Climate Change Vulnerability and Resilience of Electricity Transmission Infrastructure: The Role of Socio-Economic Factors in Kajiado County, Kenya

Clifford Siocha[1], Paul Thomas Obade[2], Felix Ming'ate[3]

[1]Department of Environmental Science and Education, Kenyatta University

[2]Senior Lecturer, Department of Environmental Science and Education, Kenyatta University

[3]Senior Lecturer, Department of Environmental Studies and Community Development, Kenyatta University

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ABSTRACT

Electricity transmission infrastructure faces mounting climate hazards compounded by socio-economic pressures in Kajiado County, Kenya. This mixed-methods study examines how socio-economic conditions shape infrastructure resilience by integrating ordinal regression, Spearman correlation, and thematic analysis. Data was collected from 87 transmission experts (questionnaires) and 10 key informants (interviews). Quantitative results demonstrate that socio-economic factors significantly predict infrastructure resilience ($\beta = 0.594$, $p = 0.046$; $\rho = 0.273$, $p = 0.028$). Qualitatively, financial constraints, governance weaknesses, vandalism, and land-use encroachment emerge as primary vulnerability drivers. Notably, a perceptual gap exists stakeholders emphasize environmental factors in 26% of responses, yet quantitative analysis reveals socio-economic and institutional drivers as statistically dominant. The model explains 17.5% of variance (Nagelkerke $R^2 = 0.175$), suggesting additional institutional dimensions not fully captured. This study concludes that infrastructure resilience in resource-constrained, semi-arid regions depends critically on socio-economic strengthening, governance effectiveness, and integrated community engagement. Integrating socio-economic impact assessment into resilience frameworks is essential for sustainable electricity transmission infrastructure.

Keywords: electricity transmission infrastructure, resilience, socio-economic determinants, governance and financing, infrastructure planning, Kenya

INTRODUCTION

Electricity transmission infrastructure constitutes the backbone of modern power systems by enabling the bulk transfer of electricity from generation facilities to distribution networks and ultimately to consumers. The reliability of these systems is fundamental to economic growth, industrial productivity, public service delivery, and social well-being. However, electricity transmission infrastructure is increasingly threatened by climate change, whose impacts extreme rainfall and extreme temperatures are placing unprecedented pressure on critical energy infrastructure worldwide (IPCC, 2022). Given their extensive spatial coverage, long operational life, and high capital investment, transmission networks are particularly susceptible to climate-related hazards that can compromise their structural integrity, operational performance, and service reliability.

Although climate hazards provide the physical trigger for infrastructure damage, vulnerability is increasingly recognised as a function of both hazard exposure and the socio-economic conditions that influence infrastructure sensitivity and adaptive capacity. The Intergovernmental Panel on Climate Change (IPCC, 2022) conceptualizes vulnerability as the interaction between exposure, sensitivity, and adaptive capacity, highlighting that infrastructure systems located in similar climatic conditions may experience markedly different outcomes depending on governance effectiveness, financial capacity, institutional preparedness, land-use planning, and community engagement. Consequently, climate change alone does not determine infrastructure vulnerability; rather, socio-economic conditions shape the ability of infrastructure systems to anticipate, withstand, respond to, and recover from climate-related disturbances.

Globally, recent studies have demonstrated that the resilience of electricity transmission systems depends as much on socio-economic and institutional capacity as on engineering design. Reviews of power grid resilience indicate that ageing infrastructure, inadequate maintenance funding, weak asset management systems, delayed investments, and governance deficiencies significantly amplify the impacts of climate hazards on electricity networks (Karagiannakis et al., 2025; Guddanti et al., 2024). Similarly, studies on power system resilience emphasize that climate adaptation requires not only technological improvements but also strengthened institutional coordination, sustainable financing mechanisms, proactive maintenance, and effective stakeholder participation to reduce system vulnerability (Mohanty et al., 2024; Kasimalla et al., 2024; Mishra et al., 2024).

These challenges are particularly pronounced in developing countries, where rapidly growing electricity demand often outpaces investments in infrastructure maintenance and climate adaptation. Socio-economic pressures including rapid urbanization, population growth, competing land uses, informal settlements, land tenure conflicts, and limited public resources increase the exposure and sensitivity of electricity infrastructure to climate hazards. At the same time, institutional constraints, inadequate regulatory enforcement, and insufficient climate finance reduce the capacity of utilities to implement preventive maintenance, infrastructure upgrades, and long-term resilience planning. Recent analyses of Kenya's electricity sector identify financing constraints, governance challenges, and limited institutional capacity as major barriers to developing a climate-resilient electricity system. Public fiscal constraints have slowed investment in transmission infrastructure and climate adaptation, while governance and regulatory weaknesses continue to affect utility performance, planning, and long-term resilience. These challenges are compounded by the need for stronger institutional coordination and increased private sector participation to finance and manage resilient electricity infrastructure (Apergi et al., 2024; Twesigye, 2024).

The impacts of climate change on electricity transmission infrastructure, however, are not determined solely by the magnitude or frequency of climate hazards. Contemporary climate vulnerability theory recognizes that infrastructure vulnerability is shaped by the interaction between hazard exposure, system sensitivity, and adaptive capacity, the latter being largely influenced by socio-economic and institutional conditions (IPCC, 2022). Consequently, factors such as governance effectiveness, financial resources, institutional capacity, stakeholder participation, land-use planning, maintenance practices, and policy implementation play a critical role in determining the ability of electricity transmission systems to anticipate, withstand, adapt to, and recover from climate-related disturbances (Apergi et al., 2024; Kasimalla et al., 2024; Mohanty et al., 2024). In many cases, these socio-economic factors exert a greater influence on infrastructure resilience than climate hazards themselves because they determine the extent to which preventive and adaptive measures can be effectively implemented.

Kajiado County provides an appropriate setting for examining these interactions because it hosts strategic national and regional electricity transmission corridors while experiencing increasing climate variability and rapid socio-economic transformation. The county has experienced rising temperatures, highly variable rainfall, recurrent droughts, flash floods, and changing land-use patterns associated with rapid urbanization, infrastructure development, and population growth (Kenya Meteorological Department, 2024). These climatic changes, combined with expanding human activities, have intensified pressures on electricity transmission infrastructure through corridor encroachment, land acquisition conflicts, vandalism, competing land uses, and reduced accessibility for inspection and maintenance during extreme weather events (Government of Kajiado County, 2023; IPCC, 2022). Moreover, financial constraints, institutional coordination challenges, limited stakeholder engagement, and competing development priorities continue to impede the implementation of effective climate adaptation and infrastructure resilience measures within the county (Apergi et al., 2024).

Despite increasing recognition that climate-resilient infrastructure requires an integrated understanding of environmental, technical, institutional, and socio-economic dimensions (IPCC, 2022; Kasimalla et al., 2024; Mohanty et al., 2024), existing studies on electricity transmission infrastructure have predominantly focused on engineering performance, asset reliability, or the direct impacts of climate hazards. Comparatively little attention has been devoted to understanding how socio-economic factors—including governance, financing, institutional capacity, land-use dynamics, stakeholder participation, and community interactions shape the vulnerability of electricity transmission infrastructure to climate change within specific local contexts (Argyroudis et al., 2020; Apergi et al., 2024). This knowledge gap limits the development of evidence-based policies and investment strategies that address the underlying drivers of infrastructure vulnerability rather than merely responding to the physical impacts of climate hazards.

This study addresses this gap by examining the socio-economic factors contributing to the vulnerability of electricity transmission infrastructure to climate change in Kajiado County. Specifically, it investigates how socio-economic conditions influence infrastructure sensitivity and adaptive capacity, with the aim of generating evidence to support climate-resilient infrastructure planning, informed investment prioritization, and effective policy interventions for enhancing the resilience, reliability, and long-term sustainability of electricity transmission infrastructure in Kenya.

LITERATURE REVIEW

Theoretical Framework

This study is anchored on Resilience Theory as conceptualized by Folke (2006), which describes resilience as the capacity of systems to absorb disturbances, adapt to changing conditions, and maintain essential structures and processes. The theory is built on foundational ecological systems work by Holling (1973), who introduced resilience as the persistence of systems in the face of environmental change. Within this framework, resilience has been widely applied to social-ecological and infrastructure systems exposed to multiple interacting stressors.

For electricity transmission infrastructure, Resilience Theory offers a useful analytical lens by emphasizing that vulnerability emerges from interactions among multiple system components rather than from isolated risk factors. Environmental stressors such as flooding and terrain variability, technical limitations in design and maintenance, and socio-economic conditions including funding levels and institutional capacity are therefore understood as interconnected determinants of system performance (Cimellaro et al., 2014; Argyroudis et al., 2020). The theory conceptualizes resilience through three core dimensions: absorptive capacity (the ability to withstand disturbances without significant functional failure), adaptive capacity (the ability to adjust operational responses under changing conditions), and transformative capacity (long-term structural or institutional changes that improve future system performance) (Folke, 2006). These dimensions align with this study's focus on identifying how environmental, technical, and socio-economic factors jointly shape infrastructure vulnerability in Kajiado County.

Although Resilience Theory provides a strong conceptual foundation, it does not in itself offer measurable indicators for quantifying infrastructure vulnerability. For this reason, it is complemented in this study by empirical statistical approaches, specifically ordinal regression and Spearman correlation analysis, which enable the operationalization of resilience outcomes and the assessment of the relative influence of different contributing factors (Cutter et al., 2014). Section 3.4 makes this operationalization explicit by mapping each socio-economic variable used in the analysis onto the absorptive, adaptive, and transformative dimensions of the theory.

Socio-Economic Factors and Infrastructure Vulnerability

Socio-economic factors significantly shape both the vulnerability and resilience of electricity transmission infrastructure by determining the availability of financial resources, institutional capacity, and stakeholder participation. Limited funding for infrastructure development and maintenance often leads to delayed repairs, inadequate system upgrades, and insufficient investment in resilience-enhancing technologies (World Bank, 2021; Mensah & Adu, 2022). Competing national development priorities and constrained budget allocations further weaken the ability of responsible agencies to implement long-term infrastructure improvement strategies, thereby increasing system fragility. Strong governance structures, adequate financing mechanisms, and effective stakeholder coordination, by contrast, enhance resilience by supporting timely maintenance, rapid fault response, and improved system monitoring (Obuya et al., 2019; IPCC, 2022).

Social Fragility, Theft, and Vandalism

A critical socio-economic factor contributing to infrastructure vulnerability in Sub-Saharan Africa is the pervasive challenge of theft and vandalism. Poverty levels exhibit a positive relationship with infrastructure-targeted crime, as economically marginalized communities sometimes resort to damaging or stealing infrastructure components to meet immediate livelihood needs (Ikejemba & Schuur, 2018). For high-value energy assets such as transmission lines, transformers, and substations, theft and vandalism carry significant operational and economic consequences. Damaged, exposed, or poorly maintained infrastructure is more susceptible to environmental hazards including windstorms, flooding, and soil erosion, compounding system fragility over time.

In Kenya and similar developing contexts, these socio-economic dynamics are particularly concerning given the dependence on reliable energy infrastructure as a foundation for economic development. Musau et al. (2022) observe that ongoing initiatives to expand electricity access to underserved and rural communities remain undermined by the persistent threat of vandalism, which erodes both service reliability and community confidence in infrastructure systems.

Governance Weaknesses and Social Barriers to Resilience

Beyond poverty-driven theft, broader governance challenges, including weak institutional capacity, inadequate enforcement, and insufficient investment in social protection systems, further erode the enabling environment required for resilient infrastructure development (Sovacool et al., 2017). Research in the African context indicates that inadequate social safety nets and weak governance limit meaningful community engagement in infrastructure planning and maintenance, thereby increasing alienation and susceptibility to infrastructure-targeted harm.

Marginalized populations often settle informally along transmission corridors or in high-risk areas due to lack of affordable alternatives, increasing both human and infrastructure vulnerability (Nyangena et al., 2018). Abebe et al. (2023) further demonstrate that without participatory governance mechanisms, infrastructure resilience strategies in East Africa tend to overlook community-level risk knowledge, reducing their effectiveness and sustainability. Strengthening governance capacity and social inclusion is therefore essential for reducing systemic vulnerabilities.

The Climate-Security Nexus and Infrastructure Vulnerability

Recent scholarships have deepened understanding of how social fragility, infrastructure insecurity, and climate hazards intersect in a mutually reinforcing manner. Mohsin et al. (2024) describe this as the ‘climate-security nexus,’ wherein socio-economic deprivation and weak governance heighten infrastructure vulnerability, while infrastructure failures whether from physical degradation, vandalism, or climate shocks further destabilize communities and exacerbate socio-political tensions. Frequent power transmission disruptions triggered by climate disasters can initiate broader socio-economic breakdowns, fueling higher crime rates, increased infrastructure sabotage, and economic instability, which in turn weaken power systems and compound future vulnerability (Figure 1).

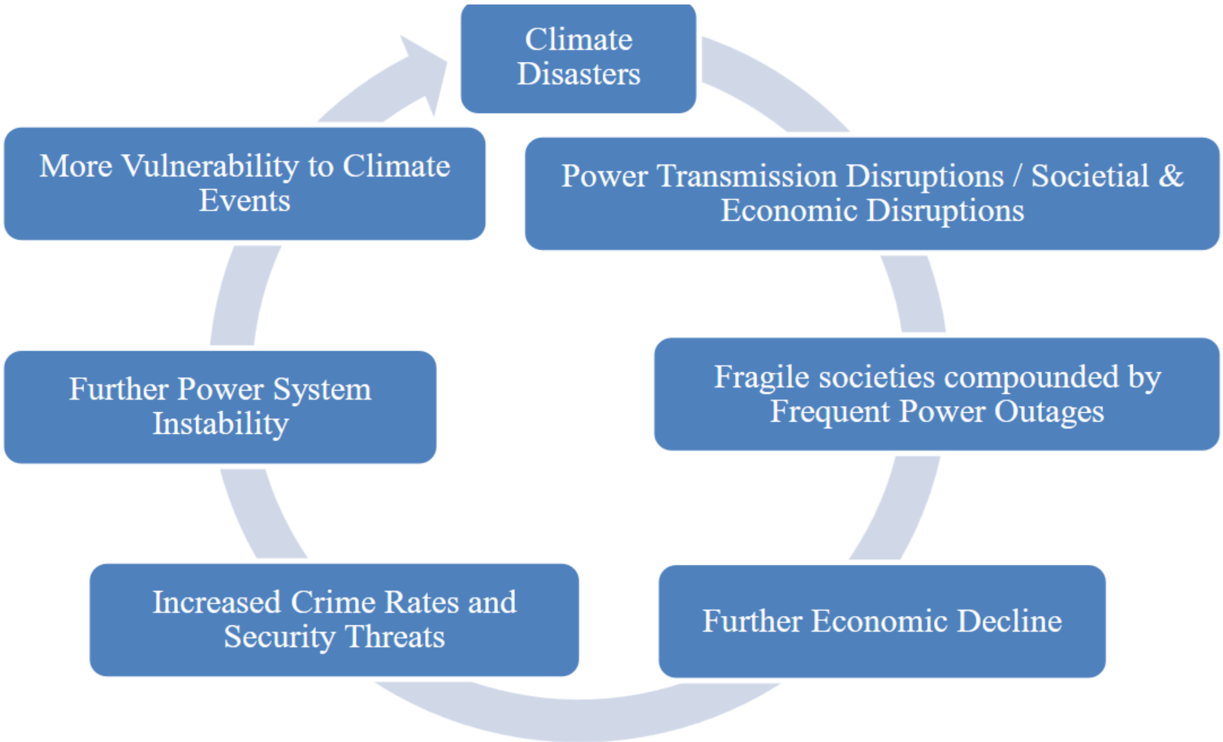

Figure 1: The Vicious Cycle of Climate-Driven Infrastructure Vulnerability

Source: Mohsin et al. (2024)

Enabling Environments for Resilient Infrastructure

The literature consistently identifies enabling environments characterized by strong institutions, inclusive development, and active community participation as critical catalysts for infrastructure resilience (Ford et al., 2016; Adger et al., 2005). Communities that are meaningfully engaged in infrastructure planning, maintenance monitoring, and reporting tend to exhibit greater adaptive capacity and lower susceptibility to climate-related disruptions.

The United Nations Office for Disaster Risk Reduction (UNDRR, 2022) and the IPCC (2022) both emphasize the importance of integrating community knowledge, including indigenous ecological knowledge, into adaptation planning. Incorporating traditional understanding of weather patterns and environmental stewardship into resilience strategies has been shown to reduce infrastructure-related risks and support more equitable outcomes (Nyong et al., 2007). Investment in public education, participatory planning, and alternative livelihood programs further reduces the structural vulnerabilities that drive infrastructure-targeted harm (Jones et al., 2014; Musau et al., 2022). These enabling approaches should be central to infrastructure planning and climate adaptation in contexts facing both environmental and socio-economic stress.

METHODOLOGY

Research Design

This study adopted a mixed-methods research design to examine socio-economic factors contributing to the vulnerability of electricity transmission infrastructure in Kajiado County, Kenya. Quantitative methods were employed to establish statistical relationships between key socio-economic variables including public participation, indigenous knowledge integration, financial constraints, land-use practices, and vandalism incidences and infrastructure vulnerability outcomes. Qualitative methods were used to provide contextual explanations of these relationships by capturing stakeholder experiences and operational realities (Creswell & Plano Clark, 2018). The integration of both approaches enabled triangulation of findings and a more comprehensive understanding of the underlying socio-economic dynamics.

Study Area

The study was conducted in Kajiado County, located in southern Kenya as shown in Figure 2. The county is characterized by a semi-arid climate, high temperature variability, and increasingly erratic rainfall patterns consistent with observed national climate trends (Kenya Meteorological Department, 2024). It forms part of a critical corridor for Kenya's national electricity transmission network, connecting major generation and load centres. The area is also exposed to climate-related hazards such as flooding, soil erosion, and prolonged dry spells, which affect infrastructure stability and accessibility (Obuya et al., 2019; De Bruijn et al., 2017). These conditions make Kajiado County a suitable case for examining how climate and socio-economic stressors interact to shape electricity transmission resilience under real-world operational conditions.

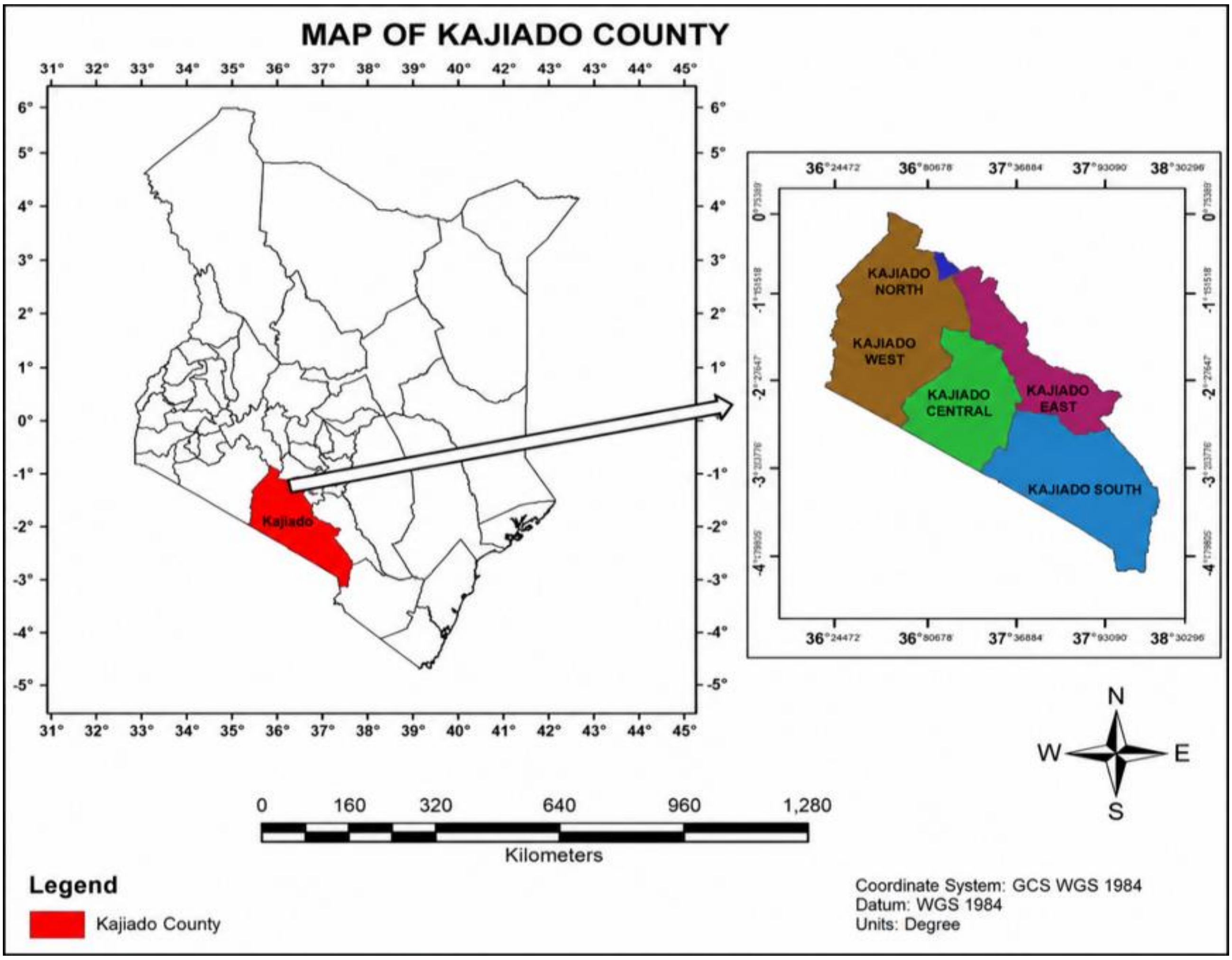

Figure 2: Map of Kajiado County

Source: Author, 2025

Data Collection Methods

Primary data were collected using a structured questionnaire administered to 87 electricity transmission experts, including engineers, environmental specialists, economists, and infrastructure planners. Respondents were selected through purposive sampling (Patton, 2015; Creswell & Creswell, 2018) based on direct professional involvement in transmission infrastructure planning, operation, or maintenance, ensuring that participants possessed sufficient technical and contextual knowledge of the factors under investigation. The questionnaire combined closed Likert-scale items capturing perceptions of socio-economic pressures, environmental exposure, and infrastructure resilience outcomes with open-ended items inviting respondents to elaborate on operational challenges and proposed interventions; responses to these open-ended items formed the primary data source for the thematic analysis reported in Section 4.3.3.

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To complement the quantitative findings, 10 Key Informant Interviews (KIIs) were conducted with purposively selected senior staff from the electricity transmission subsector occupying technical, planning, environmental safeguards, and operations and maintenance roles. Interviews continued until thematic saturation was achieved (Braun & Clarke, 2006; Guest et al., 2006), with each lasting approximately 30 minutes. The interview guide was developed from the study's conceptual framework and structured around the three dimensions of Resilience Theory (absorptive, adaptive, and transformative capacity) and the four socio-economic sub-dimensions of financial constraints, governance and stakeholder participation, social fragility and vandalism, and enabling institutional environments. Although the guide was not piloted, it was informed by the literature and administered to experienced professionals, with minor clarifications and follow-up probes used where necessary without altering its core structure. All interviews were conducted in English, with informed consent, transcribed verbatim, and analysed thematically to provide context for the quantitative findings and facilitate triangulation, thereby strengthening the credibility and depth of the study (Patton, 2015; Braun & Clarke, 2006).

Secondary data were obtained from authoritative sources including the Kenya Meteorological Department, World Bank databases, African Development Bank reports, and the Intergovernmental Panel on Climate Change (IPCC) (World Bank, 2021; IPCC, 2022).

Variables and Measurement

The classification of study variables into independent and dependent constructs is grounded in standard quantitative research design principles, where independent variables are treated as explanatory factors and the dependent variable as the outcome of interest (see Table 1). This approach enables systematic testing of hypothesized relationships between socio-economic drivers and infrastructure vulnerability outcomes, thereby improving analytical clarity and interpretability (Creswell & Creswell, 2018).

The use of socio-economic sub-dimensions such as social fragility, theft and vandalism, governance weaknesses, the climate-security nexus, and community enabling environment follows established vulnerability frameworks that recognize infrastructure risk as a function of interacting social, institutional, and environmental pressures (Ford et al., 2016). This multidimensional operationalization ensures that complex and interdependent drivers are adequately captured rather than reduced to a single aggregated construct.

Measuring all variables using a five-point Likert scale is also methodologically appropriate because it allows respondents to express varying degrees of perception intensity while maintaining simplicity and consistency across items. Likert-type scaling is widely used in infrastructure resilience and socio-economic vulnerability studies due to its suitability for capturing subjective assessments in a structured and comparable format (Joshi et al., 2015). In addition, Likert data produces ordinal-level measurements, which align with the use of non-parametric statistical techniques where assumptions of normality may not hold, thereby strengthening the robustness of subsequent inferential analysis.

Table 1: Operationalization of Resilience Theory Constructs in Study Variables

Socio-Economic Variable	Resilience Dimension	Theoretical Rationale
Financial constraints / maintenance funding	Absorptive capacity	Determines the system's immediate capacity to fund repairs and withstand disturbance without significant functional failure.
Stakeholder participation & public involvement	Adaptive capacity	Reflects the system's ability to incorporate community feedback and adjust operational responses to changing conditions.
Land-use pressures & corridor encroachment	Absorptive capacity	Influences the physical exposure of infrastructure to disturbance; effective land-use management reduces the frequency of damage events.
Vandalism & infrastructure-targeted crime	Absorptive capacity	Represents a direct threat to system integrity; resilience depends on the system's capacity to withstand and recover from such damage.
Governance coordination & institutional capacity	Transformative capacity	Captures the longer-term structural and institutional change required to durably reduce systemic vulnerability.

Indigenous knowledge integration	Adaptive / Transformative capacity	Supports both short-term adaptive responses and longer-term shifts in planning practice informed by local ecological knowledge.

Source: Authors' conceptualisation, based on Folke (2006).

Data Analysis

Quantitative data were analysed using ordinal regression and Spearman rank correlation, the latter selected in preference to Pearson correlation because it does not assume linearity or interval-level measurement, making it appropriate for the ordinal Likert-scale data collected in this study. Ordinal regression was selected because the dependent variable, infrastructure vulnerability/resilience, was measured on an ordinal five-point scale and did not satisfy the assumptions of normality required for parametric techniques, a departure from normality formally confirmed through the Kolmogorov–Smirnov and Shapiro–Wilk tests reported in Section 4.2.1. Prior to interpreting the regression coefficients, the proportional-odds (parallel lines) assumption was tested to confirm that the relationship between socio-economic factors and each cumulative threshold of the dependent variable was consistent across categories; overall model fit was further assessed using the –2 log-likelihood, model chi-square, and Akaike Information Criterion (AIC) statistics, reported alongside the regression estimates in Section 4.2. Spearman rank correlation was applied to assess the strength and direction of the monotonic association between socio-economic factors and infrastructure resilience, given the ordinal and non-normally distributed nature of both variables. This combination of fit and association statistics follows established practice for validating ordinal models of infrastructure resilience outcomes (Cutter et al., 2014).

Qualitative data obtained from the open-ended questionnaire items and key informant interviews were analyzed using thematic analysis following Braun and Clarke's (2006) framework, selected for its widely validated, systematic procedure for identifying and reporting patterns within qualitative data and applied here by working sequentially through its six phases: (1) familiarization with the data through repeated reading of transcripts and open-ended responses; (2) generation of initial codes capturing recurring concepts and concerns; (3) searching for candidate themes by collating related codes; (4) reviewing themes against the coded extracts and the dataset as a whole to ensure internal coherence; (5) defining and naming themes to capture their distinct contribution to the research questions; and (6) producing the final thematic report. Coding was undertaken using a structured coding approach that combined deductive codes derived a priori from the study's four socio-economic sub-dimensions with inductive codes generated directly from respondents' own language, an approach chosen to ensure the analysis remained grounded in the study's theoretical framework while still allowing unanticipated themes to emerge from the data, using a coding sheet aligned with the socio-economic sub-dimensions outlined in Section 2.2. The initial coding was conducted by the principal researcher and independently cross-checked by a second coder to enhance the credibility and consistency of the thematic analysis. Any discrepancies in coding or theme allocation were resolved through discussion and consensus, whereby the two coders jointly re-examined the relevant transcript or response against the coding sheet and the operational definition of the sub-dimension in question until agreement was reached on the appropriate code or theme. An inter-coder reliability statistic was not calculated, as the cross-checking process was intended to strengthen the trustworthiness and interpretive consistency of the analysis rather than to quantify coder agreement. The resulting themes were subsequently triangulated with the quantitative findings to strengthen the validity and overall robustness of the study's conclusions (Patton, 2015).

Ethical Considerations

The study ensured ethical compliance through informed consent, confidentiality of respondents, and voluntary participation, consistent with established principles for the ethical conduct of social science research (Patton, 2015). Respondents were briefed on the purpose of the study, the voluntary nature of participation, and their right to withdraw at any stage without consequence prior to providing consent. Data collected were used strictly for academic purposes. Respondents' identities were anonymized to ensure privacy and adherence to research ethical standards. Interview recordings and transcripts were stored securely and accessible only to the research team, in line with recommended practice for safeguarding qualitative data (Braun & Clarke, 2006).

RESULTS AND DISCUSSION

Spearman Correlation Analysis

To examine the relationship between socio-economic factors and climate change vulnerability of electricity transmission infrastructure in Kajiado County, a Spearman rank correlation analysis was conducted. Spearman rank correlation is widely used to assess monotonic relationships between variables measured on ordinal scales or when assumptions of normality and linearity are violated. This makes it particularly suitable for socio-economic and infrastructure resilience data that are often non-normally distributed (Conover, 1999; Field, 2018; Wisniewski & Brannan, 2024; Gibbons, 1993). This non-parametric test was therefore appropriate given the ordinal nature of the data and their non-normal distribution, a condition formally confirmed by the Kolmogorov–Smirnov and Shapiro–Wilk tests reported in Section 4.2.1 (Kvam et al., 2022). The results are presented in Table 2.

Table 2: Spearman Correlation between Socio-Economic Factors and Climate Change Resilience of Electricity Transmission Infrastructure in Kajiado County, Kenya

Variable	Resilience Correlation (ρ)	p-value	Interpretation
Socio-economic Factors	0.273	0.028	Statistically Significant

Source: Research Data, 2025.

As shown in Table 2, the Spearman correlation analysis reveals a positive correlation coefficient ($\rho = 0.273$) between socio-economic factors and infrastructure resilience. Although the magnitude of the correlation is moderate, the positive direction suggests that improvements in socio-economic conditions are associated with enhanced capacity of electricity transmission infrastructure to withstand, adapt to, and recover from climate-related stresses. This aligns with resilience theory, which conceptualizes infrastructure resilience as an emergent property shaped not only by physical exposure to hazards but also by the underlying socio-economic and institutional context in which systems operate (Folke, 2006; Cutter et al., 2008).

The statistically significant relationship ($p = 0.028 < 0.05$) indicates that the association is unlikely to have occurred by chance, thereby providing empirical support for rejecting the null hypothesis of no relationship between socio-economic factors and infrastructure resilience. However, the moderate strength of the correlation suggests that socio-economic factors are important but not exclusive determinants of resilience, implying the influence of additional drivers such as technical design standards, system redundancy, and environmental exposure characteristics.

These findings are consistent with empirical evidence from related studies. Obuya et al. (2019), in their analysis of infrastructure vulnerability in Kenya, similarly found that socio-economic conditions, including financial capacity, governance effectiveness, and settlement dynamics, play a more decisive role in shaping vulnerability outcomes than climate hazards alone. In a broader Sub-Saharan African context, Mensah and Adu (2022) observed that constraints in institutional capacity and investment financing significantly undermine climate resilience in the energy sector, often outweighing the direct effects of environmental stressors. This reinforces the interpretation that resilience is structurally mediated through socio-economic systems rather than determined solely by climatic exposure.

Comparable conclusions are drawn by Argyroudis et al. (2020), who emphasise that infrastructure resilience is strongly influenced by governance quality, maintenance regimes, and socio-economic stability, with these factors often acting as modifiers of physical hazard impacts. Similarly, Cutter et al. (2014) argue that place-based vulnerability is fundamentally shaped by social fragility and adaptive capacity, meaning that communities and systems with stronger socio-economic foundations are better positioned to absorb and recover from shocks.

More recent studies further reinforce this pattern. For instance, Henry et al. (2023) demonstrate that energy infrastructure resilience in developing regions is highly sensitive to institutional capacity and investment continuity, while physical climate stressors become more dominant only where socio-economic systems are already weakened. In addition, IPCC (2022) highlights that adaptive capacity largely driven by socio-economic development, governance quality, and institutional strength is a core determinant of system-level resilience across sectors, including energy transmission networks.

Overall, the convergence of evidence from both this study and the wider literature suggests that socio-economic strengthening is a critical pathway for enhancing the resilience of electricity transmission infrastructure. The moderate but significant correlation observed in Kajiado County therefore reflects a broader global and regional pattern in which resilience outcomes are co-produced by both socio-economic and environmental systems, rather than being driven by climate factors in isolation.

Socio-Economic Factors: Ordinal Regression Analysis and Diagnostic Tests

Building on the correlation analysis, an ordinal logistic regression model was estimated to assess the predictive influence of socio-economic factors on climate change resilience of electricity transmission infrastructure (Cutter et al., 2014). The results are presented in Table 3.

Table 3: Ordinal Regression Model for Socio-Economic Factors and Infrastructure Resilience

Predictor	B	Std. Error	Wald	df	Sig.	95% CI
Socio-economic Factors	0.594	0.298	3.973	1	0.046	0.010 – 1.178

Dependent variable: Climate change resilience (ordinal)

Nagelkerke $R^2 = 0.175$

Source: Research Data (2025)

The results indicate a positive and statistically significant relationship between socio-economic factors and infrastructure resilience ($\beta = 0.594$, $p = 0.046$). This suggests that improvements in socio-economic conditions are associated with higher levels of resilience in electricity transmission systems. The Wald statistic (3.973) confirms that the predictor contributes significantly to the model, while the 95% confidence interval (0.010–1.178), which does not include zero, further supports the robustness of this effect. Overall, the model explains 17.5% of the variation in resilience outcomes (Nagelkerke $R^2 = 0.175$), indicating a modest but meaningful explanatory power.

To ensure model validity, diagnostic tests were conducted as presented below.

Test of Normality

The distributional properties of the socio-economic variable were assessed using Kolmogorov–Smirnov and Shapiro–Wilk tests, applied jointly because the Kolmogorov–Smirnov test is sensitive to deviations across the full distribution while the Shapiro–Wilk test offers greater statistical power for the moderate sample size ($n = 86$) used in this analysis, providing a more robust basis for assessing normality than either test alone. As shown in Table 4, the variable significantly deviates from normality ($p < 0.05$), indicating non-Gaussian distribution.

Table 4.4: Test of Normality for Socio-Economic Factors

Variable	Kolmogorov-Smirnov Statistic	df	Sig.	Shapiro-Wilk Statistic	df	Sig.
Log_socio-economic factors	0.203	86	0.000	0.910	86	0.000

Source: Research Data (2024)

However, this does not violate the assumptions of ordinal logistic regression, which does not require predictor normality.

Model Fitting Information

Model fit was evaluated using the likelihood ratio test comparing the intercept-only model with the final model. As shown in Table 5, the inclusion of socio-economic factors significantly improves model fit.

Table 5: Model Fitting Information

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	355.731	0	0	0
Final Model	339.463	16.268	4	0.003

Link function: Logit

Source: Research Data (2025)

The significant chi-square statistic (p = 0.003) indicates that socio-economic factors significantly improve the explanatory power of the model compared to the null model, confirming their relevance in explaining resilience outcomes.

Goodness-of-Fit Test

Further evaluation using Pearson and Deviance statistics is presented in Table 6.

Table 6: Goodness-of-Fit Test

Model	Chi-Square	Df	Sig.
Pearson	792.661	846	0.905
Deviance	339.463	846	1.000

Source: Research Data (2025)

The non-significant results ($p > 0.05$) indicate no statistically significant difference between observed and predicted values, confirming that the model fits the data adequately without evidence of systematic misfit.

Overall, despite the non-normal distribution of the socio-economic variable, the ordinal logistic regression model is appropriate and statistically robust. The model demonstrates significant explanatory power and satisfactory goodness-of-fit, confirming that socio-economic factors are important determinants of climate change resilience in electricity transmission infrastructure.

These findings are consistent with Argyroudis et al. (2020), who emphasize that infrastructure resilience is shaped not only by physical exposure to hazards but also by governance and socio-economic systems that influence preparedness and recovery. The results also extend the work of Panteli and Mancarella (2017) by demonstrating that socio-economic constraints such as encroachment, vandalism, and institutional underfunding can significantly undermine even technically robust infrastructure systems.

Key Socio-Economic Factors

Financial Constraints as a Barrier to Infrastructure Resilience

Financial constraints identified in Kajiado County as a leading socio-economic driver of infrastructure vulnerability are strongly consistent with existing literature on energy infrastructure resilience. The finding that 54.5% of respondents view inadequate financial resources as a major limitation reflects a broader structural challenge in developing economies, where underfunding constrains both routine maintenance and long-term adaptation investments. This aligns with Mugambi et al. (2023), who show that budgetary limitations in Kenya’s energy sector reduce maintenance frequency and quality, increasing the likelihood of transmission failures.

More broadly, the results confirm that financial capacity is a critical determinant of infrastructure resilience, as emphasized in comparative studies. Ahern et al. (2022) argues that stable financing is essential for shifting infrastructure systems from reactive to preventive maintenance regimes, while Argyroudis et al. (2020) highlights financial capacity as a foundational enabler of risk-informed planning and climate adaptation. In the African energy context, Mensah and Adu (2022) further observe that financial constraints often outweigh climatic stressors in determining infrastructure performance outcomes. Collectively, these studies reinforce the present finding that limited financial resources significantly undermine resilience, positioning financing as a central bottleneck to strengthening electricity transmission infrastructure.

Public and Stakeholder Involvement in Resilience Planning

Public participation emerged as a significant socio-economic determinant of infrastructure resilience. A substantial majority of respondents (91%) indicated that public involvement and stakeholder engagement are essential for strengthening infrastructure resilience, reflecting strong awareness of its strategic importance. Additionally, 65% of respondents reported direct involvement in project planning processes, supporting the integration of indigenous knowledge and local insights into adaptation strategies. However, 19% indicated non-involvement and 16% expressed uncertainty about their participation, revealing persistent gaps in inclusive planning that may weaken resilience outcomes. These participation gaps align with findings from Abebe et al. (2023), who demonstrated that community exclusion from energy infrastructure governance in East Africa reduces the effectiveness of resilience interventions and increases vulnerability to both human-induced and climate-related disruptions.

Public Awareness Themes from Content Analysis

Content analysis of responses from 87 participants identified ten recurring thematic areas related to public awareness and stakeholder engagement in strengthening climate-resilient electricity transmission infrastructure. The frequency distribution of these themes is presented in Table 7 below.

Table 7: Thematic Distribution of Public Awareness Proposals from Stakeholder Responses (n = 87)

Theme	No. of Mentions	Frequency (%)	Description / Key Points
Environmental Impact Awareness	88	26%	Risks of deforestation, soil erosion, flooding, and terrain instability affecting infrastructure integrity.
Climate Change Awareness & Education	62	18%	Understanding climate-related hazards, mitigation approaches, and adaptation strategies to build community capacity.
Community Adaptation & Participation	55	16%	Local actions such as tree planting, erosion control, sustainable land use, and ecosystem stewardship.
Public Sensitization & Communication	50	15%	Use of community forums (barazas), radio, social media, and workshops to disseminate resilience information.
Early Warning & Disaster Preparedness	25	7%	Establishment of early warning systems and disaster preparedness drills to improve community readiness.
Behaviour Change & Ownership	20	6%	Encouraging responsible community conduct, including prevention of vandalism and timely reporting of infrastructure damage.
Training & Capacity Building	15	4%	Skills development in sustainable land management, erosion control, and community-level climate adaptation techniques.
Infrastructure Vulnerability Awareness	10	3%	Educating communities about risks including tower collapse, flood damage, and line failure under extreme conditions.
Indigenous Knowledge Integration	8	2%	Incorporating traditional ecological knowledge of weather and environmental patterns into resilience planning.

Theme	No. of Mentions	Frequency (%)	Description / Key Points
Practical Examples Communication	7	2%	Sharing local and global case studies illustrating climate risks and adaptation outcomes.

Source: Research Data, 2025.

The thematic findings in Table 7 show that Environmental Impact Awareness was the most frequently cited theme (26%; 88 mentions), with respondents mainly associating infrastructure vulnerability with deforestation, soil erosion, and flooding. This was followed by Climate Change Awareness and Education (18%; 62 mentions), Community Adaptation and Participation (16%; 55 mentions), and Public Sensitization and Communication (15%; 50 mentions), indicating that stakeholders predominantly interpret infrastructure vulnerability through observable environmental processes and awareness-related dimensions. Less frequently cited themes, Training and Capacity Building (4%), Infrastructure Vulnerability Awareness (3%), Indigenous Knowledge Integration (2%), and Practical Examples Communication (2%) suggest that deeper systemic and knowledge-based resilience enablers are comparatively under-emphasized in practice, despite their strong theoretical grounding. This is consistent with Nyong et al. (2007) and UNDRR (2022), who emphasize that indigenous and local knowledge systems significantly enhance the contextual relevance and effectiveness of climate adaptation and resilience planning.

When interpreted alongside the quantitative results, these qualitative findings provide important explanatory depth. The dominance of environmental awareness-related themes suggests that stakeholders primarily conceptualize vulnerability in biophysical terms, even though the regression results show that socio-economic factors exert a statistically significant influence on resilience outcomes ($\beta = 0.594$, $p = 0.046$). This aligns with Cutter et al. (2008), who argue in the social vulnerability framework that environmental hazards perceived often overshadow underlying social and institutional drivers, even though the latter are more structurally determinant of resilience outcomes. Similarly, Argyroudis et al. (2020) emphasize that governance quality, institutional capacity, and socio-economic conditions are often more decisive than hazard exposure in shaping infrastructure resilience, reinforcing the interpretation that socio-economic drivers may be under-recognized in stakeholder perceptions.

The relatively modest Spearman correlation ($\rho = 0.273$) can therefore be partially explained by this perceptual gap between environmental framing and socio-economic reality. While respondents strongly acknowledge participation-related factors reflected in Community Adaptation and Participation (16%) and Public Sensitization (15%) the low frequency of Training and Capacity Building (4%) and Indigenous Knowledge Integration (2%) points to implementation weaknesses in translating awareness into sustained capacity development. This is consistent with Reed et al. (2018), who highlight that effective stakeholder engagement must go beyond consultation to include continuous learning, capacity strengthening, and feedback loops to meaningfully enhance resilience outcomes.

Moreover, Cutter et al. (2014) and Folke (2006) argue that resilience is an emergent property shaped by adaptive capacity, institutional strength, and social learning processes rather than environmental awareness alone. The limited emphasis on capacity building and indigenous knowledge therefore suggests a structural disconnect between recognized resilience principles and their operationalization in transmission infrastructure governance. This is further supported by Obuya et al. (2019) and Mensah and Adu (2022), who show that in African energy systems, socio-economic constraints including institutional weakness and limited knowledge integration often outweigh climatic exposure in determining vulnerability outcomes.

Synthesis of Quantitative and Qualitative Findings

While ordinal regression and Spearman correlation analysis confirm the statistical significance of socio-economic factors ($p < 0.05$), the thematic analysis reveals an important disconnect between stakeholder perceptions and quantitative evidence. Respondents emphasize environmental awareness-related themes (44% of combined mentions), whereas the ordinal regression model identifies socio-economic constraints (financial, governance, participation) as statistically dominant predictors of resilience outcomes. This perceptual-empirical gap may reflect stakeholder cognitive biases toward visible, environmental hazards over structural socio-economic barriers that are less tangible but more determinant. Addressing this gap requires strengthening awareness campaigns that explicitly connect environmental management to governance and financing capacity, ensuring that interventions target the actual drivers of infrastructure vulnerability rather than those most salient to community perception.

CONCLUSION

The study set out to examine the socio-economic determinants of electricity transmission infrastructure vulnerability in Kajiado County, Kenya, within the framework of Resilience Theory. The findings demonstrate that socio-economic conditions are not peripheral influences but central and statistically significant determinants of infrastructure resilience outcomes. Financial constraints, governance weaknesses, limited stakeholder participation, and community-level pressures such as encroachment and vandalism emerged as the key mechanisms through which socio-economic vulnerability is transmitted into infrastructure performance outcomes. This aligns with resilience scholarship which emphasizes that infrastructure performance is shaped by interacting social, institutional, and technical systems rather than hazard exposure alone (Folke, 2006; Cutter et al., 2008; Argyroudis et al., 2020).

When interpreted through the three dimensions of Resilience Theory, the results show that absorptive capacity is constrained mainly by financial limitations and direct human pressures, adaptive capacity is shaped by the extent of stakeholder engagement and indigenous knowledge integration, and transformative capacity is influenced by institutional coordination and governance effectiveness. Similar interpretations are supported in the literature, where adaptive capacity is strongly linked to participation, knowledge systems, and learning processes (Reed et al., 2018; Nyong et al., 2007; UNDRR, 2022). The qualitative findings reinforce these relationships while also revealing a perceptual gap between high environmental awareness and comparatively weak emphasis on socio-economic drivers of resilience. Overall, the evidence confirms that infrastructure resilience in Kajiado County is fundamentally shaped by socio-economic conditions, consistent with findings in African energy systems where institutional and financial constraints often outweigh climatic exposure in determining outcomes (Mensah & Adu, 2022; Obuya et al., 2019).

However, the model explains a moderate proportion of variance (Nagelkerke $R^2 = 0.175$), suggesting the presence of additional influencing factors such as institutional depth, enforcement effectiveness, and the extent of indigenous knowledge integration. This is consistent with Cutter et al. (2014), who argue that resilience is an emergent property influenced by multiple interacting social and institutional dimensions not always fully captured in quantitative models. Notwithstanding this limitation, the study provides strong empirical evidence for integrating socio-economic considerations into electricity transmission planning and resilience policy, particularly in semi-arid and resource-constrained contexts where vulnerabilities are compounded.

RECOMMENDATIONS

Policymakers and energy sector stakeholders should prioritise sustained and predictable financing for transmission infrastructure maintenance, upgrades, and climate-resilient investments. Establishing dedicated budget lines for resilience will help shift infrastructure management from reactive maintenance to preventive and risk-informed planning. This responds directly to the finding that 54.5% of respondents identified financial constraints as a major barrier to resilience and is supported by literature showing that inadequate financing undermines infrastructure reliability and increases lifecycle risk (World Bank, 2021; Ahern et al., 2022; Mugambi et al., 2023).

Community engagement and public awareness programs should be strengthened along transmission corridors to reduce risks associated with encroachment, vandalism, and unsafe land-use practices. These programs should integrate indigenous knowledge systems and utilize accessible communication platforms such as community forums and local media. This recommendation reflects both the high importance placed on participation by respondents (91%) and the low representation of indigenous knowledge integration (2%), consistent with evidence that local knowledge and participation improve adaptation outcomes and resilience effectiveness (Nyong et al., 2007; Reed et al., 2018; UNDRR, 2022).

Intergovernmental coordination between national and county governments should be enhanced to ensure strict enforcement of wayleave protection and improved regulation of land use near transmission infrastructure. Collaborative governance involving utilities, regulators, and local communities is essential to address institutional fragmentation and reduce infrastructure exposure to socio-economic risks. This aligns with Argyroudis et al. (2020), who emphasize that governance quality and institutional coordination are critical determinants of infrastructure resilience.

Finally, socio-economic impact assessments should be fully integrated into infrastructure planning and resilience frameworks. This will ensure that investment decisions systematically account for financial, institutional, and community-level conditions that shape long-term infrastructure sustainability. This recommendation is consistent with Cutter et al. (2008) and IPCC (2022), who highlight that vulnerability and resilience assessments must embed socio-economic dimensions to accurately reflect real-world risk and adaptive capacity.

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