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Comparing forest policy outcomes and plantation investment across East Africa

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Abstract

National participatory forest policies have been widely adopted across East Africa to combat deforestation and empower local communities. However, empirical assessments reveal profoundly heterogeneous outcomes. This study conducted a quantitative comparative analysis of forest cover outcomes associated with major policy implementations in Tanzania (2002), Uganda (2003), Kenya (2005), and Rwanda (2011). Using a balanced panel dataset (FAO FRA 1990–2025) and fixed-effects regression with bootstrap inference, we examined the association between implementation strategy, specifically the scale of state-led plantation investment and divergent forest cover outcomes. Rwanda's policy was associated with a significant net forest cover gain of 6.04 percentage points, whereas Uganda experienced a significant loss of 6.89 percentage points and Tanzania a loss of 7.10 percentage points. Kenya's policy showed no statistically significant effect (estimated change = +0.05 percentage points, 95% CI −0.52 to +0.57). A fixed-effects panel regression identified a significant positive interaction ($\beta = 0.181$, $p < 0.01$) between post-policy status and plantation share, suggesting the policy-outcome association varies with investment intensity. High plantation investment appears to create enabling conditions for participatory models to succeed. We conclude that translating participatory designs into positive outcomes is fundamentally linked to the scale of complementary resource commitment. Our analysis reveals that participatory policies without substantial complementary investment are associated with continued forest loss, while those coupled with high plantation investment (as in Rwanda) show significant gains. These findings suggest an association between implementation intensity and forest policy outcomes in East Africa; however, causality cannot be established from this observational study.

Keywords: Participatory forest management, Forest policy implementation, East Africa, Forest cover change, Plantation investment

1 Introduction

Forests are a cornerstone of global environmental sustainability, providing critical ecosystem services, supporting biodiversity, and playing a pivotal role in climate change mitigation [15, 35]. According to the latest FAO Global Forest Resources Assessment [15], the world retains 4.14 billion hectares of forests covering approximately 32% of Earth's land area, storing an estimated 714 billion tonnes of carbon [15]. While global net forest loss has declined encouragingly from 10.7 million hectares annually in the 1990s

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to 4.12 million hectares annually in 2015–2025, regional disparities persist. The situation remains most acute in Africa, which contains 16% of global forests but experienced the second-highest rate of net forest loss worldwide from 2010 to 2020 [32]. This crisis is particularly severe in East Africa, where nations like Uganda lost nearly half its forest cover between 1990 and 2015, plummeting from 24 to 12.4% of its land area, and current deforestation trajectories in Tanzania project complete forest loss within decades [32, 45]. This rampant deforestation, driven by agricultural expansion, wood harvesting, and overlapping land rights [7], is associated with the undermining of climate resilience, biodiversity, and the livelihoods of millions who depend on forest resources [43].

In response to these escalating pressures, East African nations have widely embraced decentralized forest governance reforms by enacting major national forest policies grounded in participatory governance. Over two decades, Kenya, Rwanda, Tanzania, and Uganda have each launched flagship reforms: Tanzania's National Forest Policy (2002), Uganda's National Forestry Policy (2003), Kenya's Forest Policy (2005), and Rwanda's National Forest Policy (2011). These policies share a common theoretical foundation, promoting Participatory Forest Management (PFM), Community Forest Associations (CFAs), and similar frameworks that devolve management rights to local communities [8, 26]. This represents a significant, coordinated shift in environmental governance across the region, moving from state-centric models towards more inclusive, community-based management intended to incentivize sustainable stewardship and improve livelihoods [18].

Extensive research has shown that the outcomes of these participatory reforms are characterized by profound and puzzling heterogeneity [8, 20, 31]. Although policy documents reflect comparable ambitions, empirical evidence consistently uncovers a notable contradiction. While some cases, like the Duru–Haitemba forest in Tanzania, are cited as successes [43], many more studies report policy failure, continued degradation, elite capture, and incomplete devolution [27, 42]. For instance, assessments indicate that decentralization reforms in Kenya and Uganda have yielded limited livelihood benefits and mixed impacts on forest conditions [31, 32], while in Tanzania, reforms have coincided with ongoing high deforestation rates [8]. This suggests a critical disconnect: the mere adoption of a participatory policy framework is an insufficient condition for success.

The central, unresolved question is why these four contemporaneous policies have produced such divergent trajectories. Previous studies have often suffered from a focus on single-country analyses or theoretical critiques [20, 34], with fewer systematic, quantitative comparisons that empirically link national outcomes to specific, measurable implementation variables. What is less clear are the concrete implementation drivers such as the scale of complementary investment, enforcement capacity, or specific governance arrangements that can robustly explain why Rwanda's 2011 policy is frequently noted as a potential success story against a backdrop of regional struggle [29, 32].

Emerging from implementation theory [19, 39] is the resource-commitment hypothesis, which posits that the scale of complementary investment and material support is a critical moderator of policy success. Applied to participatory forestry, successful local institutions may require not only autonomy but also substantial external support [18]. This hypothesis finds indirect support in descriptive accounts linking Rwanda's

outcomes to its "aggressive plantation strategy" [32] and recent studies documenting Rwanda's extensive plantation establishment and nationwide agroforestry campaigns [9, 29]. However, this remains a suggestive rather than a tested proposition in comparative quantitative frameworks.

To address this evidence gap, this study conducted the first quantitative, cross-national panel analysis comparing forest cover outcomes associated with the major participatory forest policies in Tanzania (2002), Uganda (2003), Kenya (2005), and Rwanda (2011). We hypothesized that the effect of participatory forest policies on forest cover would be positively associated with the scale of complementary plantation investment.

We recognize that alternative explanations for divergent forest outcomes exist, including biophysical conditions (e.g., rainfall variability, soil fertility, topography) and political economy factors (e.g., state capacity, governance quality, elite capture). Our analysis focuses on investment intensity while acknowledging these as important limitations.

The aims of this study were threefold: first, to quantify the magnitude and statistical significance of forest cover changes following major national forest policy implementations; second, to systematically compare these outcomes to assess Rwanda's performance as a potential positive outlier; and third, to empirically test whether variation in implementation strategy specifically the scale of state-led plantation investment is associated with these divergent policy outcomes.

This work contributes new insights into the critical link between participatory policy design, implementation intensity, and environmental outcomes. It is the first study to directly compare the quantitative forest cover outcomes of these four policies within a unified analytical framework. The findings would make an important contribution to the fields of forest policy and environmental governance by moving beyond documenting heterogeneity to identifying a plausible, quantifiable mechanism for success. The specific knowledge gap this research addresses is the lack of quantitative, cross-national evidence linking participatory policy adoption to measurable forest cover outcomes while testing a specific implementation mechanism. This study contributes by providing the first quantitative test of the resource-commitment hypothesis across the four East African cases, while acknowledging that observational data limit causal claims.

2 Literature review

2.1 Theoretical context

Forest governance has shifted globally from centralized control toward decentralized, participatory models. Grounded in theories of democratic decentralization and common-pool resource management, this shift posits that transferring authority to local levels enhances sustainability by incorporating local knowledge and fostering stewardship [25, 36]. In East Africa, this paradigm materialized through national policies promoting Participatory Forest Management (PFM) and Community Forest Associations (CFAs) [8, 18].

2.2 The implementation challenge

The translation of policy intent into positive outcomes is notoriously complex. Implementation theory argues that this process depends on a "complex chain of reciprocal interactions" among multiple actors, leading to a pervasive "policy-implementation gap"

[19, 39]. Applied to natural resources, successful decentralization depends not only on legal frameworks but also on government commitment, local capacity building, and resolution of tenure conflicts [4, 24].

2.3 Heterogeneous outcomes in East Africa

Empirical evidence reveals persistent high deforestation rates despite reforms. Uganda's forest cover plummeted from 24 to 12.4% of land area between 1990 and 2015, while Tanzania's deforestation trajectories project complete forest loss within decades [32]. Studies identify recurring problems: elite capture, incomplete devolution, weak enforcement, and high transaction costs [7, 27, 28]. In contrast, Rwanda has emerged as a positive outlier, achieving significant net forest cover gains post-2011 through an aggressive, state-coordinated strategy involving large-scale restoration and nationwide agroforestry campaigns [29, 33].

2.4 Explaining divergence

2.4.1 Institutional design and political economy

Outcomes hinge on the specific powers transferred and downward accountability of local actors [3, 25]. Legal frameworks often stop short of full devolution, transferring responsibilities without adequate rights or resources [26]. Forest outcomes are also shaped by power struggles among state, business, and community actors [20, 34].

2.4.2 The resource-commitment hypothesis

The scale of complementary investment and material support is a critical moderator of policy success. Execution depends on adequate financial, technical, and human resources [19, 39]. Applied to participatory forestry, successful local institutions may require substantial external support [12, 18]. Mwangi et al. [32] descriptively link Rwanda's outcomes to its "aggressive plantation strategy." However, this hypothesis remains largely untested in comparative quantitative frameworks.

2.4.3 Biophysical and environmental determinants

Beyond governance factors, biophysical conditions influence forest cover change. Topography, soil fertility, rainfall variability, and population pressure significantly affect deforestation and regeneration [38, 40, 45]. Rwanda's favorable rainfall patterns and volcanic soils could contribute to its forest recovery independently of plantation investment. Our analysis does not include these variables due to sample size constraints (see Sect. 3.5).

3 Research gap

The literature converges on two major limitations. First, there is a persistent methodological disconnect: few studies systematically link national policy interventions to quantitative ecological outcomes across multiple countries using robust causal inference methods [14, 20]. Second, the resource-commitment hypothesis remains speculative and untested. No study has:

- Operationalized resource commitment using a consistent, measurable proxy (e.g., national plantation share)

- Empirically tested its interaction with the adoption of national PFM policy across core East African cases
- Quantified whether this implementation variable explains the stark divergence between Rwanda's success and its neighbors' struggles

This study addresses this gap by testing whether variation in implementation strategy specifically the scale of complementary state-led plantation investment is associated with divergent forest cover outcomes.

4 Methods

4.1 Study area and country context

The study focused on four East African countries: Kenya, Rwanda, Tanzania, and Uganda. These countries shared several similarities: all were located in the East African region, had experienced significant deforestation over recent decades, and had adopted national participatory forest policies between 2002 and 2011. However, they differed substantially in baseline forest cover, political systems, state capacity, and implementation approaches. Tanzania had the highest initial forest cover (approximately 60% in 1990) but experienced persistent decline; Uganda lost nearly half its forest cover between 1990 and 2015; Kenya maintained low forest cover (around 6–7%) throughout the period; and Rwanda, with relatively modest initial cover (approximately 17% in 1990), showed notable recovery post-2011. Politically, Rwanda operated under a highly centralized governance system with strong state capacity, while Tanzania, Uganda, and Kenya had more decentralized or fragmented political landscapes. These contextual differences were important for interpreting our findings, as discussed in Sect. 5.

5 Research design and data

This study used a quantitative comparative longitudinal design to analyze the associations between participatory forest policies and forest cover outcomes across four East African countries. The methodological approach combined descriptive trend analysis, non-parametric statistical testing (bootstrap inference), and fixed-effects panel regression models to estimate associations while controlling for time-invariant country characteristics.

This study utilized secondary data on forest cover and composition from the Food and Agriculture Organization (FAO) of the United Nations, Forest Resource Assessment (FRA FAO, [15]). Released in October 2025, FRA 2025 represented the most comprehensive worldwide evaluation of forest resources, covering trends from 1990 to 2025 based on official national data from 236 countries and areas. The dataset provided standardized measures of forest area, type, and change over time, enabling cross-national comparison of forest outcomes in East Africa. The FRA data were publicly accessible at: http://www.fao.org/forest-resources-assessment. The analysis focused on four East African countries; Kenya, Rwanda, Uganda, and Tanzania with data extracted at six time points (1990, 2000, 2010, 2015, 2020, 2025), creating a balanced panel dataset of 24 country-year observations. National policy implementation years were determined through systematic review of legislative documents and policy evaluation reports.

The selection of these countries was based on their shared adoption of participatory forest management frameworks but divergent implementation approaches. All countries in the region that had implemented national participatory forest policies by 2011 were included to ensure comprehensive regional coverage. The time frame was selected to provide sufficient pre- and post-policy observations for meaningful trend analysis.

5.1 Variable definitions and measurement

The core variables used in the analysis are defined in Table 1. These variables were selected to capture both outcome measures (forest cover) and key explanatory factors (policy status and implementation intensity). The plantation share variable was particularly important as it operationalized the hypothesis that implementation strategy, specifically investment in plantation forestry, moderated policy effectiveness.

The Plantation Share was operationalized as the time-invariant mean for each country across all six observation years (1990, 2000, 2010, 2015, 2020, 2025). This measure captured the country's enduring strategic emphasis on plantation forestry as a proxy for sustained investment intensity over the 35-year study period.

The plantation share variable (PLANT_i) served as our proxy for the scale of state-led complementary investment in forest restoration, a key implementation factor hypothesized in the literature [18, 32]. We operationalized it as the country mean percentage of total forest area composed of planted forests. This measure captured the structural emphasis on investment in forest capital over the study period and reflected enduring strategic differences in implementation intensity. While time-varying financial data would have been ideal, consistent annual investment figures were unavailable across all four countries for the full 35-year period. The mean plantation share was a defensible proxy: it was a consistent, measurable outcome of sustained investment and material commitment, effectively distinguishing high-investment (Rwanda) from low-investment strategies (Tanzania, Uganda, Kenya) [29].

Table 1 Variable definitions and measurement

Variable	Measurement	Source
Dependent variable		
Forest cover	Percentage of total land area covered by forest (natural and planted)	FAO FRA 2025
Independent variables		
Post-policy indicator	Binary variable: 1 for years after policy implementation, 0 otherwise	National Policy Documents
Plantation share	Percentage of total forest area composed of planted forests (country mean over the study period 1990–2025)	FAO FRA 2025
Policy-plantation interaction	Interaction term (post-policy × plantation share) testing moderation effect	Constructed
Control variables		
Country fixed effects	Dummy variables capturing time-invariant country characteristics	Constructed
Year fixed effects	Dummy variables capturing common temporal shocks	Constructed

The share of plantation area represented a structural outcome of long-term investment strategy and was less volatile than annual budget allocations, making it a stable proxy for a country's enduring commitment to forest capital investment [22, 41].

5.2 Analytical strategy

5.2.1 Descriptive and trend analysis

The first stage involved descriptive analysis to document the magnitude and direction of forest cover changes. For each country, pre- and post-policy average forest cover was calculated. The pre-policy average was computed as the mean of all observations before the policy year, while the post-policy average was the mean of all observations from the policy year onward.

This calculation can be represented as:

Pre-policy average: $\overline{FC}_{pre} = \frac{1}{T_{pre}} \sum_{t=1}^{T_{pre}} FC_{it}$

Post-policy average: $\overline{FC}_{post} = \frac{1}{T_{post}} \sum_{t=T_{pre+1}}^{T} FC_{it}$where:

FC_{it} = Forest cover for country i at time t

T_{pre} = Number of observation years before the policy

T_{post} = Number of observation years after the policy

T = Total number of observations

The net change in forest cover attributable to the policy was then computed as:

$\Delta FC = \overline{FC}_{\text{post}} - \overline{FC}_{\text{pre}}$. This simple difference in means provided the initial measure of policy impact.

To compare trends more precisely, annualized growth rates were calculated. This metric standardized the rate of change per year, allowing for comparison between countries with different baseline forest cover and different policy timelines.

The growth rate between any two time points was calculated as:

$$g = \frac{FC_{t2} - FC_{t1}}{t_2 - t_1}$$

where:

g = Annual growth rate (percentage points per year)

FC_{t2} = Forest cover at the end of the period

FC_{t1} = Forest cover at the start of the period

$t_2 - t_1$ = Number of years in the period

Separate growth rates were computed for:

- The overall study period (1990–2025)
- The pre-policy period
- The post-policy period

This approach was adopted because annualized growth rates provided a standardized metric that was independent of a country's initial forest cover, enabling a direct comparison of trajectory steepness between countries like Tanzania (high initial cover) and Kenya (low initial cover).

5.2.2 Statistical significance testing

Given the small sample size (six observations per country), conventional parametric tests were deemed inappropriate. Instead, a non-parametric bootstrapping procedure was employed with 1000 replications to generate robust confidence intervals. The bootstrap algorithm proceeded as follows: for each country, observations were resampled with replacement; the policy effect $\widehat{\theta_b^*} = \overline{FC^*}_{\text{post,b}} - \overline{FC^*}_{\text{pre,b}}$ was calculated for each bootstrap sample b = 1,...,1000b = 1,...,1000; and 95% confidence intervals were constructed using the percentile method: $[\theta_{2.5\%}, \theta_{97.5\%}]$.

Statistical significance was determined by whether the confidence interval excluded zero. This method was selected for its advantages in small-sample inference without requiring normality assumptions. The boot package in R was utilized to implement the procedure with seed set to 123 for reproducibility.

5.2.3 Econometric analysis: fixed-effects panel models

To test the hypothesis that implementation strategy was associated with divergent outcomes, three fixed-effects panel models were specified and estimated. Fixed-effects models were chosen to control for time-invariant unobserved heterogeneity at the country level, addressing potential omitted variable bias. Fixed-effects models, developed by econometricians including Mundlak [30] and Hausman [17], are standard in panel data analysis for controlling time-invariant unobserved heterogeneity.

A key assumption of fixed-effects models in policy evaluation contexts is the parallel trends assumption: in the absence of the policy, forest cover trends in each country would have evolved similarly to their own pre-policy trajectories. We could not formally test this assumption due to the limited number of pre-policy observations (2–3 time points per country). Visual inspection of Fig. 1 showed relatively stable pre-policy trajectories for Rwanda (flat), Uganda (steady decline), Tanzania (steady decline), and Kenya (flat low). However, this visual evidence did not rule out divergence in the absence of policy. The estimated policy associations were interpreted as correlational, not causal.

Model 1: two-way fixed effects

This baseline model was specified as:

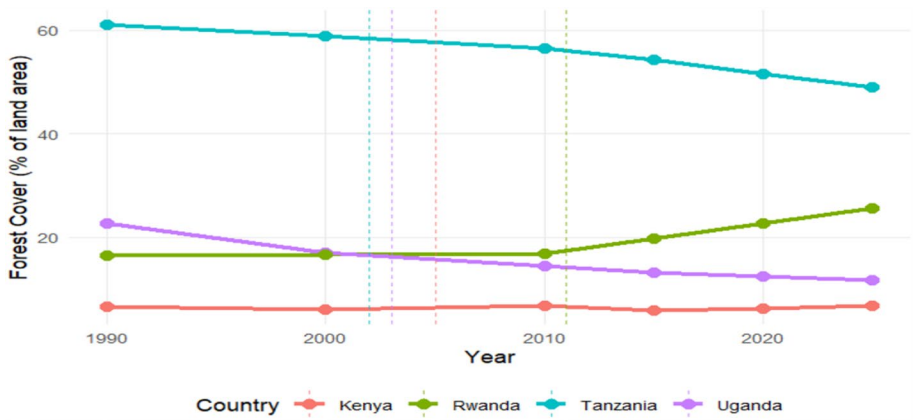

Fig. 1 Forest cover trends (1990–2025) for Kenya, Rwanda, Tanzania, and Uganda. Vertical dashed lines indicate national PFM policy implementation years. [15] Source: FAO FRA

$$FC_{it} = \alpha_i + \gamma_t + \beta_i POST_{it} + \varepsilon_i$$

Where α_i represents country fixed effects, γ_t represents year fixed effects, $POST_{it}$ is the post-policy indicator, and ε_i is the error term. This model provided an estimate of the average policy association across all countries after controlling for time-invariant country characteristics and common temporal trends.

Model 2: plantation interaction model

To test the moderation hypothesis, the model was specified as:

$$FC_{it} = \alpha_i + \beta_1 POST_{it} + \beta_2 (POST_{it} \times PLANT_i) + \varepsilon_i$$

where $PLANT_i$ is the time-invariant mean plantation share for country i*i*, and the interaction term $POST_{it} \times PLANT_i$ tests whether policy effectiveness depends on plantation investment levels. The coefficient β_2 captures the marginal effect of plantation investment on policy effectiveness. Marginal effects were calculated as $\frac{\partial FC}{\partial POST} = \beta_1 + \beta_2 \times PLANT_i$ at observed plantation shares.

Note that the moderator, $PLANT_i$ is a time-invariant country mean. In a fixed-effects specification, such time-invariant characteristics are absorbed by the country fixed effects α_i. However, the interaction term $POST_{it} \times PLANT_i$ remains identified because the post-policy indicator varies over time. This interaction directly tests our hypothesis that the effect of the policy depends on the country's level of plantation investment.

Model 3: country-specific effects model

To estimate heterogeneous treatment effects, the model was specified as:

$$FC_{it} = \beta_0 + \beta_1 (RWA_i \times POST_{it}) + \beta_2 (TZA_i \times POST_{it}) + \beta_3 (UGA_i \times POST_{it}) + \varepsilon_i$$

Where RWA_i, TZA_i, and UGA_i are country indicators, and Kenya serves as the reference category. This specification allows for differential policy effects across countries while maintaining a unified modeling framework.

The primary threat to causal inference in our cross-country comparison was omitted variable bias. Countries differed in countless ways that affected forest cover (e.g., baseline institutional quality, predominant agro-ecological zones, population density trends, or long-standing land tenure systems). A pooled OLS or random-effects model would have produced biased estimates if these unobserved factors were correlated with our key variables; policy adoption and plantation investment.

The choice of a fixed-effects panel model was driven by the need to control for unobserved time-invariant heterogeneity across countries (e.g., historical institutional legacies, permanent geographical features). This estimator leveraged within-country variation over time, allowing us to estimate the association between policy adoption and forest cover by comparing each country to itself before and after the intervention. The use of fixed effects over a random-effects specification was validated using a Hausman test ($p < 0.05$), which rejected the hypothesis that country-specific effects were uncorrelated with the regressors, supporting our modeling choice for estimating these associations.

All models were estimated using ordinary least squares (OLS) with robust standard errors clustered at the country level. Model fit was assessed using R^2, within R^2 for fixed

effects models, and root mean square error (RMSE). The fixest package in R was utilized for estimation due to its computational efficiency and robust standard error options.

The statistical power of our panel analysis was constrained by the small number of temporal observations (N = 24; 4 countries × 6 time points). While this limited the complexity of the models we could estimate, the fixed-effects estimator remained appropriate as it relied on within-country variation over time to identify the policy association. With six observations per country spanning 35 years, we obtained a meaningful basis for comparing pre- and post-policy trajectories. To address inferential concerns arising from the small sample, we employed bootstrap procedures for our primary estimates and conducted extensive robustness checks, including leave-one-out analysis and placebo tests. This multi-pronged approach strengthened confidence in the observed patterns, consistent with recommendations for small-N comparative policy analysis [10].

The high R^2 values observed in our models (0.975–0.985) should be interpreted cautiously. With only 24 observations and a small number of parameters, these values may reflect overfitting rather than genuine explanatory power. We treated our findings as hypothesis-generating and illustrative, requiring replication with larger samples. Our leave-one-out analysis (Table 6) provided some indication of stability, but out-of-sample validation was not possible with this dataset.

5.2.4 Robustness checks and sensitivity analysis

To assess the robustness of the findings, multiple supplementary analyses were conducted. A leave-one-out sensitivity analysis was performed by systematically excluding each country and recalculating the average policy effect:$\bar{\theta}_{-j} = \frac{1}{N-1}\sum_{i \neq j}\bar{\theta}_i$ where $\bar{\theta}_i$ is the estimated effect for country *i*.

A placebo test was implemented for Rwanda by assigning 100 false policy years $\tau_f \in [1995, 2020]$ and estimating placebo effects $\bar{\theta}_{\tau_f}^{placebo}$. The p-value was calculated as $P = \frac{1}{100}\sum_{f=1}^{100} \| \left(\left| \hat{\theta}_{\tau_f}^{placebo} \right| \geq \left| \hat{\theta}^{true} \right| \right)$ where $\| (\cdot)$ is the indicator function.

Cross-sectional validation was conducted by regressing country-level policy effects on mean plantation shares: $\widehat{\theta}_i = \alpha_0 + \alpha_1 \overline{PLANT}_i + \nu_i$. This provided independent verification of the relationship identified in the panel models.

5.3 Methodological limitations

Several limitations should be acknowledged in interpreting the results. The small sample size (six observations per country) limited statistical power despite bootstrap corrections. Future research with longer time series would allow for more precise estimation of policy associations and better testing of parallel trends assumptions.

The time-invariant measurement of plantation share represented another limitation, as it did not capture dynamic changes in plantation investment over time. This simplification was necessary due to data constraints but may obscure important temporal variations in implementation intensity.

Omitted variables posed a potential threat to causal inference, as unobserved time-varying factors could influence both plantation investment decisions and forest outcomes. While fixed-effects models controlled for time-invariant confounders, they could not address all sources of endogeneity.

The causal interpretation of interaction effects relied on the assumption that plantation investment modified policy associations rather than merely correlating with other success factors. Despite these limitations, the methodological approach offered important advantages through its multiple estimation strategies and comprehensive robustness checks, providing a rigorous foundation for policy-relevant conclusions.

Additionally, while our fixed-effects approach controlled for time-invariant country characteristics, we could not fully rule out reverse causality: countries with greater state capacity or political commitment to forest conservation might be more likely to both invest in plantations and implement participatory policies effectively. Future research using instrumental variables or natural experiments could help disentangle these relationships.

A significant limitation was the omission of biophysical and environmental covariates that influence forest cover change, including topography (slope, elevation), soil fertility, rainfall variability, drought frequency, flood regimes, agro-ecological zones, and population density/pressure. These factors were not included due to the small sample size (which precluded additional parameters without overfitting) and the lack of consistent, comparable time-series data across all four countries for the full study period. For example, Rwanda's favorable rainfall patterns and volcanic soils could contribute to its forest recovery independently of plantation investment. Future research with larger samples or subnational data should incorporate these variables to isolate policy associations from environmental determinants.

Furthermore, our analysis used forest cover percentage as the primary outcome, which did not capture forest quality, biodiversity, or ecosystem service provision. Future research should incorporate these multidimensional measures of forest health.

6 Results

6.1 Descriptive trends in forest cover change

The first set of analyses aimed to quantify the magnitude of forest cover changes following major national policy implementations. As shown in Table 2, the results reveal a dramatic divergence. What stands out in this table is the difference between Rwanda's substantial net gain of 6.04 percentage points (+36.10%) and the significant losses experienced by Uganda (− 6.89 pp) and Tanzania (− 7.10 pp). Kenya showed minimal net change. It is apparent from this table that Rwanda's exceptionally high mean plantation share (61.90%) coincides with its positive outcome, while the other three countries, with shares below 14%, experienced neutral or negative trends.

Table 2 Forest cover change before and after policy implementation

Country	Policy year	Pre-policy avg (%)	Post-policy avg (%)	Net change (pp)	Percent change	Mean planted share (%)
Rwanda	2011	16.73	22.77	+6.04	+36.10	61.90
Kenya	2005	6.40	6.45	+0.05	+0.74	4.12
Uganda	2003	19.89	13.00	− 6.89	− 34.65	13.35
Tanzania	2002	59.98	52.87	− 7.10	− 11.84	1.13

pp percentage points

Table 3 Annual forest cover growth rates by period

Country	Policy year	Overall rate	Pre-policy rate	Post-policy rate	Growth change
Rwanda	2011	+0.261	+0.014	+0.590	+0.576
Kenya	2005	+0.001	− 0.061	− 0.005	+0.056
Uganda	2003	− 0.313	− 0.574	− 0.177	+0.397
Tanzania	2002	− 0.346	− 0.227	− 0.504	− 0.277

Table 4 Bootstrapped 95% confidence intervals for policy effects

Country	Estimate	95% CI lower	95% CI upper	Significant
Rwanda	+6.040	+3.055	+8.990	Yes
Uganda	− 6.892	− 10.280	−3.340	Yes
Tanzania	− 7.102	−10.597	−3.718	Yes
Kenya	+0.048	−0.516	+0.569	No

To compare the difference in trajectories more precisely, annualized growth rates were examined (Table 3).

Figure 1 provides an overview of forest cover trends in East Africa from 1990 to 2025, illustrating the divergent trajectories among Kenya, Rwanda, Tanzania, and Uganda. As shown in the figure, the dashed lines mark each country's primary forest policy implementation year (2002 for Tanzania, 2003 for Uganda, 2005 for Kenya, and 2011 for Rwanda).

From the graph, we can see that Rwanda's forest cover-initially stable-began a clear upward trend following its 2011 policy. In contrast, Uganda and Tanzania show persistent declines both before and after their respective policy implementations, while Kenya's forest cover remained low and largely unchanged throughout the period.

The most striking result from Table 3 is that Rwanda's growth rate accelerated dramatically from + 0.014% to + 0.590% annually after its policy, a 41-fold increase. In contrast, there is a clear trend of decreasing growth in Tanzania, where the annual decline worsened from − 0.227% to − 0.504%. This is a significant outcome, as it suggests policy interventions did not simply coincide with, but may be actively associated with these divergent growth paths. The stark contrast between Rwanda's success and the continued challenges in neighboring countries highlights the inadequacy of a one-size-fits-all explanation for forest policy outcomes.

6.2 Statistical significance of policy effects

Given the constraints of small sample sizes (six observations per country), a non-parametric bootstrapping procedure with 1000 replications was employed to generate robust confidence intervals for the estimated policy effects. The results obtained from this analysis are presented in Table 4.

This table is quite revealing in several ways. First, it confirms with high confidence that Rwanda's positive effect is statistically significant (95% CI + 3.055 to + 8.990). Second, the substantial losses in Uganda and Tanzania are also statistically significant. Third, Kenya's near-zero effect is not statistically significant, as its confidence interval includes

zero. There was no evidence that the policy in Kenya had a measurable impact, positive or negative, within the study period. These findings solidify the descriptive results, confirming that the observed changes are unlikely to be due to random variation and warrant a search for potential drivers.

Figure 2 brings the analysis to life by showing the wide gap between national outcomes in net forest cover change post-policy.

As can be seen from the chart, Rwanda stands out with a substantial + 6.0 percentage point net gain. In sharp contrast, both Uganda and Tanzania experienced significant net losses, with − 6.9 and − 7.1 percentage points, respectively. Kenya's bar shows a near-zero change, indicating no significant net impact from its policy.

Figure 2 visually confirms the central finding that, despite similar policy ambitions across the region, the results are profoundly heterogeneous, with Rwanda's performance being a clear positive outlier.

6.3 Econometric analysis: testing the role of implementation

To distinguish between possible explanations for heterogeneity, regression analysis was used to predict forest cover based on policy status and implementation factors. Three fixed-effects panel models were estimated, and the results are set out in Table 5. The most striking result to emerge from the data is the significant interaction effect in Model 2. A positive correlation was found between the Post-Policy × Plantation Share interaction term and forest cover (coefficient = 0.181, $p < 0.01$). This indicates that the policy's effect is not uniform but varies with the level of plantation investment.

As shown in Table 5, this association suggests a plausible mechanism for the observed national differences. The model indicates that the standalone indicator of a participatory policy (the negative coefficient on Post-Policy) may be associated with ineffectiveness or even counterproductive outcomes when considered without substantial complementary investment. This finding shifts analytical focus from the formal design of participatory policy to the substantive strategy of its implementation. For example, the marginal association for Rwanda (62% plantation share) is + 5.60 percentage points, while for Tanzania (1% share) it is − 5.42 percentage points. This result suggests-but does not demonstrate-that high levels of plantation investment

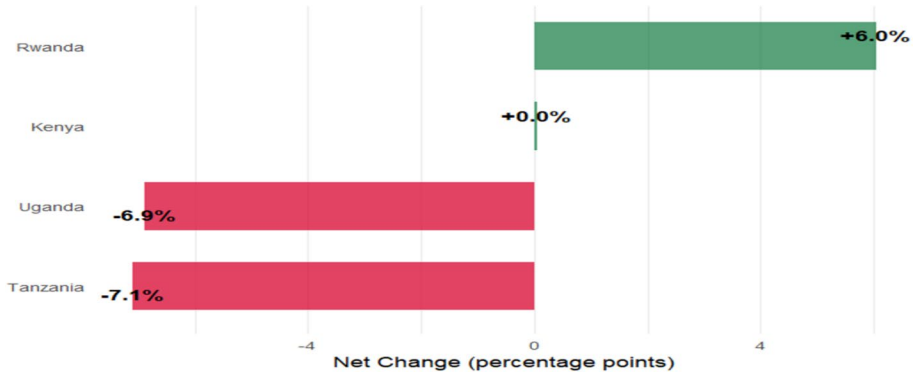

Fig. 2 Net forest cover change (percentage points) following policy implementation by country. Error bars represent 95% bootstrapped confidence intervals. Source: Author's analysis of FAO FRA data

Table 5 Regression models of forest cover determinants

Variable	Two-way FE	Plantation interaction	Country-specific effects
Post-policy	3.799 (4.912)	− 5.602** (1.490)	
Post × plantation share		0.181*** (0.045)	
Country FE: Rwanda		7.279** (2.110)	
Country FE: Tanzania		49.163*** (1.540)	
Country FE: Uganda		7.745*** (1.562)	
Rwanda × post			3.652 (9.495)
Tanzania × post			33.754*** (8.476)
Uganda × post			− 6.121 (8.476)
Intercept	9.675*** (1.423)	19.118*** (4.111)	
Observations	24	24	24
R^2	0.975	0.985	0.485
RMSE	2.97	2.31	13.53

*** $p < 0.01$, * $p < 0.05$; Standard errors in parentheses

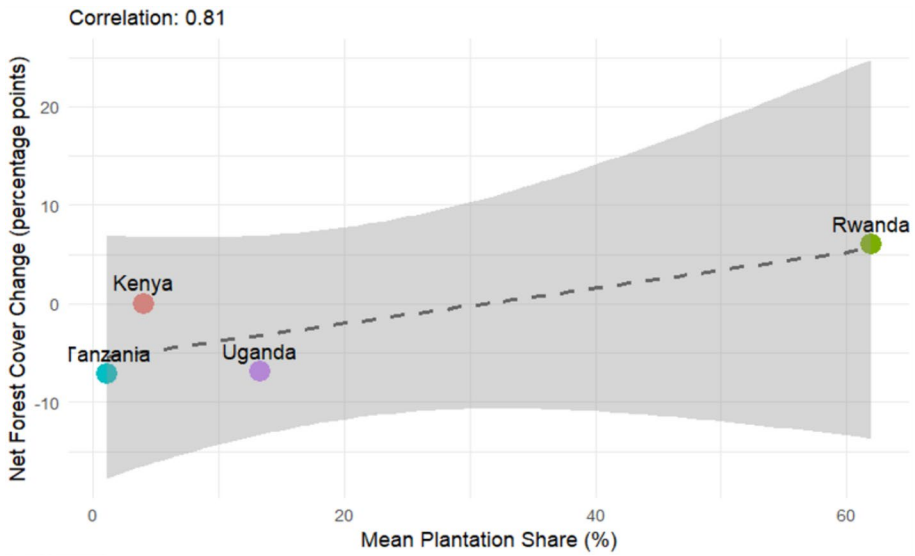

Fig. 3 Relationship between mean plantation share (%) and net forest cover change (%) following policy implementation. Circle size represents country forest area. The regression line (r = 0.81) shows the positive correlation between investment intensity and policy success. Source: Author's analysis

may help unlock the potential of participatory frameworks, potentially by providing economic incentives and relieving pressure on natural forests during restoration phases.

Figure 3 illustrates the strong positive relationship between a country's reliance on plantation forestry and its forest policy success. The scatter plot compares the mean plantation share (%) against the net forest cover change (%) for each country.

From the data in this figure, it can be seen that Rwanda is positioned as a distinct outlier in the top-right quadrant, combining a high mean plantation share with a strongly positive outcome. In contrast, Uganda, Tanzania, and Kenya cluster in the lower-left quadrant with low plantation shares and negative or negligible net changes. The results show a clear positive correlation (r = 0.81), as indicated in the figure. This

visual evidence supports the hypothesis that aggressive, state-led plantation investment-exemplified by Rwanda's strategy-is a key implementation factor associated with successful forest recovery in East Africa.

6.4 Robustness of the findings

Further analysis was conducted to assess the sensitivity of the core finding. A leave-one-out analysis revealed that when Rwanda was excluded, the average regional policy effect became sharply negative (− 4.649), confirming its status as a positive outlier (Table 6).

Additionally, further analysis showed that a placebo test with 100 false policy years for Rwanda yielded a p-value of 0.042. This indicates that only 4.2% of placebo effects exceeded Rwanda's actual effect in magnitude. These results suggest that Rwanda's observed success is statistically unusual and unlikely to have occurred by chance. Rwanda's outcome represents a true policy-associated change rather than a statistical artifact or pre-existing trend.

7 Discussion

This study was designed to examine the heterogeneous associations between national participatory forest policies and forest cover and to test whether implementation strategy is associated with these divergent outcomes. The most striking finding is the dramatic divergence itself: Rwanda's 2011 policy is associated with a significant net gain of 6.04 percentage points, while Uganda's and Tanzania's policies are linked to significant losses, and Kenya's shows no measurable effect. This confirms the heterogeneity documented in qualitative and case-study research [8, 20, 43] but provides its first quantitative, cross-national measurement.

7.1 The implementation-intensity mechanism

The core explanatory finding is the significant positive interaction between the post-policy indicator and plantation share ($\beta = 0.181$, $p < 0.01$). This finding provides quantitative support consistent with the resource-commitment hypothesis derived from implementation theory [19, 39] and extends earlier descriptive observations linking Rwanda's outcomes to plantation investment [29, 32]. The results suggest that the standalone declaration of a participatory policy may be ineffective or even counterproductive without substantial complementary investment. For Rwanda, with a plantation share of 62%, the marginal policy effect is strongly positive (+ 5.60%), whereas for Tanzania (1% plantation share), it is negative (− 5.42%). This indicates that high levels of plantation investment are associated with enabling the success of participatory frameworks.

Table 6 Leave-one-out sensitivity analysis

Country removed	Average policy effect
Uganda	− 0.338
Tanzania	− 0.268
Rwanda	− 4.649
Kenya	− 2.652

We posit this occurs through several interlinked pathways: (1) Provision of Alternatives: Plantations supply timber and fuelwood, relieving subsistence pressure on natural forests and altering local economic incentives [29], (2) Signal of Credible Commitment: Large-scale investment demonstrates strong state prioritization, which can strengthen enforcement legitimacy and foster local buy-in; and (3) Creation of Enabling Infrastructure: Investment often builds the technical and administrative capacity needed to support devolved management.

However, we caution that these findings are observational. The positive interaction coefficient indicates a statistical association, not a causal moderation effect. Unobserved confounders including state capacity, enforcement quality, and biophysical conditions could influence both plantation investment and forest outcomes, creating spurious associations. Future research using instrumental variables or natural experiments is needed to test whether the relationship is causal.

This finding offers a plausible mechanism for the widely discussed "policy-implementation gap" in natural resource management [1, 24]. It suggests that aggressive, state-led investment can create the necessary enabling conditions for participatory models to function by: (1) providing immediate economic incentives and alternative resources (e.g., timber, fuelwood) that relieve subsistence pressure on natural forests [6, 29], (2) signaling strong and credible state commitment, which can strengthen enforcement and local buy-in; and (3) facilitating the "nesting" of local institutions within a supportive, resource-rich structure, as theorized by Hayes and Persha [18]. It is important to note that 'plantation' in the Rwandan context, as captured by the FAO data, encompasses a spectrum of planted forests. This includes state-led industrial woodlots, but also, crucially, nationwide agroforestry campaigns that integrate millions of trees on smallholder farms [29]. This distinction matters: the investment proxy likely reflects not just monolithic timber plantations, but a broad-based, farm-level restoration strategy that directly addresses local fuelwood and subsistence needs, thereby reducing pressure on natural forests more effectively than a narrow plantation model might.

Furthermore, the capacity to execute such a high-investment strategy cannot be divorced from Rwanda's distinctive political context. The findings align with political economy perspectives emphasizing state capacity and political will as prerequisites for effective policy implementation [34, 46]. Rwanda's centralized, high-capacity state apparatus may have been uniquely positioned to mobilize resources, coordinate nationwide campaigns, and maintain consistent enforcement-factors that likely interacted with the investment scale to produce the observed success. In contrast, the more fragmented political landscapes and lower state capacity in Uganda and Tanzania may have constrained similar large-scale, coordinated investment, contributing to the implementation gap [7, 45].

Recent studies on Rwanda's forest transition corroborate this mechanism, documenting how extensive plantation establishment and agroforestry campaigns have created economic alternatives while restoring forest cover [29, 33].

7.2 Reconciling with existing explanatory frameworks

Our results complement but also challenge dominant explanations focused solely on institutional design and political economy. The institutional lens emphasizes that

successful decentralization requires the transfer of meaningful powers to downwardly accountable local actors [3, 25]. Our findings do not contradict this but add a crucial precondition: even well-designed devolution may fail without the material resources to make local management viable, as evidenced by studies documenting elite capture and incomplete devolution in Tanzania and Uganda [27, 42].

The political economy perspective highlights how power relations and elite interests shape outcomes [20, 34]. Rwanda's centralized, high-capacity state may have been uniquely positioned to marshal resources and implement its strategy effectively, overcoming or bypassing local elite capture dynamics noted in other studies [27, 45]. Thus, investment intensity may interact with state capacity and political will—key variables in the implementation literature [46].

Our findings also resonate with recent literature on forest governance challenges in East Africa. Studies documenting corruption and weak property rights implementation in Uganda [7], overlapping land rights contributing to deforestation [45], and limited benefits from PFM in Kenya [31] collectively paint a picture of participatory frameworks struggling without adequate resource backing. In contrast, Rwanda's success aligns with recent evidence of effective smallholder engagement in forest restoration [29] and participatory mapping identifying local values in restoration landscapes [33].

7.3 Limitations and future research

These results must be interpreted with caution. The small sample size limits statistical power, and the time-invariant plantation share measure cannot capture annual investment fluctuations. While fixed-effects models control for time-invariant country heterogeneity, unobserved time-varying confounders (e.g., concurrent economic policies, climate variations, or external shocks like COVID-19 as documented by [2, 13]) could influence both investment and forest outcomes. The causal interpretation of the interaction effect assumes plantation investment modifies policy success rather than merely correlating with other success factors.

Future research should investigate several promising avenues: First, the political economy of investment decisions—what enables a state to commit to large-scale plantation programs while others do not? Second, longitudinal, mixed-methods studies are needed to unpack how investment enables success through specific pathways like improved livelihoods, strengthened tenure security, or enhanced enforcement capacity [28]. Third, the ecological trade-offs of a plantation-heavy strategy require assessment, particularly regarding biodiversity and ecosystem services [33, 35]. Recent work on native species reforestation in Rwanda highlights both opportunities and challenges in balancing ecological and economic objectives [9, 44].

Beyond ecological considerations, the social implications of Rwanda's investment-heavy model warrant examination. While effective for forest cover recovery, a top-down approach emphasizing plantation targets may come at the cost of the genuine grassroots empowerment and adaptive local governance that participatory policies originally aimed to foster [23, 37]. Future implementation should seek to balance substantial investment with mechanisms that preserve and enhance community autonomy and decision-making power.

Finally, future studies should explore how Rwanda's model might be adapted to different governance contexts, considering lessons from other regions [5] and the role of emerging mechanisms like REDD + [11, 16].

A critical reflection on our findings is warranted. The associations we observe may overstate the role of plantation investment if unmeasured factors are the true drivers. Specifically, we cannot distinguish between an "investment effect" and a "state capacity effect." Rwanda's high plantation share coincides with its centralized governance system, strong enforcement capacity, and distinctive land governance regime—factors that may be as important as, or more important than, plantation investment per se. Similarly, biophysical conditions (rainfall, soils, topography) could contribute to forest recovery independently of policy. Our analysis cannot disentangle these mechanisms with available data. Readers should interpret the investment-moderation hypothesis as a candidate explanation requiring further testing with quasi-experimental designs, larger samples, and richer covariate sets.

7.4 Policy implications

This study challenges the notion that participatory policy design is the primary determinant of success. Instead, it demonstrates that the translation of participatory principles into positive forest cover outcomes may be fundamentally dependent on the scale of complementary resource investment. The findings provide a quantitative evidence base for the adage that "implementation matters" [19].

For policymakers, the implication is clear: pairing decentralization with large-scale, long-term restoration financing is not optional but essential for achieving forest recovery. Legal devolution must be matched with material commitment to bridge the implementation gap and create the enabling conditions for communities to become effective stewards of their forests. This aligns with recent calls for integrated approaches to sustainable forest management [21, 41].

However, policymakers should consider potential trade-offs: while plantation-driven strategies may accelerate forest cover recovery, they may not deliver the same biodiversity or ecosystem service benefits as natural forest restoration [33, 35]. Future policy should therefore balance investment in fast-growing plantations for immediate cover and economic benefits with longer-term support for natural forest regeneration and community-based management of diverse forest ecosystems. Lessons from Rwanda suggest that incorporating native species and addressing local values in restoration planning can enhance both ecological and social outcomes [9, 33].

Ultimately, successful forest governance in East Africa requires moving beyond the participatory label to focus on the substantive investments and strategic implementation that enable participatory frameworks to function effectively.

A critical caveat is that forest cover, while a vital metric, does not capture forest quality, biodiversity, or ecosystem service provision [35]. A policy success defined by plantation expansion must be evaluated against potential trade-offs with natural forest conservation and ecological resilience. Future policies should therefore aim to balance investment in fast-growing plantations for immediate cover and economic benefits with longer-term support for natural forest regeneration and the community-based management of diverse forest ecosystems [9].

A practical implication is that international climate finance mechanisms (e.g., REDD+) should be structured not only to reward verified emission reductions but also to provide front-loaded, large-scale investment in complementary programs like plantation establishment and agroforestry that create the enabling conditions for participatory management to succeed.

8 Conclusion

8.1 6.1 Summary of findings

This study examined associations between national participatory forest policies and forest cover change in four East African countries. Rwanda's 2011 policy was associated with a net forest cover gain of 6.04 percentage points, while Uganda and Tanzania showed significant losses, and Kenya showed no measurable association. These findings confirm the heterogeneity documented in qualitative research and provide its first quantitative measurement.

8.2 Theoretical implications

Formal adoption of a participatory policy framework appears insufficient for success. The significant positive interaction between post-policy status and plantation share suggests that policy-outcome associations vary with investment intensity. This finding is consistent with—but does not prove—the resource-commitment hypothesis. Plantation investment (as a proxy for sustained state commitment) is a factor associated with the dramatic differences between Rwanda and its neighbors. These findings are observational and hypothesis-generating.

8.3 Limitations

This study has significant limitations: small sample (24 observations), time-invariant plantation share measure, omitted biophysical and state capacity variables, potential reverse causality, untestable parallel trends, and limited generalizability from Rwanda's unique political context. Findings should be interpreted as correlational, not causal.

8.4 Future research directions

Future studies should use larger samples, subnational data, or quasi-experimental designs. Research is needed on the political economy of investment decisions, mechanisms linking investment to outcomes, ecological trade-offs, and whether Rwanda's model generalizes to different governance contexts.

8.5 Policy recommendations

With observational caveats, findings suggest participatory forest policies may benefit from substantial, long-term financial commitments for restoration. Policymakers considering Rwanda's approach should adapt it to local contexts, address ecological trade-offs, and recognize that state capacity and political will may be as important as investment itself.

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Author contributions
Ronald Ogenrwot: Conceptualization, Methodology, Formal Analysis, Data Curation, Writing—Original Draft, Writing—Review and Editing, Visualization.

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Data availability
The data that support the findings of this study are openly available from the FAO Forest Resource Assessment (FRA) 2025 at http://www.fao.org/forest-resources-assessment. The analysis code is available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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