



Research Article

Resource Mobilization Efficiency of Household Biogas Potential in a Pastoral Economy: The Case of Mt. Suswa, Kenya

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Abstract

Despite abundant cattle-dung resources, household biogas adoption remains low across Kenya's arid and semi-arid pastoral zones. Only 0.5% of Narok County households use biogas as their primary cooking fuel, and prior research has not examined how efficiently pastoralist households can mobilize this feedstock. This study assessed feedstock-mobilization efficiency and its determinants among pastoralist households in Mt. Suswa, Narok County, Kenya, using a non-experimental, cross-sectional design grounded in Production and Efficiency theories. A census of 150 livestock-keeping households was attempted, and 114 complete questionnaires (76.0%) were analyzed. Potential biogas yield was derived from herd size, assuming 9.0 kg of dung per head per day and 50% collection efficiency. It was modelled as an ex-ante resource-mobilization frontier using a Battese–Coelli Translog stochastic frontier with an inefficiency-effects component. Likelihood-ratio tests favored the stochastic Translog specification over both OLS and Cobb–Douglas. Mean mobilization efficiency was 67.04%, revealing a 32.96% structural gap, and 28.1% of households fell below 60% efficiency. Returns to scale were strongly diminishing (0.55 under individual grazing and 0.38 under communal grazing). A significant negative water-access-by-grazing-distance interaction pointed to compounding spatial constraints. Livestock maintenance cost and grazing distance raised the frontier, while communal grazing lowered it by 24.68%. Cultural compatibility with dung-derived energy reduced inefficiency, whereas formal education increased it, a pattern interpreted through life-cycle and Chayanovian accounts of livestock accumulation. Modern cooking-energy use and technology awareness showed marginal, opposing effects. Closing half the efficiency gap could yield about 208 m³ of additional biogas per household annually, displacing roughly 1.26 tonnes of firewood worth KES 18,303. These results suggest that clean-energy deficit stems from spatial, environmental, and institutional frictions. Biogas policy should therefore target household-level mobilization constraints, through culturally anchored extension, co-location of water and energy infrastructure, and localized paddocking, rather than aggregate biomass availability.

Keywords

Cattle Dung, Biogas, Resource Mobilization Efficiency, Stochastic Frontier Analysis, Translog Frontier, Pastoralist Households, Mt. Suswa, Kenya

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1. Introduction

Kenya's centralized electricity grid is notably progressive, consisting predominantly of renewable sources [1]. Despite this clean electricity mix, the country faces steep domestic energy hurdles. Residential and commercial electricity tariffs remain high at USD 0.257 per kWh and USD 0.185 per kWh, respectively, exceeding the global average of USD 0.142 per kWh [2]. Further, local firms suffer annual financial losses equivalent to 7% of total sales due to power supply unreliability, forcing commercial entities and households to rely on costly alternatives like diesel generators and kerosene lamps [3]. While urban centres in Kenya enjoy a near-universal electricity access rate of 97%, rural access drops to 68% [4]. This regional imbalance restricts rural communities from engaging in modern, income-generating economic activities.

Biomass remains the primary cooking fuel for 80% of Kenyan households [5]. Foraging for traditional biomass exerts an unequal time burden on women and children, who spend an average of three to five hours daily collecting firewood, which directly reduces their participation in formal education and the wage-earning labor market [6]. Moreover, rural households face rising energy procurement costs as commercial biomass scarcity worsens. Dry firewood in rural agricultural zones cost on average KES 14.48 per kg [7]. This reliance on inefficient fuels creates a heavy financial drain on rural household finances as rural families spend up to 30% of their monthly income on energy compared to less than 10% in urban areas [3].

To address these systemic energy, health, and environmental challenges, the Kenya Bioenergy Strategy (2020-2027) was launched in 2020 as a national roadmap to achieve 100% universal access to modern bioenergy services by 2030 and clean cooking by 2028, targeting an annual deployment of 6,500 domestic biogas digesters against an estimated national potential of 2.3 million units [8].

Biogas technology offers a viable decentralized, off-grid solution capable of mitigating local energy shortages, minimizing grid instability and reducing household energy expenses, potentially saving households up to \$25 (approximately KES 3,223) monthly in 2024 prices by displacing commercial liquefied petroleum gas (LPG), charcoal, and firewood [9]. Additionally, household-scale biogas digesters operate at an energy replacement conversion ratio where 1 m³ of produced biogas reliably displaces approximately 6.07 kg of dry fuelwood [10]. Additionally, small-scale anaerobic digesters provide a cost-effective methane mitigation pathway by capturing livestock waste emissions that would otherwise enter the atmosphere, unmanaged livestock manure currently accounts for 7% to 10% of global agricultural methane emissions [11]. Transitioning from traditional biomass to biogas can reduce household carbon emissions by up to 60% while simultaneously reducing particulate matter exposure [5]. These dual environmental and health externalities transform biogas into a clean cooking solution and a climate finance opportunity, aligning Kenya's domestic energy policy directly

with its international commitments under the Paris Agreement and COP28 targets. For biogas technology to be viable and sustainable, a consistent supply of feedstock and an efficient conversion system are essential to maximize biogas yield and byproduct utilization per unit of input [12, 13].

Narok County is one of the Arid and Semi-Arid Lands (ASAL) with the highest livestock densities in Kenya [14]. However, domestic clean energy transition remains severely constrained, with only 0.5% of households (approximately 1 in 200) reporting biogas as their primary cooking fuel [15]. Energy access challenges coupled with the availability of livestock waste in cattle kraals has prompted the county to recognize the potential of biogas technology in sustainable development, thereby prioritizing the exploration of biogas.

Despite a growing body of empirical literature exploring smallholder biogas systems in Sub-Saharan Africa, a methodological gap arises from the limited application of frontier efficiency modeling to household biomass systems in pastoral economies. The Battese and Coelli [16] parametric SFA model employed in this study solves this problem by decomposing the error term to separate uncontrollable random shocks from actionable mobilization inefficiency, generating highly reliable and statistically robust efficiency estimates within the volatile, low-infrastructure, and climate-exposed environments typical of Kenyan ASALs, extending the theoretical understanding of renewable energy transitions in resource-rich but adoption-poor contexts, while providing direct, actionable empirical evidence to support Kenya's national Bioenergy Strategy (2020-2027).

This study measured the resource mobilization efficiency of household biogas feedstock and its determinants using stochastic frontier analysis in Mt. Suswa, Narok County.

1.1. Theoretical Literature

1.1.1. Theory of Production

Production theory formalizes the technical relationship between inputs and output. The Cobb-Douglas function [17] is specified as:

$$Q = A \cdot L^{\alpha} \cdot K^{\beta} \quad (1)$$

Where Q represents total output, L is labor input, K is capital input, and A represents a Hicks-neutral technology parameter capturing Total Factor Productivity (TFP). The exponents α and β represent the output elasticities of labor and capital, respectively, bounded such that $0 < \alpha < 1$ and $0 < \beta < 1$.

For the Cobb-Douglas functional form, the elasticity of substitution is mathematically constrained to be exactly equal to unity ($\sigma = 1$).

To relax these restrictive assumptions, Christensen, Jorgenson, and Lau [18] introduced the Transcendental Logarithmic (Translog) production function. The Translog model serves as

a second-order Taylor series approximation to an unspecified underlying production frontier, formalized as:

$$\ln Y_i = \beta_0 + \sum_{j=1}^k \beta_j \ln X_{ji} + \frac{1}{2} \sum_{j=1}^k \sum_{m=1}^k \beta_{jm} \ln X_{ji} \ln X_{mi} \quad (2)$$

Unlike the Cobb-Douglas model, the Translog specification allows output elasticities to vary across different scales of input utilization and permits the elasticity of substitution to deviate from unity.

To operationalize this, Aigner, Lovell, and Schmidt [19] extended production theory by introducing the SFA model. The general empirical specification for household i is formulated as:

$$\ln(Q_i) = \ln(f(X_i)) + \varepsilon_i \quad (3)$$

The composite error term ε_i is decomposed into two structurally distinct parts:

$$\varepsilon_i = v_i - u_i \quad (4)$$

Where v_i and u_i are governed by specific, formal distributional assumptions of Random Shocks (v_i) and Technical Inefficiency (u_i).

This framework is central to this study because it allows for the explicit separation of baseline resource endowments (the capacity effect) from systemic mobilization frictions (the inefficiency effect), which constitutes the core economic puzzle of this study.

1.1.2. Theory of Efficiency

Farrell [20] distinguished technical efficiency (maximum output from given inputs) from allocative efficiency (optimal input mix given prices). The stochastic frontier approach [16] operationalizes technical efficiency measurement by modeling u_i as a function of household characteristics:

$$u_i = \delta_0 + \delta_1 Z_{1i} + \delta_2 Z_{2i} + \dots + \delta_m Z_{mi} + \omega_i \quad (5)$$

Building on this, Aigner, Lovell, and Schmidt [19] introduced the SFA, a parametric approach that separates inefficiency from random shocks in production, while Charnes, Cooper, and Rhodes [21] developed Data Envelopment Analysis (DEA), a non-parametric method that evaluates efficiency by comparing each unit to a constructed “best practice frontier.” This study adopts the Battese-Coelli [16] one-step SFA to simultaneously estimate the potential feedstock mobilization frontier and the determinants of resource mobilization inefficiency.

1.1.3. Life-Cycle Hypothesis of Savings and Asset Accumulation

The Life-Cycle Hypothesis, developed by Ando and Modigliani [22] and Modigliani and Brumberg [23], models household wealth accumulation as a function of age: individuals build assets across their working years toward a lifetime consumption-smoothing target, so accumulated wealth tends to increase with age and years of economic activity rather than with formal educational attainment. Applied to pastoral households, the theory suggests that older, longer-established household heads accumulate larger livestock holdings over time through this life-cycle savings process, largely independent of their level of formal schooling.

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1.1.4. Chayanovian Theory of the Peasant/Pastoral Economy

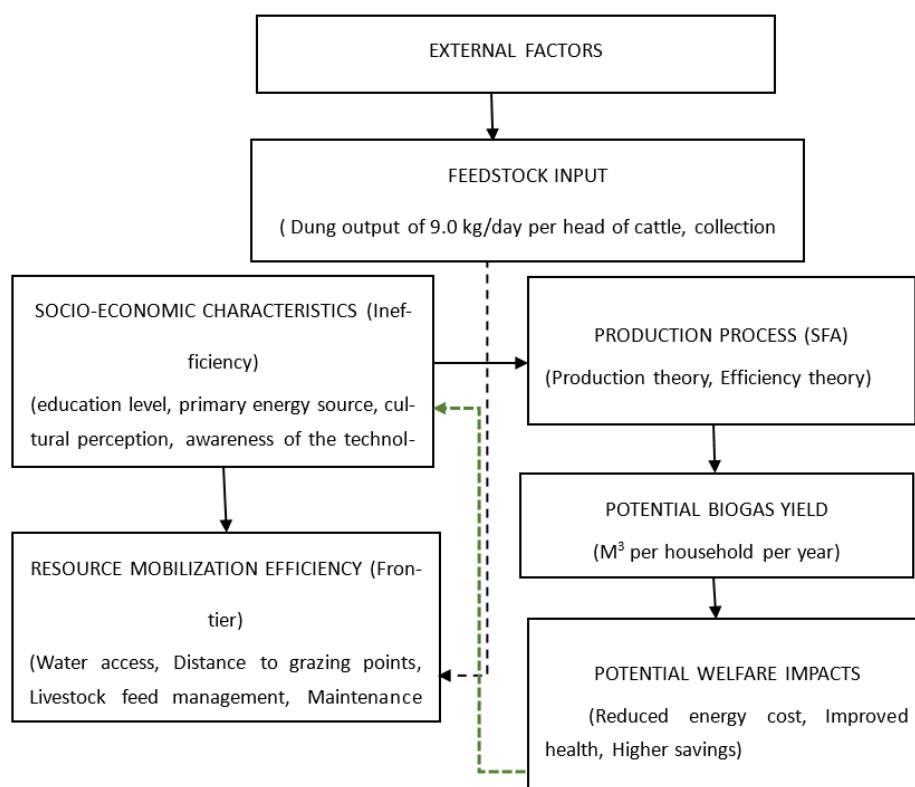
Chayanov's theory of the peasant economy [24] argues that household production and asset-holding decisions in subsistence and pastoral economies are driven primarily by the household's labor-to-consumer ratio and generational demographic structure, rather than by market-style returns to formal human capital. Chayanov's framework predicts that household asset accumulation, including livestock herds, tracks family life-cycle stage and labor availability rather than the education of the household head.

These two frameworks are introduced here as theoretical lenses; Section 3.3.3 draws on them, alongside applied pastoral-livelihoods literature [25, 26], to interpret the unanticipated positive relationship between education and resource mobilization inefficiency.

1.2. Empirical Literature: Technical Efficiency of Biogas Production per Household

Gbadeyan et al. [27] identified feedstock supply variability and post-setup maintenance gaps as the primary bottlenecks impairing system efficiency. Juma [28] revealed that operational efficiency and functional utilization rates of communal bio-centres drop drastically due to socio-cultural taboos surrounding human-waste-derived feedstock and physical distance from households to the bio-centre. Clemens et al. [29] reviewed the Africa Biogas Partnership Program across East Africa and noted that while households meet baseline specifications, operational efficiency lags behind projections due to fragile post-installation servicing networks and steep upfront capital costs. Ong'ayo [30], applying a Binary Logistic Regression model in Kilifi County, established that sustained utilization efficiency depends heavily on land size, cattle herd size for steady feedstock supply, and structured technical training. Households lacking formal maintenance knowledge experienced rapid disuse and eventual abandonment of installed digesters. None of the studies applied SFA to household-scale biogas in a pastoral setting; this study does.

1.3. Conceptual Framework



Source: Author (2026)

Figure 1. Conceptual Framework.

The framework hypothesizes that baseline biomass feedstock availability provides the physical foundation for household potential biogas yield capacity. Socio-economic factors (education level, cultural perception, technology awareness, and primary cooking energy source) jointly determine the resource mobilization efficiency with which households can consolidate those inputs toward the frontier (modeled via the SFA inefficiency effects vector). Arrows within the conceptual layout indicate the hypothesized direction of these structural effects, derived from classical Production Theory, and Efficiency Theory.

2. Materials and Methods

2.1. Research Design

This study adopts a non-experimental research design [31]. This design is appropriate because the research questions seek to describe and explain variation in potential biogas yield and efficiency across households in their natural setting, without manipulation, keeping the data grounded in the actual daily realities and operational constraints of pastoral life. Experimental or quasi-experimental designs were ruled out because

key factors like herd size and livestock feed management system are fixed household characteristics and cannot be randomly assigned or artificially manipulated. A longitudinal study was also not possible, since historical panel data for Mt. Suswa households was not available.

2.2. Study Area and Target Population

The study was conducted in Mt. Suswa, Narok County, Kenya. Narok County lies between latitudes 0.7 °S and 2.0 °S and longitudes 34.5 °E to 36.0 °E; it covers an approximate 17,950.3 km² in land size with a population density of 65 people per km² and an annual growth rate of 3.3% [15]. The county borders Kajiado County to the east, Nakuru County to the north, Bomet County to the northwest and Migori County to the west. The main economic activities include tourism, livestock keeping, crop farming and mining, as documented in the Narok County Integrated Development Plan (CIDP) 2023-2027 [32]. Major livestock composition is 1.4 million cattle; 2.6 million sheep; 1.01 million goats; 0.9 million poultry; 81,932 donkeys; 3,679 rabbits; 2,054 pigs; 49,857 beehives; and 1,619 camels [15].

Mount Suswa is located at approximately 1°09'00"S latitude and 36°21'00"E longitude. Land elevation varies from

lowlands (1,500 metres) to higher altitude (2,356 metres), covering about 12 km². It is situated in Suswa Ward, Narok East Sub-County and Ewaso Oo Nkidong'i, Kajiado West Sub-County (see Appendix 1). Mt. Suswa represents a typical pastoralist and agro-pastoralist region within Kenya's broader livestock economy. Energy challenges such as reliance on traditional biomass energy sources including firewood, charcoal and kerosene remain persistent despite the availability of significant renewable energy resources.

The target population was 150 livestock-keeping households [33].

2.3. Sample Frame and Sample Size Determination

A sample represents a mathematically selected subset of a target population deployed to draw valid statistical inferences regarding the collective whole [34]. A sample frame is the list of members of the population of interest from which a probability sample is selected [35]. The sampling frame for this study draws on the most complete available household register for Mt. Suswa [33]; while this minimizes (but cannot fully eliminate) frame omissions such as households formed or relocated since the register's compilation, it represents the best available enumeration for the study area. Because a target population of 150 households was manageable, a census was attempted; 119 complete questionnaires were obtained from the field, and 5 observations were then dropped after cleaning due to recording the value zero on number of cattle owned during normal periods, when there is no drought, which is a key variable in the computation of Y (potential biogas yield), consequently introducing error on log transformation. Ultimately, 114 households (response rate 76.0%) provided complete questionnaires, yielding the analytical sample.

2.4. Statistical Power and Non-Response

Because 20.7% of the target population did not respond, due to pastoral polygamous structures (more than one household having the same household head) and field absences, and a further 3.3% were dropped after cleaning, treating the final 114 units as a simple random sample introduces a risk of non-response bias. A post-hoc power calculation was used to assess the statistical sensitivity of the final sample to a medium-sized effect; it does not, however, establish the absence of non-response or selection bias. The sample size meets Maximum Likelihood Estimation (MLE) requirements for the SFA. For the full Translog specification comprising 21 parameters across the frontier inputs, quadratic terms, interaction terms, and exogenous inefficiency determinants (Z_i), a commonly used practical benchmark suggests approximately 5 observations per parameter ($21 \times 5 = 105$ observations). The sample of $n = 114$ exceeds this requirement marginally, providing an observation-to-parameter ratio of 5.43:1, which satisfies the degrees of freedom and finite-sample consistency conditions

needed for stable MLE parameter convergence [36]. While statistical power is adequate for the planned analyses, the absence of complete characteristics data for non-respondents means representativeness relative to the full target population cannot be fully verified and is noted as a limitation.

2.5. Sampling Units and Stratification Mechanisms

The primary sampling unit is the individual household, defined as a co-residential unit sharing cooking arrangements and managing a joint herd. Because a census of all 150 livestock-owning households was attempted, standard probability sampling fractions were not utilized a priori.

2.6. Research Instruments and Data Collection Procedure

Primary data were collected using semi-structured household questionnaires administered via face-to-face interviews. A semi-structured questionnaire is a research tool that combines both closed-ended questions, such as household demographic data and biogas feedstock distribution, and open-ended questions, such as the cultural perceptions surrounding dung usage, allowing for consistency in responses as well as flexibility for deeper exploration leading to richer data collection [37].

Primary field data collection was executed by the researcher alongside trained local guides speaking fluent Maa. Questionnaires were filled out manually by the researcher during face-to-face household visits to minimize missing data and the illiteracy constraint on the part of the respondents. Secondary data was compiled from KNBS census archives [15, 38], Narok County agricultural reports [32] and peer-reviewed bioenergy literature to triangulate the primary survey metrics.

2.7. Data Processing and Analysis

The collected data was systematically cleaned, coded and analyzed. The data were examined for completeness, accuracy, consistency and relevance to the research objectives. Incomplete responses (5) were excluded from the analysis. Valid responses were entered into R version 4.5.2 for statistical analysis. SFA was conducted using the *frontier: Stochastic Frontier Analysis* R package, version 1.1 (Coelli & Henningsen, 2013).

2.8. Analytical Frameworks

Stage 1: Feedstock Distribution

Annual dung per household (Qd) is computed as:

$$Qd_{\text{Annual}} = Qd_{\text{Normal period}} + Qd_{\text{Migrate}} \quad (6)$$

Where: daily dung per cattle is assumed at 9.0 kg [39] with

50% collection efficiency [40].

$$Qd_{\text{Normal period}} = \text{no.Cattle} \times 9.0 \times 0.5 \times (360 - \text{dmigrate}) \quad (7)$$

$$Qd_{\text{Migrate}} = \text{no.Cattle Retained} \times 9.0 \times 0.5 \times (\text{dmigrate}) \quad (8)$$

where $Qd_{\text{Normal period}}$ is the quantity of dung available for collection when the entire cattle holding is present at the household, Qd_{Migrate} is the quantity of dung available for collection during periods when part of the cattle holding have migrated for pasture or drought, 360 is the total number of days in a year assuming 30 days/month, $dmigrate$ is the number of days per year cattle are away due to drought (obtained by multiplying the number of months reported by 30 assumed days per month), and $\text{no.Cattle Retained}$ is the number of cattle left at the household after migration of the rest due to drought. The 360-day (30 days/month) convention is a simplifying approximation used to convert reported migration duration in months to days, and it produces a uniform, non-material understatement of roughly 1.4% relative to a 365-day year.

Stage 2: Potential Biogas Yield

Dry matter (total solids, TS) in cattle dung is approximately 25%, and volatile solids (VS) content is 80% of dry matter [41]. Biogas yield from cow dung can range from 0.2 to 0.3 cubic metres per kilogram of volatile solids [42]. Using total solids (TS = 25%) of (Qd) and volatile solids (VS = 80%) of (TS), potential yield is:

$$Y = Qd \times TS \times VS \times 0.25 = 0.05 \times Qd \quad (9)$$

Where $0.25 \text{ m}^3/\text{kg}$ is the midpoint of the KENPRO [42] range. Because TS, VS and the specific yield are fixed constants, Y is a deterministic linear transformation of Qd with composite factor $k = 0.05$.

Stage 3: Resource Mobilization Efficiency (SFA Model)

To evaluate how effectively households consolidate base-line biomass, this study applies SFA [16] estimated simultaneously with an inefficiency effects model:

$$\ln Y_i = \beta_0 + \beta_1 \ln W + \beta_2 F + \beta_3 \ln C + \beta_4 \ln D + v_i - u_i \quad (10)$$

Where $v_i \sim N(0, \sigma^2)$ represents two-sided random noise, and $u_i \sim N^+(\mu, \sigma^2)$ represents non-negative resource mobilization inefficiency.

While the traditional Cobb-Douglas specification restricts the elasticity of substitution to unity, the unconstrained Translog production frontier alternative utilized to evaluate complex spatial interactions is specified as:

$$\ln Y_i = \beta_0 + \sum_{j=1}^k \beta_j \ln X_{ji} + \frac{1}{2} \sum_{j=1}^k \sum_{m=1}^k \beta_{jm} \ln X_{ji} \ln X_{mi} + v_i - u_i \quad (11)$$

Where X_{ji} represents the vector of continuous physical inputs (water access index, distance to grazing points, and livestock maintenance costs) for household i , and β_{jm} captures the symmetric interaction parameters where $\beta_{jm} = \beta_{mj}$. Equation (11) nests (10) as a special case when all second-order parameters are zero; this is the basis for the LR test conducted in Section 3.3.1.

The term u_i captures inefficiency:

$$u_i = \delta_0 + \delta_1 C_p + \delta_2 E_d + \delta_3 A_t + \delta_4 E_p + \omega \quad (12)$$

Resource mobilization efficiency per household is $TE_i = \exp(-u_i)$, summarized across the sample.

2.9. Model Specification and Variable Measurement

The SFA frontier model uses supply-side, logistical, and physical-access variables (water access, grazing distance, livestock feed management, livestock maintenance cost) to define the resource-mobilization frontier itself, while demand-side household variables are repositioned as determinants of deviation from that frontier in the inefficiency-effects equation. This two-stage structure separates physical/logistical constraints on reaching that potential from households' departure from it (SFA).

Table 1. Variable Definitions and Measurement for the Inefficiency Model.

Variable	Description	Measurement
$\ln Y$	Natural log of potential biogas yield	M^3/year (natural log transformed)
C_p	Cultural perception	1 = compatible, 0 = taboo
A_t	Awareness of biogas technology	1 = aware, 0 = not
E_p	Primary energy source for cooking	1 = modern (LPG/improved jiko), 0 = traditional

Variable	Description	Measurement
Edu	Education of household head	Years of formal schooling

Table 2. Variable Definitions and Measurement for the SFA Model Frontier.

Variable	Description	Measurement
lnW	Natural log of water access index	km ⁻¹
F	Livestock feed management	1 = communal, 0 = individual
lnC	Natural log of annual livestock maintenance cost	KES/year
lnD	Natural log of distance to grazing points	km

Water access index (W) = 1 / (distance to water source in km). SFA model fit: lambda ($\lambda = \sigma_u / \sigma_v$) and gamma ($\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$) are reported; γ close to 1 indicates inefficiency dominates.

It is important to note that the dependent variable LnY is a deterministic function of cattle numbers (Equation (9)). Therefore, the SFA frontier estimated here does not represent a conventional production frontier measuring conversion of physical inputs into biogas via a technical process. Instead, it represents a resource-mobilization frontier, capturing how efficiently households mobilize their theoretical feedstock ceiling given logistical constraints (water access, grazing distance, livestock feed management, livestock maintenance cost), not the technical efficiency of dung-to-gas conversion. The 'inefficiency' term therefore measures deviations from maximum feasible resource capture, not from maximum physical gas output.

2.10. Diagnostic Tests

A Likelihood-Ratio Test

A first LR test is conducted to confirm that the stochastic frontier specification is preferred to OLS. A second LR test compares the Cobb-Douglas restricted model against the Translog alternative; rejection of H0 confirms the Translog is the preferred specification.

3. Results and Discussion

3.1. Descriptive Summary of Study Variables

The demographic, institutional, and production profiles of the 114 sampled pastoralist households in Mt. Suswa, Narok County, reveal critical baseline conditions for evaluating potential biogas yield and resource mobilization efficiency. Results for continuous variables are presented in Table 3, while Table 4 presents results for categorical variables.

Table 3. Descriptive Statistics for Continuous Variables (n = 114).

Variable	Mean	Std. Dev.	Minimum	Maximum
Education of household head (Edu)	4.04	4.43	0	16
Annual livestock maintenance cost (C)	6,402	6,375	200	31,000
Water access index (W)	2.47	2.13	0.43	10
Distance to grazing points (D)	0.93	0.72	0.1	3

Formal education levels remain low, averaging only 4 years of schooling, highlighting a reliance on traditional knowledge systems and underlining the need for user-friendly, low-maintenance biogas designs. Capital investments allocated toward annual livestock maintenance costs (C) average KES

6,402.00. Physical production constraints and resource endowments are represented by water access and grazing distances. The water access index (W) was computed as the reciprocal of distance (km⁻¹) to transform physical isolation into a direct measure of resource access; thus, higher index values

indicate closer proximity to water infrastructure. The sampled households exhibit a mean water access index of 2.47 km^{-1} with a deviation of 2.13 km^{-1} , spanning from a highly constrained minimum access score of 0.43 km^{-1} to a maximum of 10.00 km^{-1} . Expressed as physical distance, this corresponds to a range from approximately 0.10 km to 2.33 km from the household to its water source. Given that water is required in

roughly equal mass to feedstock for digester operation, this range in access translates directly into a difference in daily household labour and represents a critical structural vulnerability within the Mt. Suswa region. The physical distance to livestock grazing points (D) averages 0.93 km, with a minimum of 0.10 km and a maximum of 3.00 km, defining the daily geographic boundaries of feedstock availability.

Table 4. Descriptive Statistics for Categorical/Binary Variables ($n = 114$).

Variable	Attribute (Value = 1)	Frequency (n)	Percentage (%)
Cultural perception (Cp)	Compatible with biogas	73	64.04%
Awareness of biogas technology (At)	Aware	70	61.40%
Livestock feed management (F)	Communal grazing	49	42.98%
Primary energy source for cooking (Ep)	Modern (LPG/improved jiko)	25	21.93%

64.04% view biogas generation as culturally compatible ($C_p = 1$) rather than a taboo. Biogas technology awareness (At) is similarly established at 61.40%. In terms of livestock production styles, 42.98% of households utilize communal livestock feed management ($F = 1$), leaving 57.02% practicing individual grazing. Notably, only 21.93% of households use

modern primary energy (Ep), such as LPG or improved jikos, showing that 78.07% still rely heavily on traditional biomass (firewood/charcoal) - the precise energy deficit this biogas framework intends to alleviate.

3.2. Distribution of Feedstock and Potential Biogas Yield

Table 5. Summary Statistics of Feedstock and Potential Yield.

Statistic	Qd, normal grazing (kg)	Qd, migration period (kg)	Qd, annual total (kg)	Y, potential biogas (m^3/yr)	ln Qd_Annual	ln Y
n	114	114	114	114	114	114
mean	23,603.68	1,668.67	25,272.36	1,263.62	9.72	6.72
median	14,850	891	15,741	787.05	9.66	6.67
sd	23,532.48	2,164.84	24,301.9	1,215.1	0.94	0.94
cv	1.00	1.30	0.96	0.96	0.10	0.14
q1	7,425	594	8,910	445.5	9.09	6.10
q3	29,700	1,485	32,001.75	1,600.09	10.37	7.38
IQ range	22,275	891	23,091.75	1,154.59	1.28	1.28
min	1,633.5	0	1,782	89.1	7.49	4.49
max	103,950	13,068	107,365.5	5,368.28	11.58	8.59

Annual feedstock availability averaged 25,272 kg per household against a median of 15,741 kg. Potential biogas yield is a fixed proportion of feedstock, $Y = 0.05 \text{ Qd}$, so the

distribution of Y reproduces that of Qd exactly up to scale. Mean potential yield was $1,263.6 \text{ m}^3$ per household per year, against a median of 787 m^3 .

3.3. Resource Mobilization Efficiency of Biogas Feedstock

To evaluate how efficiently pastoralist households can extract and consolidate their potential bio-energy resources, the Battese and Coelli [16] SFA framework is deployed. The study area is in a pre-adoption technology phase; the model is therefore specified, following Coelli et al. [43], as an ex-ante Stochastic Feedstock Mobilization Frontier. This framework measures how efficiently a household can consolidate its calculated potential feedstock ceiling given its spatial, environmental and behavioral constraints.

3.3.1. Functional Form Selection and Specification Diagnostics

To test the validity of the SFA framework over an ordinary OLS specification, a Likelihood Ratio (LR) test was conducted. The null hypothesis (H_0) specifies that resource mobilization inefficiency effects are absent from the model ($H_0: \gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$). The OLS model yielded a log-likelihood of -90.409 , whereas the Cobb-Douglas Efficiency Effects Frontier (EEF) increased the log-likelihood to -78.399 . The resulting LR test statistic ($\chi^2 = 24.019$, 6 degrees of freedom) is highly significant ($P < .010$). Consequently, the null hypothesis of zero resource mobilization inefficiency is rejected. This confirms that classical OLS regression is inadequate due to the significant presence of resource mobilization

inefficiency in the sample, validating the stochastic frontier approach.

Following the justification of a stochastic frontier framework, a nested LR test was performed to determine the most appropriate functional form for the resource mobilization frontier, comparing the restrictive Cobb-Douglas specification against the flexible Translog model. The null hypothesis (H_0) posits that the second-order parameters (the coefficients of the squared inputs and cross-input interaction terms) are jointly equal to zero, meaning that the production technology collapses to a standard Cobb-Douglas form. The Cobb-Douglas EEF restricted model yielded a log-likelihood of -78.399 ($df = 12$), while the unconstrained Translog specification increased the log-likelihood to -62.582 ($df = 21$). This structural expansion results in an LR test statistic χ^2 of 31.634 ($df = 9$, $P = .00023$), providing evidence to reject the null hypothesis. This indicates that the Cobb-Douglas model suffers from structural misspecification: the constant unitary elasticity of substitution ($\sigma = 1$) restriction imposed by Cobb-Douglas does not hold for this sample. Consequently, the Translog stochastic frontier model is statistically superior and is selected as the framework for evaluating resource mobilization frontier dynamics and mobilization efficiency. The mean efficiency from the Cobb-Douglas model was 0.7223 ; while that of the preferred Translog model, is 0.6704 . All subsequent results are based on the Translog specification. Table 6 presents the MLE estimates.

Table 6. Translog Resource Mobilization Frontier and Inefficiency Effects Estimates.

Variable	Coefficient	Std. Error	z-Statistic	p-Value	95% CI (Lower, Upper)
Frontier (LnY)					
(Intercept)	7.1639	0.1538	46.585	< 0.001 ***	6.8625, 7.4653
ln(W)	-0.1428	0.1043	-1.37	0.1708	-0.3472, 0.0615
ln(D)	0.3463	0.0875	3.958	< 0.001 ***	0.1748, 0.5178
F (dummy)	-0.2834	0.0915	-3.097	0.0020 **	-0.4627, -0.1040
ln(C)	0.3445	0.0671	5.135	< 0.001 ***	0.2130, 0.4759
$0.5 \times [\ln(W)]^2$	0.0781	0.0857	0.911	0.3621	-0.0898, 0.2461
$0.5 \times [\ln(D)]^2$	0.0587	0.0618	0.949	0.3425	-0.0625, 0.1798
$0.5 \times [\ln(C)]^2$	-0.0361	0.0568	-0.636	0.5247	-0.1474, 0.0752
$\ln(W) \times \ln(D)$	-0.1910	0.0928	-2.059	0.0395 *	-0.3728, -0.0092
$\ln(W) \times F$	0.0354	0.1406	0.252	0.8014	-0.2402, 0.3110
$\ln(W) \times \ln(C)$	-0.0091	0.0935	-0.097	0.9226	-0.1923, 0.1741
$\ln(D) \times F$	-0.1680	0.1201	-1.399	0.1620	-0.4035, 0.0675
$\ln(D) \times \ln(C)$	0.0443	0.0716	0.619	0.5362	-0.0960, 0.1846
$F \times \ln(C)$	-0.0377	0.1041	-0.362	0.7174	-0.2418, 0.1664
Inefficiency (Z)					

Variable	Coefficient	Std. Error	z-Statistic	p-Value	95% CI (Lower, Upper)
Z (Intercept)	0.3716	0.2979	1.247	0.2123	-0.2124, 0.9555
Z_Cp	-0.8727	0.3440	-2.537	0.0112 *	-1.5470, -0.1984
Z_Edu	0.0542	0.0247	2.196	0.0281 *	0.0058, 0.1026
Z_At	0.4697	0.2460	1.910	0.0562 †	-0.0124, 0.9518
Z_Ep	-0.6706	0.3593	-1.867	0.0620 †	-1.3748, 0.0335
Variance Parameters					
sigmaSq (σ^2)	0.2611	0.0858	3.044	0.0023 **	0.0930, 0.4292
gamma (γ)	0.6217	0.2008	3.097	0.0020 **	0.2283, 1.000

Notes: $n = 114$; log-likelihood = -62.582; mean resource mobilization efficiency = 0.6704. Significance: * $p < 0.001$, $p < 0.01$, * $p < 0.05$, † $p < 0.10$. $\sigma^2 = (\sigma_u^2 + \sigma_v^2)$ represents the total composite error variance, combining white noise (σ_v^2) and inefficiency (σ_u^2). The gamma parameter ($\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$) indicates that 62.17% of the composite error variance is attributable to systemic inefficiency. Because γ is bounded on $[0, 1]$ and its 95% confidence interval reaches the upper boundary (1.000), the Wald/z-test reported for γ should be treated cautiously; the one-sided likelihood-ratio test in Section 3.3.1, which does not rely on the same boundary-sensitive asymptotic approximation, is the more reliable basis for concluding that inefficiency is present. Interpretation note: in the Battese and Coelli [16] framework, a negative coefficient in the Z vector means the variable reduces inefficiency (thereby increasing resource mobilization efficiency). Coefficients are reported as raw deltas.

The technical inefficiency effects model was specified following Battese and Coelli [16], wherein the inefficiency term u_i is assumed to follow a truncated normal distribution ($u_i \sim N(\mu, \sigma^2)$), with the mean parameterized as a linear function of household-specific determinants (Z-variables). By modeling $\mu = \delta Z_i$, the formulation explicitly accounts for non-zero mode heterogeneity across the $n = 114$ sampled households. This ensures that the predicted mean resource mobilization efficiency of 67.04% is robustly estimated without imposing an unconditioned zero-mean half-normal restriction.

3.3.2. Production Frontier Function Components

The first-order frontier coefficients reveal that the primary physical inputs exhibit strong individual effects. The cost of livestock maintenance had a significant positive effect ($\ln C = 0.3445$, $P < .001$), as does the distance to grazing points ($\ln D$

$= 0.3463$, $P < .001$). Conversely, the baseline first-order coefficient for the water access index ($\ln W = -0.1428$, $P = .1708$) remains negative and fails to achieve statistical significance at conventional levels. A higher value of $\ln W$ indicates closer water proximity; the negative coefficient therefore implies that households with greater water access face reduced feed-stock mobilization pressure, a possible reflection of pastoral production dynamics. The binary dummy variable F introduces a significant negative structural shift ($F = -0.2834$, $P < .010$) to the overall frontier baseline. The interaction term $\ln(W) \times \ln(D)$ is significant at the 5% level ($\ln W \times \ln D = -0.1910$, $P < .05$). The economic relationship is uncovered by computing the partial production elasticities at the sample mean, holding livestock feed management (dummy) at communal grazing ($F = 1$) and at individual grazing ($F = 0$). Table 7 presents the resulting elasticities.

Table 7. First-Order Frontier Input Elasticities.

Input	Individual grazing ($F = 0$)	Communal grazing ($F = 1$)
$\ln(W)$ - Water access index	-0.1428	-0.1075
$\ln(D)$ - Distance to grazing points	0.3463	0.1783
$\ln(C)$ - Cost of livestock maintenance	0.3445	0.3068
Overall Returns to Scale (RTS)	0.5480	0.3776
Structural frontier shift	0.00%	-24.68%

Because the dependent variable ($\ln Y$) represents a deterministic potential biogas yield mathematically derived from livestock counts, these elasticities map the binding structural constraints of pastoral herd economics across different management regimes.

Under both grazing systems, the annual cost of livestock maintenance ($\ln C$) yields a positive partial elasticity (0.3445 for individual and 0.3068 for communal). Because higher capital expenditure on veterinary care, feed supplements, and herd security directly tracks larger, healthier herd scales, $\ln C$ acts as a reliable monetary proxy for intensive livestock capital investment. Additionally, distance to grazing points ($\ln D$) also shows positive elasticities under both regimes (0.3463 for individual; 0.1783 for communal), suggesting that within these spatial frameworks, households traveling further often maintain access to larger or more viable grazing patches to sustain herd sizes, though this effect is halved under communal systems. Conversely, the water access index ($\ln W$) displays negative partial elasticities under both regimes (-0.1428 for individual; -0.1075 for communal). Because W is defined as reciprocal distance, a higher index denotes closer proximity to water, so these coefficients indicate that households situated nearer to water infrastructure hold smaller effective herds. This is consistent with settlement congestion around permanent water points: proximity to water attracts settlement, which in turn intensifies grazing pressure on the surrounding rangeland and constrains sustainable herd size. The result should not be read as indicating that water access impedes production; rather, the sites offering the best water access are also those under the greatest competing pressure on pasture.

Crucially, the Overall Returns to Scale (RTS), calculated as the sum of the partial elasticities for $\ln W$, $\ln D$, and $\ln C$, is highly inelastic under both systems, remaining severely constrained at 0.5480 for individual grazing and dropping even lower to 0.3776 under communal grazing. Under a standard SFA, $RTS < 1$ from the partial elasticities of production inputs means that scaling inputs does not proportionally increase output, implying decreasing/diminishing returns to scale. The decreasing returns to scale observed provide empirical evidence that increasing livestock maintenance costs and grazing distance simultaneously, within the current socio-spatial framework, does not result in a proportional expansion of predictable potential bio-resource capacity. The landscape itself imposes a strict economic ceiling on resource accumulation. This ceiling becomes starkly visible when moving from individual to communal grazing, where the structural frontier shifts downward by -24.68%. This shift represents a severe penalty on potential bio-resource yield inherent to the communal grazing system, likely driven by pasture degradation and shared-resource friction.

This environmental constraint is explicitly verified by the structural interaction term between water access and grazing distance ($\ln W \times \ln D$, $\beta = -0.1910$, $P < .05$). This statistically significant negative parameter demonstrates a compounding

spatial constraint: when the water access index and distance to grazing points expand simultaneously, the pastoral household's capacity to maintain stable herd dynamics drops non-linearly. This trade-off effectively strips the frontier of structural resilience, consistent with spatial fragmentation and resource isolation acting as significant bottlenecks to resource mobilization under both individual and communal systems.

3.3.3. The Inefficiency Effects Model

The inefficiency effects model was estimated simultaneously with the stochastic production frontier to identify the socioeconomic and behavioral frictions that prevent households from achieving their maximum potential resource mobilization frontier. In the Battese and Coelli [16] SFA framework, a negative coefficient in the Z -vector means the variable reduces inefficiency (thereby increasing resource mobilization efficiency). Results are presented in Table 6.

Cultural perception ($Z_Cp = -0.8727$, $P < .05$) emerged as a statistically robust and impactful determinant within the inefficiency model. The negative sign indicates that a positive cultural alignment with bio-digestion technology is associated with substantially lower measured inefficiency, bringing the household closer to its maximum potential resource frontier. This finding provides empirical support for the Multi-Level Perspective (MLP) on socio-technical transitions [44, 45]. Within the MLP framework, a successful technology shift requires alignment between the macro-level landscape and the meso-level institutional regime. In pastoral ASALs, deep-seated cultural norms regarding open-range livestock prestige, taboos surrounding animal waste handling, and traditional wood-fueled cooking habits constitute an incredibly rigid regime. The statistical dominance of cultural perception in the inefficiency model indicates that cultural alignment is the strongest observable correlate of resource mobilization efficiency in this sample. Cultural buy-in is associated with households reorganizing their daily routines in ways that capture and preserve the resource potential of their livestock; because the design is cross-sectional and non-experimental (Section 2.1), this association should not be read as establishing that cultural acceptance causes the reorganization, and reverse causality or unmeasured confounders such as household wealth cannot be ruled out.

Formal education ($Z_Edu = 0.0542$, $P < 0.05$) is positive and statistically significant, indicating that higher formal educational attainment by the household head increases resource mobilization inefficiency. Because $\ln Y$ is a deterministic function of herd size, this statistical paradox is deeply rooted in Modigliani's Life-Cycle Hypothesis [22, 23] and Chayanov's theory of the peasant economy [24], as applied to pastoral economies [25, 26]. These frameworks were introduced in Sections 1.1.3 and 1.1.4 as ex-post interpretive tools for this unanticipated finding. In pastoral ASAL systems, asset accumulation is a multi-decadal process driven by time, inheritance, and social reciprocity. Older household heads have

spent lifetimes accumulating substantial livestock wealth. While they frequently lack formal education, their large biological capital naturally positions them at the ceiling of the calculated potential yield (LnY). This demographic friction also explains the behavior of the technology awareness variable (At): its positive, marginally significant coefficient demonstrates that superficial, informational awareness campaigns do not overcome structural asset deficits. Table 8 outlines the frequency distribution of household resource mobilization efficiency scores derived from the Translog model.

Table 8. Frequency Distribution of RME Scores.

Efficiency Range	Number of Households	Percentage
< 0.40	13	11.40%
0.40 - 0.59	19	16.67%
0.60 - 0.79	46	40.35%
0.80 - 0.89	34	29.82%
≥ 0.90	2	1.75%
Total	114	100%

The modal cohort consists of 46 households (40.4%) clustering within the 0.60-0.79 range, representing a transitional tier that maintains basic herd stability but fails to systematically exploit its raw resource base. Crucially, 28.1% of the sample falls completely below an RME score of 0.60, indicating a substantial collapse in resource tracking. The ultimate driver of this operational variance is uncovered by the net structural effect of the livestock feed management dummy variable, which reveals a total marginal impact of -24.68% when $F = 1$. Under a communal open-access grazing regime ($F = 1$), a household's resource consolidation efficiency plummets by nearly a quarter compared to individual management ($F = 0$). The institutional structure of communal grazing creates an irreconcilable gap between theoretical bio-resource potential and actual logistical harvest-ability, dragging 28.1% of potential users into severe efficiency deficits (< 0.60 RME).

Counterfactual estimates suggest that optimizing current systems to close half of this resource mobilization efficiency gap would deliver immediate economic and environmental dividends. It would save households an average of KES 18,303 and displace 1.26 tonnes of firewood per household annually, unlocking vital climate-resilience and indoor-air-quality benefits without requiring any expansion of baseline herd sizes.

The counterfactual benefits are calculated as follows:

- 1) Current mean resource mobilization efficiency (RME = 67.04%); total inefficiency gap = 32.96%. Closing half the gap: $32.96\% \times 0.50 = 16.48\%$. Target efficiency: $67.04\% + 16.48\% = 83.52\%$.

- 2) Additional biogas yield realized = additional RME $\times$ average annual biogas yield = $0.1648 \times 1,263.6 \text{ m}^3 = 208.24 \text{ m}^3$ of biogas per household per year.

- 3) Firewood displaced: using the SNV [10] benchmark (1 m^3 biogas = 6.07 kg dry fuelwood), firewood saved = $208.24 \text{ m}^3 \times 6.07 \text{ kg/m}^3 = 1,264.02 \text{ kg}$, approximately 1.26 tonnes per household per year.

- 4) Monetary savings in KES, based on baseline prices of KES 14.48/kg [7]: KES savings = $1,264.02 \text{ kg} \times \text{KES } 14.48/\text{kg} = \text{KES } 18,303$ per household per year.

These empirical findings offer direct, actionable insights for Kenya's Bioenergy Strategy and the United Nations Sustainable Development Goal 7 (SDG7: Affordable and Clean Energy).

National frameworks should focus on institutional land-use: the model indicates that 28.1% of prospective feedstock mobilizers operate below 60% of their calculated potential given current resources, and the overall mobilization function faces a highly inelastic RTS (0.3776). Furthermore, the marginal association of primary energy utilization ($E_p = -0.6706$, $P < .10$) is consistent with households that have already begun transitioning away from traditional biomass showing lower measured inefficiency; given the cross-sectional design, this association does not establish that the transition causes closure of the efficiency gap.

To successfully scale renewable energy transitions across African ASALs, policymakers should focus on spatial intensification and waste centralization. Communal grazing ($F = 1$) collapses waste collection efficiency by 24.68%; policy must actively incentivize a transition toward localized individual paddock systems or community-managed night-kraals. This institutional land-use adjustment restricts open-range waste scattering, directly reducing the labor cost of waste harvesting and validating the baseline collection assumptions of renewable energy models.

To mitigate the negative water elasticity (-0.1075) and the severe compounding shock of the water-grazing interaction vector ($\ln W \times \ln D = -0.1910$, $P < .05$), energy planners should advocate for co-location of water and energy infrastructure. Reducing the spatial and physical labor burden of water hauling stabilizes the household labor supply, allowing pastoral families to successfully bridge the 32.96% gap between their raw livestock resource potential and their realizable energy security.

4. Conclusions and Recommendations

4.1. Conclusions

Stochastic frontier analysis reveals that the operation of specialized green assets in a pastoral economy does not conform to conventional development assumptions. The estimated Translog resource mobilization frontier is severely constrained by a compounding spatial penalty, where water access interacts negatively with grazing distance. Concurrently,

the inefficiency model exposes an education-labor paradox: higher formal education levels are associated with a counter-intuitive increase in mobilization inefficiency, and superficial technology awareness becomes an efficiency liability when it diverts attention from active livestock management. Additionally, pastoralist households in Mt. Suswa face a substantial resource mobilization efficiency deficit. This operational gap is fundamentally driven by livestock management choices, such as the annual cost of herd maintenance, which carries the highest positive frontier elasticity under communal grazing. Cultural compatibility remains the most dominant lever for closing this gap.

4.2. Policy Recommendations

Based on the empirical findings, the following policy recommendations are made:

1) *Culturally Anchored Extension Pilot*

Narok County Government and Kajiado County Government, through their respective Departments of Energy should partner with respected Maasai cultural elders (*ilaiguanak*) to pilot a biogas extension programme across Mt. Suswa that frames the technology as a clean asset-preservation tool, directly breaking the cultural barrier.

2) *Reoriented Vocational Training Framework*

Sub-county agricultural officers should prioritize training slots for domestic farm laborers and family members who handle daily livestock chores, rather than focusing solely on the formally educated household heads.

3) *Subsidized Fixed-Dome Asset Financing*

Narok County should establish a revolving credit fund subsidy to encourage the adoption of masonry-built fixed-dome biogas digesters.

4) *Co-location of Water and Energy Infrastructure*

County water departments should integrate water-point siting as an energy planning instrument, and the benefit stream in appraisal should be measured as displaced household labour rather than as an abstract efficiency gain.

5) *Joint Narok-Kajiado Implementation Framework*

The two counties (Narok and Kajiado) should establish a joint implementation framework for pastoral bioenergy, which would also serve as a template for the wider problem in devolved ASAL planning of administrative boundaries partitioning rangeland systems that function as a single unit.

6) *Promote and Incentivize Localized Paddocking and Semi-Zero Grazing*

The Narok County livestock department should provide targeted financial instruments, such as subsidized fencing materials and water-trough installation, to enable pastoralists to establish enclosed paddocks promoted as climate-adaptation strategies in order to align livestock management directly with household clean-energy infrastructure.

Abbreviations

ASAL	Arid and Semi-Arid Lands
CIDP	County Integrated Development Plan
DRS	Decreasing/Diminishing Returns to Scale
EPRA	Energy and Petroleum Regulatory Authority
GDP	Gross Domestic Product
IEA	International Energy Agency
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
KIPPRA	Kenya Institute for Public Policy Research and Analysis
KES	Kenya Shilling
KNBS	Kenya National Bureau of Statistics
MLP	Multi-Level Perspective
RME	Resource Mobilization Efficiency
SFA	Stochastic Frontier Analysis

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Author Contributions

Parsariro Agnes Naini: Conceptualization, Data curation, Methodology, Visualization, Writing – original draft

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Data Availability Statement

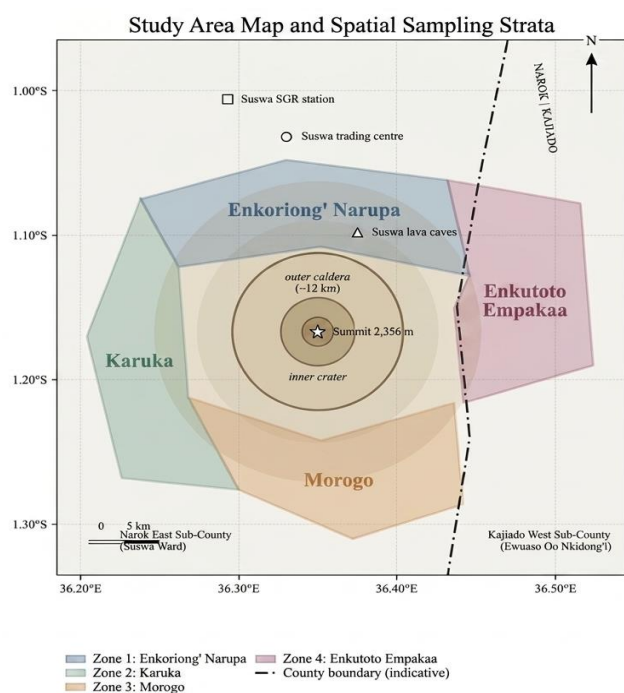
The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflict of interest.

Appendix

Study Area Map



Source: Author (2026)

Figure A1. Study Area Map and Spatial Sampling Strata.

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Biography



Parsariro Agnes Naini is an economist and researcher with a focus on economic policy and development. She earned her Bachelor of Science degree in Economics and Statistics (first-class honors) from Machakos University in 2022 and is completing her Master of Science degree in Economic Policy Analysis and Management at Maasai Mara University in December 2026. Her research interests include development economics, agricultural economics, natural resources, energy systems, renewable energy, resource-use efficiency, and sustainable, inclusive socioeconomic development.



Maurice Ochieng Ombok is a Senior Economist and Dean of the School of Business and Economics at Maasai Mara University, with over 20 years of research, policy and consulting experience across Kenya, East Africa and the COMESA region. His core expertise lies in Environmental & Natural Resource Economics, anchored by a PhD from Kenyatta University and research spanning land-use change, wetland valuation, water accessibility, artisanal mining and biogas policy for climate-smart agriculture. Building on this foundation, he has expanded his research into Energy Economics, serving as

Technical Expert on a KSH 44 million-equivalent CNRS Joint Research Programme (2023-2027) on low-technology alternative energy production in East Africa.



Job Ochieng Ogada is an experienced professional with expertise in Agricultural Economics, Natural Resource Management, and Environmental Economics. He holds a Master of Science degree in Agricultural Economics. His work focuses on agricultural development, sustainable natural resource management, environmental sustainability, and evidence-based policy analysis.

Research Field

Parsariro Agnes Naini: Development economics, Agricultural economics, Natural resource economics, Industrial economics, Energy economics

Maurice Ochieng Ombok: Environmental & Natural Resource Economics, Energy Economics, International Trade Economics

Job Ochieng Ogada: Agricultural Economics, Natural Resource Economics, Environmental Economics