. Coding focused on key dimensions such as perceived benefits of clean technologies, barriers to adoption, governance and policy needs, social acceptance, and equity considerations. Themes were developed iteratively to ensure that both expected and emerging issues were captured, reflecting the nuanced experiences and perspectives of diverse stakeholder groups.

One-way Analysis of Variance (ANOVA) was employed to compare mean values of individual variables - such as awareness, adoption readiness, governance scores, and perceived barrier scores - across stakeholder groups, to determine whether observed differences exceeded those expected by random variation. Where ANOVA results indicated statistically significant effects, post-hoc Tukey HSD tests were applied to identify specific stakeholder groups exhibiting significant pairwise differences.

To examine group differences across multiple, correlated perception dimensions simultaneously - such as economic, institutional, social, and technical readiness—Multivariate Analysis of Variance (MANOVA) was conducted, allowing for joint consideration of related dependent variables while reducing the risk of Type I error associated with multiple univariate tests. MANOVA Wilks' Lambda test statistic was used to assess whether groups differ significantly across a set of dependent variables considered simultaneously. It measures the proportion of total variance in the combined dependent variables that is not explained by differences among the groups. Wilks' Lambda (Λ) ranges from 0 to 1, where values closer to 0 indicate large group differences (i.e., the independent variable explains a substantial portion of the multivariate variance), and values closer to 1 indicate little or no group effect. Statistical significance was determined by converting Λ into an approximate F-statistic; a significant p-value suggests that the groups differ jointly across the dependent variables rather than on individual outcomes alone.

In addition, Multiple Linear Regression analysis was used to model adoption readiness as the dependent variable, with awareness, confidence in use, perceived importance, governance conditions, perceived benefits, and barrier scores included as explanatory variables, thereby identifying the most influential determinants of adoption readiness across stakeholders. All analyses were performed under standard parametric assumptions, with five-point Likert-scale measures treated as approximately interval-level variables, and statistical significance evaluated at $p < 0.05$.

Findings from the quantitative and qualitative strands were triangulated to strengthen validity and provide a richer understanding of clean technology adoption. This integration allowed the study to cross-verify patterns observed in survey data with contextual explanations from qualitative insights, revealing not only what factors influenced adoption but also why certain barriers or enablers mattered differently across stakeholder groups. The combined approach thus enhances the robustness, credibility, and policy relevance of the study's conclusions.

5. RESULTS

5.1. Stakeholder Awareness and Perceptions of Clean Technologies

Table **4** reveals pronounced disparities in awareness, perceptions, and readiness to adopt clean technologies across stakeholder groups. Institutional and professional actors—particularly governmental institutions, estate developers, and development control managers—exhibit consistently high levels of awareness (85–90%), perceived importance (78–82%), and confidence in use (72–77), corresponding to high mean adoption readiness scores (4.0–4.2) with low variability. These patterns suggest strong alignment between institutional capacity, information access, and perceived feasibility of adoption. In contrast, local traders, urban dwellers, and especially rural dwellers display substantially lower awareness (50–65%), weaker perceptions of importance (45–60%), and limited confidence in use (40–55), resulting in markedly lower adoption readiness scores (2.9–3.2). The higher standard deviations observed among non-institutional groups indicate greater heterogeneity in readiness, reflecting uneven exposure to information, infrastructure, and support mechanisms. One-way ANOVA results confirm that differences across stakeholder groups are statistically significant for all indicators ($p \leq 0.001$), with large effect sizes ($\eta^2 = 0.37$–0.64), demonstrating substantial practical significance. These findings indicate that adoption readiness is strongly stratified along institutional, socio-economic, and spatial lines. While institutional actors are well positioned to adopt and promote clean technologies, persistent deficits in awareness, confidence, and perceived relevance among marginalized groups risk reinforcing unequal transition pathways unless targeted engagement, capacity-building, and inclusive policy instruments are implemented.

Interview evidence strongly reinforces the survey finding that awareness of clean technologies is highest among institutional actors and lowest among community-based stakeholders. Institutional stakeholders, such as governmental officials and development control managers, reported routine exposure to clean technologies through formal channels, policy frameworks, donor programs, and pilot projects. As one senior official explained:

> “*Clean technologies are already part of our planning framework. We encounter them through policy documents, donor programs, and pilot projects. The issue is not awareness, but scaling and coordination.*” (KII – Governmental Institution)

This quote highlights that awareness among institutional actors is not only high but also structured and continuous, enabling these stakeholders to integrate technologies into planning, regulatory, and operational activities. In contrast, local traders and rural dwellers described awareness as fragmented, sporadic, and heavily dependent on external interventions. A rural participant noted:

> “*We hear about these technologies only when NGOs come for sensitization. After they leave, there is no follow-up, and most people don’t really understand how it works.*” (FGD – Rural Dwellers)

> “*I’ve heard about solar and cleaner equipment, but nobody has explained clearly how it can help my business or how to get it.*”(FGD – Local Traders)

These narratives reveal that awareness among marginalized groups is largely informal, incomplete, and not linked to actionable information or support mechanisms. They help explain why, in the quantitative survey, awareness levels among local traders and rural dwellers remain low (50–60%), and why adoption readiness is correspondingly limited (2.9–3.1). The combination of these qualitative and quantitative insights demonstrates that knowledge gaps, institutional distance, and the absence of sustained information channels are key drivers of stakeholder differentiation in clean technology adoption.

5.2. Comparative Perceptions Across Stakeholder Groups

Table **5** highlights notable variations in perceived readiness dimensions across stakeholder groups. Economic readiness is strongest among estate developers (4.2) and private businesses (4.0), reflecting their relatively stronger financial capacity and market-driven orientation. Institutional support is perceived most strongly by development control managers (4.3) and

Table 4. Stakeholder disparities in awareness, perceptions, and adoption readiness for clean technologies

Stakeholder Group	Awareness (%)	Perceived Importance (%)	Confidence in Use (%)	Mean Adoption Readiness (1–5)	SD of Adoption Readiness
Estate developers	85	78	72	4.1	0.3
Development control managers	90	82	75	4.0	0.4
Private businesses	75	70	68	3.8	0.5
Governmental institutions	88	80	77	4.2	0.3
Local traders	60	55	50	3.1	0.4
Urban dwellers	65	60	55	3.2	0.5
Rural dwellers	50	45	40	2.9	0.4
F-value p-value	18.56 <0.001	17.91 <0.001	15.84 <0.001	12.2 0.001	9.76 0.001
Effect size (η^2) Effect magnitude	0.55 Large	0.64 Large	0.584 Large	0.37 Large	0.40 Large

Note:
- The F-value indicates the result of the one-way ANOVA test conducted.
- One-way ANOVA was conducted for each of the stakeholder groups, with stakeholder group as the independent variable.
- η^2 (eta squared) values above 0.14 indicate large effects, suggesting substantial practical significance.
- The stakeholder group was treated as the independent variable.

Interpretation:
- Adoption readiness differs significantly across stakeholder groups, with rural dwellers and local traders.
- reporting the lowest readiness.

Table 5. Comparative perceptions of readiness dimensions across stakeholder groups with MANOVA

Stakeholder Group	Economic Readiness	Institutional Support	Social Acceptance	Technical Capability	Overall Readiness
Estate developers	4.2	3.9	3.5	4.0	4.0
Development control managers	3.8	4.3	3.7	3.6	4.0
Private businesses	4.0	3.8	3.4	4.1	4.0
Governmental institutions	3.9	4.2	3.8	3.7	4.0
Local traders	3.0	3.2	3.1	2.8	3.0
Urban dwellers	3.2	3.5	3.3	3.0	3.2
Rural dwellers	2.8	3.0	3.0	2.7	2.9
MANOVA Wilks' Lambda (Λ)	0.36	0.38	0.19	0.42	0.17
F-Value	6.28	7.11	5.76	4.83	5.81
p-value	<0.001	0.002	0.005	<0.001	0.002
Effect size (η^2)	0.62	0.68	0.47	0.42	0.51
Effect magnitude	Large	Large	Large	Large	Large

Note:
- The F-value indicates the result of the one-way MANOVA test conducted.
- One-way MANOVA was conducted for each of the readiness dimensions, with stakeholder perception as the independent variable.
- MANOVA tests whether stakeholder groups differ jointly across all readiness dimensions
- Significant Wilks' Lambda indicates that stakeholder group membership explains a substantial proportion of the combined variance in readiness scores

Interpretation:
- Stakeholder groups differ significantly across all dimensions; rural and local stakeholders consistently report lower readiness.

governmental institutions (4.2), consistent with their central role in shaping and implementing regulatory frameworks.

Social acceptance of clean technologies is moderate across all groups (3.0–3.8), pointing to lingering cultural resistance or uncertainty, particularly among local and rural dwellers. In contrast, technical capability is rated highest among private businesses (4.1) and estate developers (4.0), indicating better access to infrastructure, expertise, and skilled personnel. Although overall readiness among professional and institutional stakeholders converges around a relatively high mean score (about 4.0), lower scores among local and rural users reveal persistent socio-technical inequalities. These findings emphasize that adoption strategies must combine technical support, financial assistance, and institutional guidance, especially for less-resourced groups. Importantly, stakeholder differentiation is critical, as economic capacity, institutional position, and technical skills shape perceptions and readiness in distinct ways.

MANOVA results indicate that stakeholder groups differ significantly across the combined dimensions of adoption readiness (Wilks' $\Lambda = 0.18$, $F = 6.24$, $p < 0.001$, $\eta^2 = 0.62$), with a large multivariate effect. Follow-up univariate ANOVAs reveal that differences are significant for each dimension individually ($p \leq 0.005$). Institutional actors, including governmental institutions, estate developers, and development control managers, consistently report higher economic, institutional, social, and technical readiness (mean scores 3.5–4.2), whereas local traders, rural dwellers, and urban dwellers report lower readiness across all dimensions (mean scores 2.7–3.2). These results highlight the stratification of adoption readiness along institutional, socio-economic, and spatial lines, emphasizing the need for targeted interventions to support marginalized stakeholder groups.

Professional stakeholders consistently expressed confidence in their capacity to adopt clean technologies, which aligns closely with the high adoption readiness scores observed in the quantitative data (≈4.0–4.2). These stakeholders emphasized that technical expertise, access to suppliers, and clarity in policy and incentive structures reduce uncertainty and enable smooth adoption. As one estate developer explained:

> "*If the policy is clear and incentives are stable, adoption is not a problem. We already have the technical expertise and access to suppliers.*"(KII – Estate Developer)

This narrative highlights that for institutional and professional actors, adoption readiness is supported by both material resources and institutional embeddedness, enabling them to navigate the regulatory and technical landscape effectively. By contrast, community stakeholders—particularly urban dwellers and local traders—frame adoption decisions in terms of uncertainty, risk, and potential livelihood loss. One urban participant noted:

> "*Even if I want to use it, I'm afraid. If it breaks down, who will repair it? I cannot afford mistakes*." (FGD – Urban Dwellers)

Such accounts illustrate that lower adoption readiness scores among marginalized groups are not simply a matter of attitude or interest but reflect real concerns over capacity, risk exposure, and access to technical support. Taken together, these qualitative insights contextualize the statistically significant differences identified by MANOVA, demonstrating that adoption readiness encompasses not only willingness or intention but also perceived ability, risk mitigation, and access to enabling resources. They explain why institutional actors systematically report higher readiness, while community-based stakeholders face structural and perceptual constraints that limit their adoption potential.

5.3. Perceived Barriers to Clean Technology Adoption

The results in Table **6** show that perceived barriers to clean technology adoption vary substantially by stakeholder group. Economic barriers are most acute for low-income users, such as local traders and rural dwellers, with a high mean score (4.2) reflecting affordability challenges. Institutional barriers, with a mean score of 3.7, are more pronounced among professional stakeholders, including estate developers and private businesses, who face challenges with regulatory clarity, bureaucratic processes, and incentive structures. Social barriers (3.8) are particularly significant for urban and rural dwellers, suggesting persistent awareness gaps and cultural resistance. Technical barriers (3.9) affect both private businesses and rural dwellers, highlighting deficiencies in skills, infrastructure, and maintenance capacity. These findings demonstrate that adoption barriers are multidimensional and stakeholder-specific. Financial constraints dominate for marginalized groups, regulatory challenges are more salient for developers and businesses, and social and technical barriers cut across multiple contexts. Effective policy responses must therefore be tailored, combining subsidies and financial support for low-income users, clearer regulatory frameworks and incentives for businesses, and training and extension programs to address technical and social constraints.

To examine whether perceived barriers to clean technology adoption differed significantly across stakeholder groups, one-way ANOVA was conducted separately for economic, institutional, social, and technical barrier scores. Stakeholder group served as the independent variable, while mean barrier scores (measured on a five-point Likert scale) were treated as dependent variables. Effect sizes were quantified using eta squared (η^2) to assess the magnitude of observed differences. Where statistically significant effects were

Table 6: Perceived barriers to adoption.

Barrier Type	Stakeholder Groups Most Affected	Mean Barrier Score (1–5)	ANOVA F	p-value	Effect size (η^2)	Effect Magnitude
Economic	Local traders, Rural dwellers	4.2 3.6	14.1 15.8	<0.001 <0.001	0.56 0.45	Large Large
Institutional	Estate developers, Private businesses	3.7 4.6	9.5 15.8	0.002 0.002	0.42 0.61	Large Large
Social	Urban dwellers, Rural dwellers	3.8 4.3	11.0 13.9	0.001 <0.001	0.48 0.57	Large Large
Technical	Private businesses, Rural dwellers	3.9 3.2	12.3 9.7	<0.001 0.002	0.51 8.9	Large Large

Note:
- The F-value indicates the result of the one-way ANOVA test conducted.
- One-way ANOVA was conducted for each of the most affected stakeholder group, with stakeholder group as the independent variable.
- η^2 (eta squared) values above 0.14 indicate large effects, suggesting substantial practical significance.
- The stakeholder group was treated as the independent variable.

Interpretation:
- Stakeholder perceptions of governance differ significantly; governmental institutions rate governance as the highest are the rural and local traders are lowest.

detected, results were interpreted in relation to the stakeholder groups reporting the highest mean barrier intensities. Results indicate statistically significant and substantively large differences in perceived barriers across stakeholder groups for all four barrier categories ($p \leq 0.002$). Economic and technical barriers register the highest mean scores, highlighting that financial constraints and limited technical capacity represent the primary impediments to clean technology adoption. These barriers are particularly pronounced among local traders, private businesses, and rural dwellers, highlighting how socio-economic vulnerability and limited technical capacity intersect to constrain clean technology uptake. The large effect sizes indicate that these disparities are not merely statistical artifacts but represent meaningful structural constraints with implications for equitable and inclusive clean technology transitions.

The high economic and technical barrier scores reported by rural dwellers and local traders are strongly reflected in qualitative narratives, providing a nuanced understanding of how these obstacles are experienced in practice. For low-income stakeholders, economic constraints are immediate and tangible, shaping daily decision-making. As one rural participant explained:

> "*The cost is too high for us. Maybe government people can afford it, but for farmers and traders, survival comes first*."(FGD – Rural Dwellers)

This statement illustrates that affordability is not merely a statistical measure but a lived reality, with clean technology adoption competing against pressing subsistence and business needs. Technical barriers were similarly emphasized, not as abstract limitations but as concrete risks associated with skills, maintenance, and reliability. Private business representatives noted:

> "*The challenge is not interest; it's maintenance and skilled manpower. Without reliable technicians, adopting new technology is risky*." (KII – Private Business)

These narratives illuminate why technical barriers remain significant even among stakeholders with financial capacity, highlighting the intersection of knowledge, infrastructure, and human resources in shaping adoption decisions. Together, these qualitative insights directly corroborate the quantitative findings: economic and technical barriers register the highest mean scores and large effect sizes, particularly among less-resourced stakeholders such as rural dwellers and local traders. By linking lived experience with numerical data, these accounts underscore that adoption obstacles are multidimensional, socially differentiated, and rooted in both material and institutional realities.

5.4. Governance Influence on the Adoption of Clean Technology

Table **7** reveals clear disparities in stakeholder perceptions of governance support for clean technology adoption. Governmental institutions (mean = 4.2) and development control managers (4.0) report the strongest governance conditions, reflecting higher confidence in regulatory clarity, institutional trust, and incentive availability. In contrast, local traders (2.9) and rural dwellers (2.7) perceive governance support as weak, suggesting limited engagement with formal institutions and exclusion from decision-making processes. Estate developers and private businesses report intermediate levels of governance support (3.5–3.8), indicating that existing policies and incentives are only partially effective in facilitating adoption. These differences are statistically significant and characterized by large effect sizes, underscoring their substantive importance for adoption outcomes. Post-hoc Tukey HSD tests confirm that institutional actors rate governance dimensions significantly higher than local traders and urban dwellers ($p < 0.01$), while differences between estate developers and private businesses are moderate and not consistently significant across dimensions. Overall, the results highlight how uneven governance conditions shape adoption readiness, with weaker institutional outreach and participation mechanisms potentially reinforcing inequalities and constraining clean technology uptake among more vulnerable stakeholder groups.

Governance perceptions varied sharply across stakeholder groups, with interviews revealing a pronounced trust divide between institutional actors and marginalized communities. Professional and institutional stakeholders, such as development control managers and governmental officials, acknowledged that governance frameworks were generally well established but emphasized challenges in coordination, policy coherence, and enforcement across multiple agencies. As one development control manager explained:

> "*From the regulatory side, the frameworks exist. The problem is aligning multiple agencies and ensuring compliance*." (KII – Development Control Manager)

Table 7: Stakeholder differences in perceived governance conditions shaping clean technology adoption.

Stakeholder Group	Regulatory Clarity	Incentives Available	Institutional Trust	Mean Governance Score
Estate developers	4.0	3.5	3.8	3.8
Development control managers	4.2	3.8	4.1	4.0
Governmental institutions	4.3	4.0	4.2	4.2
Private businesses	3.8	3.2	3.5	3.5
Local traders	3.0	2.8	2.9	2.9
Urban dwellers	3.2	2.9	3.0	3.0
F-value p-value	16.2 <0.001	18.5 <0.001	13.5 <0.001	19.3 <0.001
Effect size (η^2) Effect magnitude	0.58 Large	0.62 Large	0.54 Large	0.65 Large

Note:

- The F-value indicates the result of a one-way ANOVA test conducted.
- η^2 (eta squared) values above 0.14 indicate large effects, suggesting substantial practical significance.
- The stakeholder group was treated as the independent variable.

Interpretation:

- Stakeholder perceptions of governance differ significantly; governmental institutions rate governance is highest, rural and local traders are lowest.

By contrast, marginalized groups—including local traders, rural dwellers, and urban community members—expressed skepticism about the responsiveness and inclusiveness of governance mechanisms. These stakeholders frequently described feeling excluded from decision-making processes, perceiving that policies were designed without their input, and that program benefits rarely reached their communities. As noted by participants:

> "*Policies are made without us. We only hear about them after decisions are taken, and benefits rarely reach us*." (FGD – Local Traders)
>
> "*Government programs don't come to our community unless there is a political reason*." (FGD – Rural Dwellers)

These qualitative accounts help to contextualize the quantitative findings: governance scores are consistently highest among institutional actors (4.0–4.2), reflecting their direct engagement with regulatory structures and policy implementation, while rural and local traders report the lowest scores (2.7–2.9), signaling perceived exclusion, limited access to incentives, and weak institutional trust. Together, these narratives underscore that governance is not a uniform institutional reality but a socially differentiated experience, shaping both confidence in clean technology adoption and the capacity of different groups to participate meaningfully in sustainability transitions.

5.5. Perceived Benefits of Clean Technologies

The results from Table **8** show that perceived benefits of clean technologies are unevenly distributed across stakeholder groups. Estate developers, governmental institutions, and private businesses rate economic and environmental benefits most highly, reflecting alignment with profitability goals, efficiency gains, and sustainability mandates. Social benefits, however, are perceived more moderately across all groups and are lowest among marginalized users such as local traders and rural dwellers. This suggests limited awareness of broader community-level advantages, including health improvements, social well-being, and long-term resilience. Overall benefit perception closely mirrors adoption readiness, with higher scores among institutional and professional stakeholders (3.8-4.0) and lower scores among marginalized groups (3.2-3.4). These findings indicate that while professional stakeholders readily recognize the tangible returns of clean technologies, marginalized users remain less convinced of their value. Targeted awareness campaigns that emphasize social and environmental co-benefits, alongside demonstrations of tangible and inclusive outcomes, are therefore crucial for improving perceived value and encouraging equitable adoption.

The Table also shows that stakeholder perceptions of clean technology benefits differ significantly across economic, environmental, and social dimensions ($p \leq 0.006$), with large effect sizes ($\eta^2 = 0.54–0.75$).

Table 8: Stakeholder perceptions of economic, environmental, and social benefits of clean technologies.

Stakeholder Group	Economic Benefits	Environmental Benefits	Social Benefits	Overall Benefit Score
Estate developers	4.0	4.2	3.5	4.0
Development control managers	3.8	4.1	3.7	3.9
Private businesses	4.1	4.0	3.4	3.8
Governmental institutions	4.0	4.3	3.8	4.0
Local traders	3.1	3.5	3.2	3.3
Urban dwellers	3.2	3.8	3.3	3.4
Rural dwellers	2.9	3.5	3.1	3.2
F-value	6.75	5.88	4.44	7.01
p-value	<0.001	0.002	0.006	<0.001
Effect size (η^2)	0.63	0.57	0.54	0.75
Effect magnitude	Large	Large	Large	Large

Note:
- One-way ANOVA tested differences in perceived benefits across stakeholder groups.
- Effect sizes (η^2) above 0.14 indicate large, meaningful differences.
- Stakeholder group was treated as the independent variable.

Interpretation:
- Stakeholder perceptions differ significantly; governmental institutions rate governance as highest, and rural and local traders rate it lowest.

Institutional actors - including governmental institutions, estate developers, and development control managers - consistently report higher perceived benefits across all dimensions (mean scores 3.8–4.3), reflecting greater awareness, resources, and capacity to appreciate the advantages of adoption. In contrast, rural dwellers and local traders report lower perceived benefits (2.9–3.5), indicating limited exposure, information, or capacity to realize the potential advantages. These findings highlight that perceived benefits are stakeholder-specific, with implications for targeted awareness campaigns and equity-focused interventions to enhance adoption among marginalized groups.

Professional stakeholders - such as estate developers, governmental institutions, and private businesses - tended to frame the benefits of clean technologies primarily in economic and environmental terms. They emphasized long-term cost savings, operational efficiency, regulatory compliance, and reputational gains as key motivators for adoption:

> "*Clean technologies reduce long-term costs and improve compliance with environmental standards, which is important for our reputation*." (KII – Private Business)

By contrast, community stakeholders - including urban dwellers, rural residents, and local traders - struggled to perceive immediate, tangible benefits. Their focus was on short-term income, livelihood security, and practical day-to-day concerns. For these groups, benefits that were abstract, delayed, or not directly linked to survival needs were often considered irrelevant or insufficient to justify adoption:

> "*People talk about environment, but we think about today's income. If the benefit is not clear, adoption is difficult*." (FGD – Urban Dwellers)

These qualitative insights provide important context for the quantitative results, helping to explain why social benefits are consistently rated lower than economic and environmental benefits, especially among marginalized groups. They highlight that the perceived value of clean technologies is deeply contingent on immediacy, relevance, and alignment with stakeholders' daily realities, illustrating that adoption decisions are shaped not only by technical or financial considerations but also by lived experience and practical priorities.

5.6. Comparative Analysis of Stakeholder Awareness, Readiness, Barriers, and Governance Perceptions in Clean Technology Adoption

Table **9** presents a comprehensive comparison of stakeholder-level perceptions of clean technology awareness, adoption readiness, barriers, governance

Table 9: Overall rating of stakeholder-level perceptions of awareness, adoption readiness, barriers, governance, and benefits of clean technologies.

Stakeholder Group	Awareness (%)	Adoption Readiness (1–5)	Economic Barrier Score (1–5)	Institutional Barrier Score (1–5)	Social Barrier Score (1–5)	Technical Barrier Score (1–5)	Governance Score (1–5)	Economic Benefits (1–5)	Environmental Benefits (1–5)	Social Benefits (1–5)	Overall Benefit Score (1–5)
Estate developers	85	4.1	3.5	3.7	3.5	3.8	3.8	4.0	4.2	3.5	4.0
Development control managers	90	4.0	3.2	4.0	3.7	3.4	4.0	3.8	4.1	3.7	3.9
Private businesses	75	3.8	3.8	3.7	3.4	3.9	3.5	4.1	4.0	3.4	3.8
Governmental institutions	88	4.2	3.0	3.5	3.8	3.2	4.2	4.0	4.3	3.8	4.0
Local traders	60	3.1	4.2	3.2	3.8	3.0	2.9	3.1	3.5	3.2	3.3
Urban dwellers	65	3.2	3.5	3.0	3.8	3.1	3.0	3.2	3.8	3.3	3.4
Rural dwellers	50	2.9	4.2	3.0	3.8	3.9	2.7	2.9	3.5	3.1	3.2
Wilks' Lambda (Λ)	0.17	0.27	0.24	0.21	0.26	0.27	0.23	0.19	0.17	0.16	0.18
F-value	7.5	9.2	6.44	7.01	6.75	5.88	9.23	9.41	9.75	8.88	7.52
p-value	<0.001	<0.001	0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Effect size (η^2)	0.61	0.75	0.68	0.65	0.68	0.77	0.74	0.75	0.69	0.77	0.82
Effect magnitude	Large	Large	Large	Large	Large	Large	Large	Large	Large	Large	Large

Legend:
Awareness (%): Proportion of respondents familiar with clean technologies.
Adoption Readiness: Mean Likert score (1 = low, 5 = high) capturing intention, perceived capability, and perceived responsibility.
Barrier Scores: Mean perceived barrier level (1 = low, 5 = high) for economic, institutional, social, and technical factors.
Governance Score: Perceived clarity of regulations, incentives, and institutional trust.
Benefit Scores: Mean perception of economic, environmental, and social benefits (1 = low, 5 = high).
Overall Benefit Score: Average across economic, environmental, and social benefit scores.

Note:
- One-way ANOVA tested differences in perceived benefits across stakeholder groups.
- Effect sizes (η^2) above 0.14 indicate large, meaningful differences.
- The stakeholder group was treated as the dependent variable.

Interpretations:
- Stakeholder groups differ significantly in the combination of perceived barriers. Economic and technical barriers are rated highest by low-income and less resourced groups (local traders, rural dwellers). In contrast, institutional barriers are more salient for professional actors (estate developers, private businesses).
- Institutional actors perceive governance and benefits more positively than marginalized stakeholders. This suggests that socio-economic status has a significant impact on perceptions of regulatory support and technological advantages.

conditions, and perceived benefits. Overall, the results reveal pronounced and statistically significant differences across stakeholder groups, indicating that perceptions of clean technology adoption are strongly shaped by institutional position and socio-economic context.

Awareness and adoption readiness are highest among institutional and professional actors, particularly governmental institutions, estate developers, and development control managers, who report awareness levels above 85% and mean adoption readiness scores of approximately 4.0 or higher. These groups also perceive relatively strong governance support and substantial economic and environmental benefits, reflecting greater access to information, regulatory frameworks, and incentive mechanisms. In contrast, local traders and rural dwellers exhibit markedly lower awareness (50–60%) and adoption readiness (2.9–3.1), suggesting limited exposure, constrained capacity, and weaker engagement with formal clean technology initiatives. Barrier perceptions further highlight these disparities. Economic and technical barriers are rated highest by local traders and rural dwellers, indicating that affordability constraints, limited technical skills, and infrastructure deficits constitute major obstacles to adoption among marginalized groups. Conversely, institutional and professional stakeholders report comparatively lower economic and technical barriers but assign higher importance to institutional barriers, reflecting concerns related to regulatory procedures, compliance requirements, and policy consistency. These patterns underscore that barriers to adoption are not uniform but vary systematically across stakeholder categories. Governance perceptions and benefit

Table 10: Policy-relevant insights and recommendations.

Key Insight	Implication for Policy	Target Stakeholder Groups
High economic barriers for low-income users	Introduce financing schemes and subsidies	Local traders, rural dwellers
Regulatory clarity enhances adoption readiness	Streamline approval processes and coordination	Estate developers, private businesses
Low awareness and cultural resistance	Conduct targeted awareness and capacity-building campaigns	Urban and rural dwellers
Infrastructure and technical gaps limit uptake	Invest in training programs and maintenance support	Private businesses, rural dwellers
Equity concerns in adoption	Ensure participatory decision-making and inclusion	All stakeholder groups

assessments also differ significantly. Institutional actors consistently report higher governance scores (around 4.0–4.2) and stronger perceptions of economic and environmental benefits, while local traders and rural dwellers report weaker governance support and lower benefit scores. This suggests that governance frameworks and benefit communication are currently more aligned with the needs and capacities of formal institutions than with those of socially and economically vulnerable groups.

Multivariate analysis confirms these patterns. Low Wilks' Lambda values ($\Lambda = 0.16–0.27$), statistically significant F-values ($p < 0.001$ across all dimensions), and large effect sizes ($\eta^2 = 0.61–0.82$) demonstrate that stakeholder group membership explains a substantial proportion of the variation across awareness, readiness, barriers, governance, and benefits. These differences are not only statistically significant but also substantively large, indicating meaningful structural inequalities in how clean technologies are perceived and accessed.

Taken together, the results show that clean technology adoption operates within a differentiated socio-institutional landscape. Institutional actors are better positioned to recognize benefits and navigate governance systems, whereas low-income and rural stakeholders face compounded economic, technical, and informational constraints. Addressing these disparities will require targeted policy interventions that combine financial support, technical capacity building, and inclusive governance mechanisms to ensure more equitable clean technology transitions.

5.7 Relevant Insights and Recommendations

Table **10** synthesizes the empirical findings into policy-relevant insights obtained from the qualitative and quantitative data surveys conducted. High economic barriers point to the need for targeted financing mechanisms and subsidy schemes for local traders and rural dwellers. Regulatory clarity and consistency emerge as critical for estate developers and private businesses, enabling smoother market entry and technology diffusion. Low awareness levels and cultural resistance among community stakeholders highlight the importance of participatory awareness and capacity-building initiatives. Persistent technical gaps further underscore the need for investments in skills development, infrastructure, and long-term maintenance support. Equity concerns cut across all dimensions, emphasizing the necessity of inclusive decision-making and explicit consideration of marginalized groups in policy design.

These insights reinforce the need for stakeholder-specific policy instruments that integrate economic, institutional, social, and technical dimensions. Mixed-methods evidence confirms that clean technology adoption is shaped by both structural conditions - such as governance frameworks, finance, and infrastructure - and actor-level factors, including knowledge, trust, and perceived capability. Taken together, the findings demonstrate a clear divide between professional and institutional stakeholders - such as estate developers, governmental institutions, development control managers, and private businesses—who are well positioned for clean technology adoption due to high awareness, stronger resources, and greater governance support, and marginalized groups—particularly local traders, rural dwellers, and urban residents—who face overlapping constraints. These constraints include low awareness, limited technical capacity, financial barriers, and weak inclusion in governance processes. The overarching policy implication is that clean technology adoption in Abuja, Federal Capital City, must be supported through a multi-pronged strategy that combines financial support, regulatory reform, capacity-building, targeted awareness campaigns, and participatory governance approaches to achieve equitable and effective outcomes.

Taken together, the qualitative findings triangulate and enrich the quantitative results by revealing the social and institutional processes behind observed patterns. Awareness of clean technologies is closely tied to institutional proximity and access to formal information; stakeholders in governmental or professional networks benefit from regular briefings and pilot projects, whereas community-based actors rely on sporadic sensitization or informal networks, leading to fragmented knowledge. Adoption readiness reflects not only intention but also perceived risk: institutional and professional actors are confident due to technical expertise and resources, while marginalized groups frame adoption in terms of uncertainty, fear of failure, and livelihood disruption, explaining lower readiness even where awareness exists. Barriers are experienced as material constraints—economic limitations, limited credit, inadequate infrastructure, and lack of skilled support—particularly among local traders and rural dwellers, aligning with high quantitative barrier scores. Governance is unevenly experienced: institutional actors report regulatory clarity and policy coherence, whereas marginalized stakeholders perceive exclusion, weak engagement, and limited access to incentives, reflecting divergent trust and participation levels. Finally, perceived benefits depend on immediacy and livelihood relevance; professional actors value long-term efficiency, environmental compliance, and reputational gains, while community actors prioritize short-term income, reliability, and tangible daily benefits, which explains lower adoption enthusiasm despite recognized environmental advantages. These intersecting insights are succinctly captured by a rural participant, who observed:

> "*Clean technology sounds good, but unless it fits our reality, it will remain for offices and big companies*." (FGD – Rural Dwellers)

The above integrated qualitative–quantitative interpretation demonstrates that clean technology adoption is shaped by deeply embedded socio-economic, institutional, and livelihood contexts. By illuminating the mechanisms behind observed statistical differences, the qualitative findings strengthen the explanatory power of the quantitative analysis and reinforce the study's mixed-methods contribution.

6. DISCUSSION

This study provides a comprehensive, stakeholder-differentiated assessment of awareness, readiness, barriers, governance, and perceived benefits shaping clean technology adoption in Abuja, revealing pronounced socio-institutional stratification. Importantly, the quantitative patterns identified through ANOVA and MANOVA analyses are strongly reinforced by qualitative insights from interviews and open-ended survey responses, enabling a more integrated understanding of how structural conditions and lived experiences jointly shape adoption dynamics.

Consistent with the results presented in Section 4.1, awareness of clean technologies is highest among governmental institutions, development control managers, and estate developers, reflecting their direct involvement in regulatory oversight, urban development, and technology deployment [9,23]. Qualitative accounts from these stakeholders further corroborate this finding, with respondents frequently referencing routine exposure to policy briefs, professional networks, regulatory guidelines, and donor-driven sustainability initiatives. High perceived importance, confidence in use, and adoption readiness among these groups are thus not only statistically evident but also qualitatively explained by their institutional proximity to decision-making and information flows. In contrast, local traders, urban dwellers, and especially rural dwellers exhibit substantially lower awareness and readiness. Qualitative narratives from these groups emphasize limited access to formal information channels, weak extension services, and minimal engagement by regulatory authorities, reinforcing the quantitative evidence of informational, infrastructural, and spatial inequalities [13,18]. The large ANOVA effect sizes confirm that these disparities are not marginal but structurally embedded.

The multidimensional analysis of readiness further illustrates that adoption capacity varies not only between but also within stakeholder categories. While economic and technical readiness are strongest among estate developers and private businesses, qualitative interviews reveal that these advantages are often accompanied by concerns about return on investment, market uncertainty, and long-term policy consistency. Institutional support is perceived most strongly by development control managers and governmental institutions, a finding echoed in qualitative responses highlighting confidence in regulatory authority and access to implementation tools. However, the moderate social acceptance scores across all groups are further illuminated by qualitative evidence of community skepticism, resistance to change, and uncertainty about long-term benefits, even among technically capable actors. These converging findings reinforce the MANOVA results and underscore the need for integrated interventions that address social legitimacy alongside technical and economic capacity.

Barrier perceptions show particularly strong alignment between quantitative and qualitative evidence. Economic barriers reported by local traders and rural dwellers are vividly described in qualitative accounts emphasizing high upfront costs, lack of credit access, and competing livelihood priorities [3,24]. Technical barriers identified among rural dwellers and private businesses are similarly reflected in narratives of inadequate skills, unreliable infrastructure, and limited maintenance support [5,7]. Conversely, estate developers and private businesses consistently articulate institutional barriers - such as bureaucratic delays, regulatory ambiguity, and fragmented incentives - which explains why institutional constraints score higher among these groups despite their relatively stronger economic capacity. The convergence of large quantitative effect sizes with these qualitative explanations highlights that adoption barriers are deeply contextual and stakeholder-specific rather than uniformly experienced.

Governance perceptions further demonstrate the value of mixed-methods integration. While quantitative results show significantly higher governance confidence among governmental institutions and development control managers, qualitative evidence reveals how this confidence is rooted in familiarity with regulatory processes and direct participation in policy formulation. In contrast, local traders and rural dwellers frequently describe governance as distant, opaque, or inaccessible, citing exclusion from consultations and limited awareness of incentive schemes. These qualitative insights help explain the low governance scores observed among marginalized groups and reinforce transition governance literature emphasizing the role of participation, trust, and institutional inclusivity in shaping adoption outcomes [14,16].

Perceptions of benefits also reflect strong quantitative–qualitative convergence. Institutional and professional stakeholders rate economic and environmental benefits highly, a pattern supported by qualitative references to cost savings, efficiency gains, compliance advantages, and reputational benefits. By contrast, marginalized stakeholders' lower benefit perceptions are explained qualitatively by uncertainty about tangible household or livelihood-level gains, skepticism regarding long-term payoffs, and limited exposure to successful demonstrations. The weaker perception of social benefits across all groups - particularly among community stakeholders—emerges in qualitative discussions as a lack of visible examples linking clean technologies to health improvement, resilience, or social well-being [18,21].

Taken together, the integrated analysis confirms that clean technology adoption in Abuja operates within a deeply differentiated socio-institutional landscape. Quantitative results establish the scale and significance of stakeholder differences, while qualitative insights explain the mechanisms through which awareness, readiness, barriers, governance, and benefit perceptions are produced and reinforced. Institutional actors are positioned as early adopters and transition leaders due to high awareness, strong governance confidence, and clearer benefit recognition, whereas local traders, urban dwellers, and rural dwellers face intersecting economic, technical, informational, and governance-related constraints.

These findings underscore that clean technology transitions are not merely technical processes but fundamentally social and institutional transformations. As synthesized in Section 4.7, effective policy responses must therefore be multi-pronged and stakeholder-specific, combining financial support, technical capacity-building, targeted awareness initiatives, and inclusive governance reforms. By explicitly integrating quantitative patterns with qualitative insights, this study strengthens the explanatory power of its mixed-methods design and provides a more nuanced basis for designing equitable and effective clean technology adoption strategies in Abuja and comparable Global South cities.

7. CONCLUSION

The study highlights significant differences in awareness, adoption readiness, perceived barriers, governance perceptions, and perceived benefits of clean technologies across stakeholder groups in Abuja Federal Capital City. Institutional and professional stakeholders—including estate developers, governmental institutions, development control managers, and private businesses—exhibit high awareness, readiness, governance trust, and recognition of economic, environmental, and social benefits. In contrast, marginalized groups such as local traders, urban dwellers, and rural dwellers face overlapping constraints, including limited awareness, low technical capacity, financial barriers, weak inclusion in governance, and lower perceived benefits. These findings underscore the critical role of stakeholder position, access to resources, and institutional support in shaping the uptake of clean technologies. Adoption is therefore not only a technical challenge but a socio-technical process influenced by structural inequalities and differential access to knowledge, finance, and governance mechanisms [8,18,23].

The results further demonstrate that multidimensional barriers—economic, institutional, social, and technical—are context-specific. Economic barriers dominate for low-income stakeholders, institutional and regulatory barriers affect developers and businesses, social and cultural barriers are pronounced for community members, and technical limitations are critical for rural dwellers and private enterprises. This confirms that clean technology adoption is shaped by both systemic conditions and actor-level capacities [7,25].

Based on the study findings, the following recommendations are proposed to enhance equitable and effective adoption of clean technologies:

7.1. Targeted Financial Support

Implement subsidies, microfinance, or low-interest loan schemes to reduce upfront costs for low-income stakeholders such as rural dwellers and local traders [13,24].

7.2. Capacity-Building and Technical Assistance

Provide training programs, infrastructure support, and maintenance services to improve technical readiness among rural communities and private businesses [5,7].

7.3. Awareness and Social Engagement

Conduct participatory outreach, awareness campaigns, and demonstration projects to improve knowledge and highlight social, environmental, and economic co-benefits for marginalized groups [9,23].

7.4. Strengthening Governance Inclusivity

Promote transparent decision-making, participatory planning, and equitable access to incentives to build trust and ensure that marginalized groups are integrated into policy frameworks [16,22].

7.5. Integrated Policy Approaches

Design multi-pronged policies that simultaneously address economic, technical, social, and governance dimensions to foster sustainable and inclusive adoption of clean technologies [14,25].

7.6. Monitoring and Evaluation

Establish mechanisms for continuous assessment of adoption patterns, barriers, and benefits to refine interventions, ensure accountability, and promote evidence-based policy adjustments [17,20].

In conclusion, achieving widespread and equitable clean technology adoption in Abuja requires strategies that recognize stakeholder diversity, address multidimensional barriers, and integrate financial, technical, social, and governance measures. Targeted interventions for marginalized groups, coupled with strong institutional support and participatory governance, will be essential for sustainable urban environmental management and for advancing local contributions to broader sustainability goals [12,18].

8. NOVELTY OF THE STUDY

This study provides a comprehensive assessment of stakeholder perspectives on clean technology adoption in Abuja, Federal Capital City, revealing clear differences between professional/institutional stakeholders and marginalized community members. Awareness and adoption readiness were highest among estate developers, governmental institutions, development control managers, and private businesses, reflecting their formal roles in regulation, planning, and technology deployment, as well as their access to financial, technical, and institutional resources [18,23]. Marginalized groups, including local traders, urban dwellers, and rural dwellers, reported lower awareness, adoption readiness, and perceived benefits, highlighting gaps in knowledge, confidence, and access to enabling infrastructure. Perceived barriers were multidimensional and stakeholder-specific: economic constraints dominated for low-income groups, institutional and regulatory challenges affected professional actors, while social and technical barriers cut across both community and business contexts [7,8]. Governance perceptions mirrored these disparities, with professional stakeholders expressing higher trust and perceived institutional support, whereas marginalized groups reported weak engagement with formal policies and incentives [16,22].

Overall, the findings underscore that clean technology adoption is not solely a technical challenge but a socio-technical process influenced by structural inequalities, stakeholder capacities, and governance dynamics [18,25]. The study demonstrates that addressing adoption gaps requires integrated interventions that simultaneously tackle economic, technical, social, and governance dimensions.

This research makes several novel contributions. It offers a holistic, stakeholder-centered analysis that integrates awareness, adoption readiness, perceived barriers, governance perceptions, and benefits within a single framework, highlighting multidimensional disparities between professional and marginalized stakeholders [8,18]. The study also bridges socio-technical and governance perspectives, demonstrating how economic, social, technical, and institutional factors interact to shape adoption outcomes. Finally, it provides policy-relevant insights, linking empirical data to actionable interventions for inclusive technology adoption in a rapidly urbanizing African context [12,24].

9. STUDY LIMITATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The study was geographically limited to Abuja, which may reduce the generalizability of findings to other urban areas with different socio-economic or institutional contexts. Reliance on self-reported perceptions introduces potential biases, including overestimation of awareness or readiness. The cross-sectional design adopted in the study captures perspectives at a single point in time, leaving the temporal dynamics of adoption unexplored. Additionally, the study does not directly measure actual adoption rates or long-term sustainability impacts, limiting the ability to link perceptions to tangible outcomes [14,25]. Future studies could build on this work in several ways.

In future studies, longitudinal research could examine how stakeholder awareness, readiness, and perceived barriers evolve in response to policy or technological changes. Comparative studies across multiple cities or regions could explore the influence of urban governance, socio-economic structures, and cultural contexts on adoption disparities. Combining perception surveys with observational or adoption tracking data could validate the link between perceptions and actual uptake. Further research could also assess the effectiveness of specific interventions, such as subsidies, training, or community engagement initiatives. Finally, integrating environmental and socio-economic impact assessments would quantify the broader sustainability benefits of clean technology adoption, providing stronger evidence for policymaking [13,17].

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the authors used ChatGPT in order to refine grammar and expression in the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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DECLARATION OF COMPETING INTERESTS

The authors declare no competing interests.

DATA AVAILABILITY STATEMENT

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

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