

**The KENYA INSTITUTE for PUBLIC
POLICY RESEARCH and ANALYSIS**

Integrating Adaptive Forest Management and Transition to Alternative Energy Sources in Kenya's Tea Industry

Kaloi F. Kadipo and Rose W. Ngugi

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**THE KENYA INSTITUTE FOR PUBLIC POLICY
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Abstract

Tea processing is an energy-intensive process that requires substantial heat, mainly from fuelwood, to reduce green leaves' moisture and to dry fermented black tea. This has led to the demand for fuelwood exceeding supply. As a result, tea factories exploit the forests within their catchment areas, falling short of the necessary forest cover requirements and contributing to ecological imbalances. To address this issue, tea factories, particularly those managed by KTDA, have pursued two primary avenues for optimal energy sourcing: creating their fuelwood plantations and using briquettes for co-firing alongside fuelwood. However, the high cost of acquiring sufficient land, alongside the expenses of planting and maintaining fuelwood plantations until maturity, compared to the adoption of briquettes, is a significant challenge for these tea factories. Against this background, this study aimed to assess the pathway to the desired energy mix for KTDA tea factories and examine the factors that define this energy mix. The study was informed by the Diffusion of Innovation (DOI) theory. The main data source was the KTDA Fuelwood Plantation Programme (2015-2023). The study adopted the Ordinary Least Squares model. The findings indicate that tea factories are harvesting less than their established targets from their plantations. Furthermore, despite a 620-acre target for fuelwood production, many factories struggle to meet their goals. Those acquiring less than 50 per cent of the target land generate only 8.0 per cent of their energy needs from their own plantations, while those achieving at least 50 per cent of the target produce 13.1 per cent of their energy requirements. Additionally, the adoption of briquettes remains low, typically below 5.0 per cent. Therefore, the tea factories are at a very early stage of energy transition. Based on the findings, tea factories could enhance the alignment of tree species with site conditions to improve growth and yield. Additionally, factories could aim to harvest mature trees once they reach 6-8 years of age for optimal productivity. There should be an increase in the adoption of briquettes to boost their usage beyond the current low rates. Factories that have not acquired the necessary land could strive to meet the 620-acre target for fuelwood production to enhance energy self-sufficiency.

Abbreviations and Acronyms

AFM	Adaptive Forest Management
ASE	Alternative Sources of Energy
BETA	Bottom-up Economic Transformative Agenda
CSPT	Concentrating Solar Power Technology
DOI	Diffusion of Innovation
ITC	International Trade Centre
GHGs	Greenhouse Gas Emissions
KEFRI	Kenya Forest Research Institute
KFS	Kenya Forest Service
KTDA	Kenya Tea Development Agency
NDCs	Nationally Determined Contributions
TESA	Tea Extension Service Assistant
VAT	Value Added Tax

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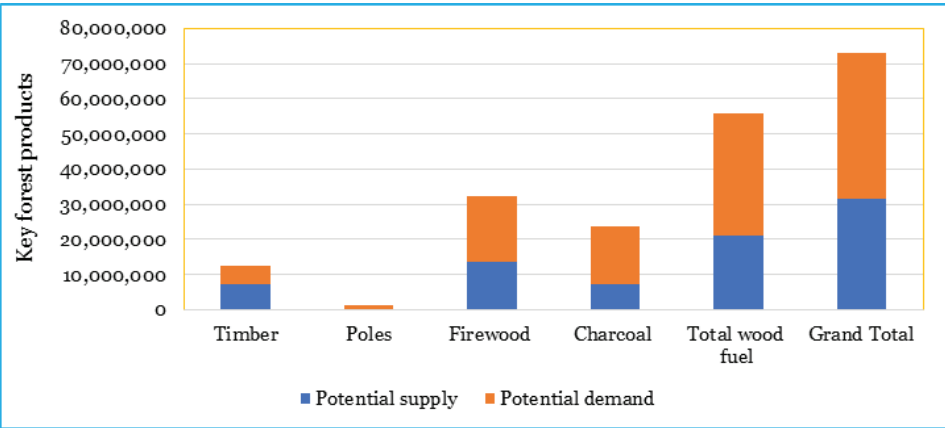
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1. Introduction

Kenya’s tea industry produces nearly one billion kilogrammes of green tea leaves each year (Mose et al., 2015). Tea processing is an energy-intensive operation, requiring approximately 85-88 per cent of energy in the form of heat and the remainder as electrical energy (Oduor and Githiomi, 2012). The heat energy is used to reduce the moisture content of the green leaf and to dry fermented tea into black tea, while electric energy powers the machinery. Currently, nearly all the heat energy used in tea processing in Kenya is derived from burning fuelwood. The Kenya Tea Development Agency (KTDA) manages 71 tea factories, which are central to the country’s tea production. These factories obtain their fuelwood from three main sources: their own plantations, government forests through licensed suppliers, and the lands of smallholder farmers (Republic of Kenya, 2018).

To produce one (1) kilogramme of tea, each factory requires two (2) kilogrammes of firewood, resulting in an average daily requirement of 250 trees per factory (Kagombe et al., 2015). KTDA tea factories require approximately three million cubic metres of firewood every year, equivalent to 5.7 million trees annually for processing tea (Republic of Kenya, 2018). As a result, factories have reported rising fuelwood costs and a decreasing wood supply, which is their primary source of heat energy (Magu, 2019). According to Kagombe et al. (2015), Kenya has the potential to sustainably supply 31,372,531 cubic metres of roundwood, broken into poles (9.7%), timber (12.6%), firewood (43.5%), and charcoal (23.5%). However, the demand for fuelwood is significantly higher at 41,700,664 cubic metres, with the deficit exceeding demand by 50 per cent, which compels fuelwood users, including tea factories, to seek alternative energy sources (Figure 1.1).

Figure 1.1: National supply and demand potential for key forest products (m³)



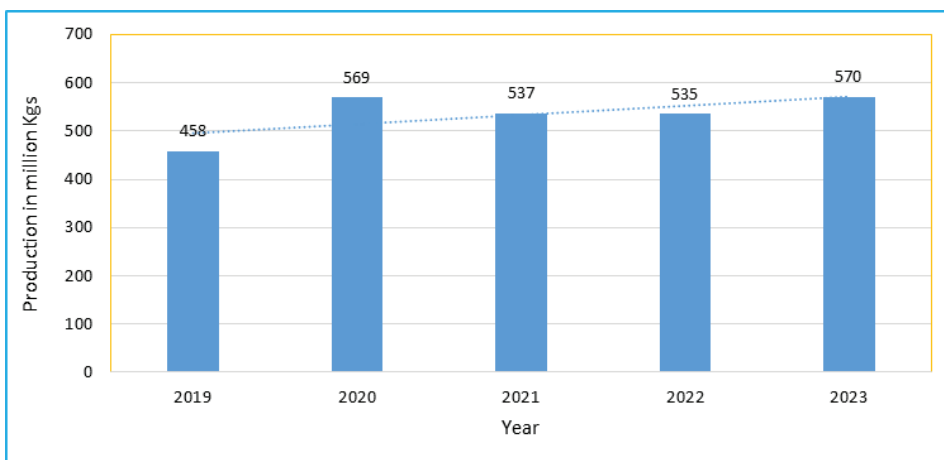
Source: MEWNR (2013)

The shortage of fuelwood has prompted the KTDA to buy or lease land for growing trees for firewood. However, the high costs associated with acquiring sufficient land and the expenses of planting and maintaining the fuelwood plantations until maturity pose significant challenges for the tea factories (Kagombe et al., 2015). To address this challenge, the factories have also recognized the potential of briquettes to supplement firewood in their processes. Briquettes, which have been introduced in tea factories through co-firing (mixing firewood and briquettes in a ratio of 70:30 in boilers), are not yet widely adopted. Recent studies indicate that operational challenges, high costs, and the distance between briquette factories and tea factories are significant barriers to their adoption (Suryani et al., 2022; Magu, 2019). This study, therefore, aimed to investigate how KTDA tea factories in Kenya are adopting alternative sources of energy (fuelwood from their own plantations and briquettes) while contributing to reduced demand pressure on forest products. Specifically, the study aimed to achieve the following objectives: analyze the path to the desired energy mix for KTDA tea factories and examine the factors that define the energy mix for KTDA factories.

2. Kenya's Tea Industry

Kenya plays a significant role in the global black Curl Tear and Cut (CTC) tea market, producing over 450 million kilogrammes of made tea annually, generating more than Kenya Shillings (Ksh) 120 billion in export earnings and Ksh 22 billion in local sales (KNBS, 2023). The industry directly and indirectly supports around five (5) million people, with approximately 650,000 tea growers depending on tea cultivation, making it one of the leading sources of livelihood in Kenya. It is a major foreign exchange earner, contributing roughly 23 per cent of total foreign exchange earnings and 2.0 per cent of the agricultural GDP. Over the past five years, tea production has increased significantly, from 458.85 million kilogrammes in 2019 to 570.26 million kilogrammes in 2023 (Figure 2.1). KTDA accounts for more than 60 per cent of the total tea production in Kenya.

Figure 2.1: Tea production trends in Kenya



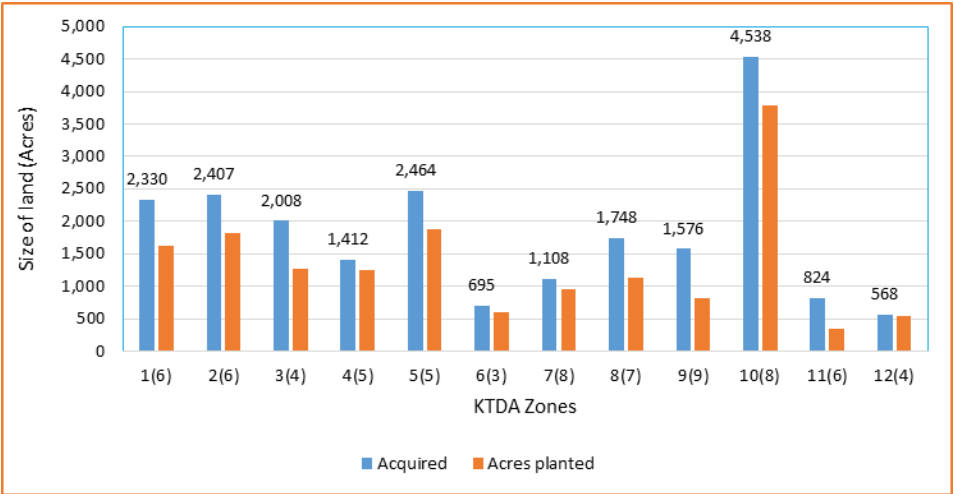
Source: Tea Board of Kenya (2024)

2.1 The Transition to Alternative Sources of Energy by KTDA Factories

The cumulative firewood consumption across KTDA factories over the past five years (2018-2023) totalled 5,735,269 cubic metres, with an average annual consumption of 1,147,053.8 cubic metres. Variations in firewood usage among different factories are closely linked to the levels of Greenleaf production within their respective catchment areas. In 2015, KTDA factories initiated the fuelwood plantation programme to secure a sustainable source of firewood. The programme saw gradual progress as factories acquired land and began planting eucalyptus trees, a fast-growing species. However, it gained significant momentum in 2018 when the Government imposed restrictions on logging, prompting KTDA to invest further in its plantations. Each KTDA-affiliated factory was required to purchase a total of 620 acres of land, resulting in a cumulative target of 44,020 acres, which

was expected to yield a total of 6,603,000 cubic metres of fuelwood after a rotation period of six to eight years. By 2020, factories had cumulatively acquired 21,678 acres and planted 15,993 acres. The programme has demonstrated steady growth, with a significant increase in land acquisition and planting, as illustrated in Figure 2.2.

Figure 2.2: Status of fuelwood programme in KTDA factories



Source: Authors' own compilation

The tea factories have also been actively incorporating briquettes to supplement firewood. The country has the potential for briquette production, as the raw materials are readily available (UNEP, 2019). Additionally, KTDA factories have explored alternative energy sources to enhance sustainability and reduce costs, particularly with regard to electricity, which constitutes 3-5 per cent of factory expenses. Factories in the same tea zone established Regional Power Companies (RPCs) to invest in small hydropower (SHP) projects, offering more stable and potentially cheaper electricity. This strategy has resulted in additional revenue generation from selling the excess power produced to the national grid. Wind energy has shown economic viability in several locations where tea factories operate in Kenya, though it addresses electricity needs rather than serving as a replacement for firewood. Various solar drying technologies have been researched for drying different types of tea, yet there is limited information on the feasibility of implementing these technologies in specific geographical areas (Suryani et al., 2022).

3. Literature Review

3.1 Theoretical Review

The adoption of technology is a vital component of a country's economy. Researchers have developed various theories to explain adoption across different sectors. This study establishes a theoretical framework based on the Diffusion of Innovation Theory, the Theory of Planned Behaviour, and Utility Theory. The three theories are discussed below.

3.1.1 *Diffusion of Innovation (DOI) Theory*

The Diffusion of Innovation (DOI) Theory, developed by Rogers (1983) describes diffusion as the process through which an innovation is communicated through specific channels over time among the members of a social system. The theory also suggests that diffusion represents a distinct form of communication, where messages pertain to new ideas. The main elements of the DOI theory include innovation, communication channels, infrastructure, and social systems (Rogers, 1983). In its most elementary form, the process involves an innovation, individuals or other units of adoption that have experience using the innovation, other individuals or units that do not have knowledge of the innovation, and the communication channels connecting the two units (Rogers, 1983). The perceived newness of an idea determines how an individual reacts to it. If an idea appears new to someone, it is regarded as an innovation. Innovation involves more than merely introducing new knowledge, as individuals or firms may be aware of innovation for some time but may not have developed a positive attitude or commitment towards it.

The newness aspect of an innovation may be expressed in terms of persuasion or a decision to adopt it (Rogers, 1983). The theory posits that the information exchange will determine whether a source transmits the innovation to the receiver and the effects of that transfer. For example, mass media channels such as radio, television, and newspapers are often the most efficient means of informing the audience about existing innovations (Rogers, 1983). The theory further posits that innovations perceived as having greater relative advantage, compatibility, observability, and trialability are more likely to be adopted than others.

3.1.2 *Theory of Planned Behaviour (TPB)*

The Theory of Planned Behaviour (TPB), developed by Icek Ajzen (1985) is a psychological framework that connects beliefs to actions. According to this theory, an individual's behavioural intentions are influenced by three key components: attitude, subjective norms, and perceived behavioural control (Irfan et al., 2021). These elements collectively shape the likelihood of an individual engaging in a particular behaviour (Li et al., 2020) only 6 per cent of Australia's total energy

consumption was derived from renewables, while 86.3 per cent of electricity was generated from fossil fuels. However, this trend has been disrupted by the recent decommissioning and closure of a fleet of ageing coal power plants, along with the country's international commitments to reduce fossil fuel emissions. Currently, Australia is at a crucial stage of its transition to renewable energy adoption. With the purpose of providing an updated depiction of renewable energy, related policy and the way ahead in the Australian context, this research paper presents a systematic review of contemporary literature from the perspectives of energy potential, utilization and policy incentives. The research analysed a total of 118 documents using an interpretivist epistemological lens. The emergent findings offer an evidence-based, lucid account of advancements in the renewable energy market. Polynomial regression analysis is also conducted on secondary data obtained from the literature to predict trends in the electricity generated by different sources of renewable energy. According to TPB, certain behaviours of individuals are determined by their behavioural intention, which measures the individual's willingness to engage in a particular behaviour. Therefore, TPB asserts that in addition to attitude towards behaviour and subjective norms, these factors also affect behavioural intention. Previous theoretical studies have used TPB to explain the adoption of technologies. The actual factors influencing consumer behaviour are rooted in behavioural intention. Purchase intention is affected by perceived subjective norms and attitude (Tu and Yang, 2019).

3.1.3 Utility Theory

The Utility Theory elucidates firm behaviour by positing that choices are consistently ranked based on preferences. Within this framework, the crucial consideration for utility regarding the choices made is whether one option holds higher utility than another, rather than quantifying the preference between available options. The decision-making process revolves around ordering the available options based on the benefits they offer (Jacksohn et al., 2019). The underlying assumption is that economic agents will opt for the alternative energy source when the expected utility or net benefit is significantly higher compared to the scenario where they do not adopt it (Hesselink and Chappin, 2019). Given the unobservable nature of utility, economic agents' actions can be gauged through their observable choices. For instance, a factory aiming to maximize production over a specific period, faced with a set of renewable energy options, would choose to adopt if the perceived utility surpasses that of other options.

This study adopts DOI Theory due to its comprehensive approach to understanding the adoption of new technologies. DOI Theory focuses on the processes and social dynamics of technology dissemination, offering insights into how innovations are adopted over time. It examines factors such as the characteristics of innovations, social networks, and communication channels, categorizing adopters into different groups to tailor strategies effectively. Unlike Utility Theory, which centres on individual decision-making based on perceived benefits and costs, DOI Theory's broader scope, including behavioural dynamics and contextual factors,

provides an understanding of technology adoption, making it particularly suitable for analyzing the complexities of new technologies in specific settings.

3.2 Empirical Review

Several studies have investigated the adoption of alternative energy sources in the tea sector. A study by Rawlins and Ashcroft, (2013) outlines the potential to accelerate the adoption of concentrated solar power (CSP) in developing countries. The main barriers identified were low awareness of CSP as a potential energy source for industrial processes and a lack of confidence in the technology's effectiveness under local conditions. Further, Kibet and Letema (2022) noted that the constant demand for energy for tea processing leads to increased environmental impacts and thus requires sustainable energy sources. The study recommends the use of briquettes as they are less bulky, yield high energy and have a relatively low environmental impact.

A study on RETs took place in the Wiyumiririe Location of Laikipia District (north-central Kenya) reviewed the use of unsubsidized solar panels. The findings revealed that nearly all respondents appreciated solar energy as a clean energy source. However, a few challenges associated with solar energy were raised, including the high capital investment and equipment maintenance costs. Furthermore, an investigation into the determinants of renewable energy adoption in Kenya indicated that investment costs significantly affect the adoption of renewable energy, particularly in solar systems. The installation costs for this technology were also found to be substantial. The study recommended better accessibility and lowering of transport costs of solar appliances for providers.

Further, a study examining the factors influencing the utilization of renewable energy in Kenya revealed that government promotional policies, socio-technical factors, economic fluctuations and technological factors influence the utilization of Alternative Sources of Energy (ASE) in the processing of tea (Mburugu and Gikonyo, 2019). The study suggests the need for training to enhance the level of awareness of the use of solar energy. The findings further indicated the need for the provision of incentives to encourage the tea industries to engage in the installation and implementation of solar energy technologies. Similar findings are suggested by Kimani et al. (2020), who assessed knowledge and awareness as determinants of renewable energy technologies. The overall findings of the study underlined the importance of strengthening communication to enhance knowledge and awareness of renewable energy technologies. This makes training essential for raising awareness of renewable energy technologies (Mosly and Makki, 2018).

Addressing environmental issues necessitates possible actions for sustainable development. Renewable energy resources seem to be among the most effective and efficient solutions. Additionally, potential solutions to present environmental challenges are identified alongside renewable energy technologies (Dincer, 2000). Renewable energy resources appear to be the one of the most efficient and effective solutions. That is why there is an intimate connection between renewable energy and sustainable development. The use of wind energy has been reported

as economically viable; however, it cannot replace firewood in the boilers of tea factories. Therefore, this solution can only address electricity demand for other purposes (Nordman and Nordman, 2014). A study in India investigated various renewable energy technologies, such as hydropower, wind, solar, and bioenergy waste. The study suggests that briquettes could supplement up to 83 per cent of heat energy requirements in the tea industry. It also proposes a combination of both biomass and solar energy for the withering of tea leaves and the drying of fermented tea (Kumar et al., 2021).

The use of briquettes by tea factories in Kenya is increasing rapidly in areas with abundant biomass, such as the sugar-belt region of western Kenya. In this region, significant amounts of sugarcane bagasse remain unutilized, leading to the emergence of industries supplying this bioenergy source to tea factories. To manage the cost of heat energy, tea factories have developed a working energy policy that aims to ensure energy efficiency in the sector (Suryani et al., 2022). Additionally, several tea factories have enhanced their wood fuel programmes and adopted alternative energy sources, such as briquettes (UNEP, 2019). A study on the drivers and barriers to substituting firewood with briquettes in Kenya's tea industry revealed that the thermal energy required for the withering and drying processes is traditionally obtained by burning firewood in boilers.

Additionally, the amount of firewood consumed in the factories varies according to their production capacity (Suryani et al., 2022). This study also highlights that Kenya has a promising bioenergy opportunity from crop residues such as husks and bagasse derived from ongoing agricultural production, including maize, sugarcane, and cassava. The study notes that briquettes have been introduced in several tea factories through co-firing. These studies emphasize the significance of transitioning to alternative energy sources in the tea sector to enhance adaptive forest management on a sustainable basis.

4. Methodology

The section discusses the theoretical and analytical framework and the measurement of variables.

4.1 Theoretical Framework

This study is underpinned by the Diffusion of Innovation Theory, which examines how various elements, including technology, innovation, and social systems, influence the adoption of alternative sources of energy by the tea factories in Kenya. This theory allows for operationalizing various elements (innovation, technology and social systems).

The tea industry's transition to alternative energy sources involves planting fast-growing trees, ensuring a sustainable supply of firewood. By sourcing firewood from these plantations, tea factories contribute to long-term environmental conservation outcomes. Furthermore, the introduction of briquettes as a supplementary fuel source for co-firing with firewood during the tea withering process is a practical measure to reduce firewood consumption. This strategy helps lessen reliance on firewood, decreases deforestation rates, and fosters more sustainable energy practices within the tea industry.

The size of a tea factory can be classified according to its optimal energy demand. Factories with a greater processing capacity can be regarded as larger, while those with a lesser capacity are smaller. The size of the factory affects resource dynamics, with larger factories exhibiting higher energy demands compared to smaller ones. Factories situated in densely populated areas may experience considerable pressure to establish their own plantations and briquettes due to intense competition for firewood among households and industrial needs. The heightened demand for fuelwood results in increased prices and potential scarcity, making it challenging for factories to secure a stable supply. Moreover, the limited availability of land for creating plantations in such areas adds to the complications. As a result, factories are often compelled to use briquettes for co-firing.

4.2 Analytical Framework

This section outlines the analytical framework employed to answer the objectives of this study: to analyze the path to the desired energy mix for KTDA tea factories and to examine the factors that determine the energy mix for KTDA factories.

4.2.1 *Readiness for energy transition in KTDA factories*

To assess whether KTDA tea factories were prepared for energy transition, two equations were estimated. The first was the ratio of the area of land acquired to the total target across all the 71 factories, and the second was the ratio of the total

area of land planted to the total land acquired. The Ordinary Least Squares (OLS) technique was employed for estimation. OLS provides the best linear unbiased estimators (BLUE), indicating that it has the smallest variance among all linear estimators when the classical assumptions are satisfied.

The empirical model specification is expressed using equations 1 and 2.

$$Y_i = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \varepsilon \quad 1$$

$$Y_2 = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \varepsilon \quad 2$$

Where Y_i is the amount of land purchased in relation to the total expected land (expressed as a percentage), and Y_2 is the amount of land planted in relation to the total land purchased (expressed as a percentage). $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ are the explanatory variables, including the age of the factory (measured as the number of years since inception), users of briquettes (as a measure of the alternative energy), size of the factory (as a measure of the annual energy demand by the individual factory), forest cover (as a measure of the proportion of forest per county), population density (as a measure of the number of persons per square kilometre), and access to credit (as a measure of those factories that have access to credit to adopt alternative sources of energy).

4.2.2 Factors influencing the energy mix

To determine the factors influencing the energy mix, two transition analyses were conducted. The first analysis employed the percentage of briquettes in relation to total energy as a measure of the energy mix. The second analysis considered the percentage of energy from fuelwood sourced from one's plantation compared to the total energy consumed in the factory as another measure of the energy mix. The Tobit model is the most suitable approach when the dependent variable is either censored a corner solution, or both. Therefore, the Tobit model was deemed appropriate for this analysis. The empirical models for the energy mix were as follows:

$$PWE = \beta_0 + AGE \beta_1 + SIZE \beta_2 + TREES \text{ HARVESTED } \beta_3 + \mu_i \quad 3$$

$$PBE = \beta_0 + AGE \beta_1 + SIZE \beta_2 + TREES \text{ HARVESTED } \beta_3 + LAND \text{ BOUGHT } \beta_4 + \mu_i \quad 4$$

μ_i is the normally distributed error term with zero and a constant variance of δ^2 which is explained by $\mu_i \sim N(0, \delta^2)$. β are the vector parameters to be estimated.

PWE refers to the percentage of energy derived from wood sourced from one's own plantation compared to the total energy; whereas PBE indicates the percentage of briquettes used in relation to total energy. The independent variables include the age of the factory, the size of the factory, the proportion of mature trees harvested, and the proportion of land acquired compared to the total expected.

4.3 Variable Specification and Measurement

This section highlights the descriptions of the various variables applied in determining the transition path and the factors influencing the energy mix among the KTDA factories. The measurement and descriptions of these variables are presented in Table 4.1.

Table 4.1: Measurement of variables for analysis

Variable	Description	Measurement
Dependent variables		
Y = alternative sources of energy	Measured as a ratio of briquettes to total energy Measured as a ratio of fuelwood from own plantation to total energy	Percentage
X ₁ = Size of the factory	Measured as the annual fuelwood demand for the factory	Cubic metres
X ₂ = Access to credit	Whether the factory has access to credit to adopt alternative sources of energy	Dummy variable: one (1) if the factory access credit, and zero (0) if otherwise
X ₃ = Proportion of land acquired	Measured as a ratio of land bought to target land to be bought	Percentage
X ₄ = Proportion of land planted	Measured as a ratio of land planted to total land bought	Percentage
X ₅ = Proportion of land harvested	Measured as a ratio of land harvested to total land planted	Percentage
X ₆ = Age of the factory	Measured as the number of years since inception	Years
X ₇ = Average annual consumption	Measured as the total amount of energy used during the withering and drying process per year	Cubic metres
X ₈ = Population density	Measured as the number of persons in a county per square kilometre	Number of persons per square kilometre
X ₉ = Forest cover	Measured as the ratio of forest land to total land in a county	Percentage

4.4 Data Sources

The study used primary and secondary data sources. The KTDA 2023 dataset on forest land acquisition encompasses the forest plantations of all 71 KTDA-managed tea factories. These factories are broadly categorized into seven regional clusters, which span fifteen counties: Kiambu, Murang'a, Nyeri, Kirinyaga, Embu, Meru, Tharaka Nithi, Bomet, Kericho, Nandi, Nakuru, Kisii, Nyamira, Kakamega, and Trans Nzoia (Annex 3).

The wood fuel development status provides information on the establishment of wood fuel plantations. It includes details on the target land designated for tree planting, the land acquired specifically for this purpose, and the subsequent categorization between areas that have been successfully planted and those that remain unplanted. Moreover, it offers data on the harvested area in acres and the overall volume in cubic metres that has been harvested. The primary data on the factors influencing the energy mix were collected across all the 71 KTDA factories.

4.5 Descriptive Statistics

The summary statistics presented in Table 4.2 are based on 67 observations. The proportion of land acquired by tea factories had a mean of 54.95 per cent, indicating that factories acquired more than half of the target land. The proportion of land that was acquired and planted had a mean of 75.34 per cent, with a minimum of 25.3 per cent and a maximum of 100 per cent. The proportion of land harvested had a mean of 25.14 per cent, ranging from zero (0) to 100 per cent. The average annual energy consumption across all tea factories ranged between 10,558 and 26,304 cubic metres, with a mean of 17,228.69 cubic metres. The proportion of briquettes to total energy had a mean of 2.04 per cent. This low percentage indicates that most factories did not achieve the required ratio of 30 per cent of the total energy used by tea factories. The proportion of own plantation to total energy consumption had a minimum of zero (0) and a maximum of 87.33 per cent, with a mean of 21.97 per cent. The size of the tea factories, measured by fuelwood demand, ranged from 18,637.09 to 31,251 cubic metres, with a mean of 18,637.09 cubic metres.

Table 4.2: Descriptive statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Proportion of land acquired	67	54.954	33.977	7.6	161.5
Proportion of land planted	67	75.344	22.543	25.3	100
Proportion of land harvested	67	25.14	29.803	0	100
Average annual consumption of fuelwood (M ³)	67	17,228.69	3,202.602	10,558	26,304
Proportion of briquettes to total energy	67	2.04	4.126	0	20.053
Proportion of own plantation to total energy	67	21.97	21.270	0	87.329
Size of the factory	67	18,637.09	6,394.534	11,333.33	31251
Age of the factory	67	42.24	13.57904	14	66
Population density	67	486	268	215	1111
Proportion of forest cover in the counties	67	18.63	8.72	10	40.86

Source: Authors' computation

5. Results and Discussion

This section presents the results of the desired energy sourcing and the factors that determine the energy mix for the KTDA factories.

5.1 Path to Desired Energy Sourcing for KTDA Tea Factories

One of the key objectives of the study was to establish the path to desired energy sourcing for KTDA tea factories. The analysis considered the proportion of land acquired by tea factories, the proportion of land planted, and the proportion harvested. To gain further insights into the desired energy source, the study compared the tea factories that used briquettes with those that used fuelwood from their own plantations.

5.1.1 Proportion of land acquired

To achieve the necessary energy sourcing, tea factories were expected to secure 620 acres of land by the end of the sixth rotational year to fully transition to a 100 per cent owned plantation.

The age of the factory, population density, use of briquettes, proportion of forest cover in the counties, and the size of the factory were assessed to determine whether they influenced the proportion of land acquired by the tea factories (Table 5.1) in preparing for their own-forest sourcing of fuelwood. Notably, the results revealed that the age of the factory had a coefficient of 0.331 ($p < 0.05$), implying that an increase in the age of the factory raised the proportion of land purchased by tea factories by 33 per cent. This can be attributed to several factors. First, older factories that had established satellite factories may need to expand their fuelwood production capacity to meet growing production demands, necessitating more fuelwood. Secondly, with their experience, older factories will likely appreciate the long-term benefits of securing a sustainable fuelwood supply, thus recognizing the need to invest in fuelwood plantations to sustainably meet their future energy demands. The results corroborate the findings of Gatimbu et al. (2020), who reported that factory age showed a positive relationship between resource acquisition and utilization to enhance sustainability.

The size of the factory had a coefficient of 0.061 ($p < 0.05$), indicating that as the demand for fuelwood increased, the proportion of land purchased by tea factories rose by 6.1 per cent. As tea factories expanded their green leaf processing capacity, additional energy was needed for tea withering and drying, and therefore factories were required to seek additional parcels of land to counter the expected future fuelwood supply. A study by Kahare (2019) reported that factories that expanded their production capacities are expected to consume enormous volumes of fuelwood to generate the required energy.

Table 5.1: OLS regression estimates for the proportion of land bought by tea factories

Variable	Coef. (p-value)	Std. Err.
Age of the factory	0.331 (0.001) ***	0.322
Population density	-0.031** (0.04)	0.068
Users of briquettes	0.456	33.277
Proportion of forest cover	-0.843	0.563
Access to credit	0.712	10.597
Size of the factory	0.061 (0.042) **	0.068
Prob > F = 0.0000 R-squared = 0.7366 Number of obs = 67		
Statistical significance at *** p<0.01, ** p<0.05, * p<0.1		

Population density was statistically significant ($p < 0.05$) with a negative coefficient. The findings suggest that an increase in population per square kilometre led to a 31 per cent reduction in the proportion of land purchased by factories. This trend can be attributed to the significant land fragmentation in counties where most factories are situated. As population density rises, land becomes increasingly divided into smaller plots, making it more challenging for tea factories to acquire large parcels of land necessary for planting trees. Similar findings were reported by Kahare (2019a), who noted that smallholder tea farmers heavily exploited the available parcels of land to the extent that they had very little space left for tree growing. Additionally, parcels of land had tea bushes virtually occupying every available space, thus limiting the capacity to allocate portions for tree planting. Consequently, the majority of tea factories acquired their parcels of land outside their tea-growing zones; for example, Kanyenyaini Tea Factory purchased 100 acres of land in Maragua for tree propagation, while Gatunguru Tea Factory bought 800 acres in Nyeri County (Kahare, 2019b).

5.1.2 Proportion of land planted by tea factories

For the tea factories to fully transition, they needed to establish plantations on the acquired land. The study evaluated the age of the factory, the size of the factory, population density, the use of briquettes, the proportion of forest cover, and access to credit as the key determinants of the amount of land planted by tea factories.

Table 5.2 presents the results on the determinants of the proportion of acquired land that was planted by tea factories.

The analysis revealed that access to credit (0.541, $p < 0.05$) and forest cover in the tea-growing counties (-0.843, $p < 0.05$) were key contributors to the proportion of land planted by the tea factories for fuelwood. An increase in financial access motivates the tea factories to establish new plantations, thereby increasing their fuelwood supply. Observing the necessary steps in developing sustainable fuelwood plantations is crucial for ensuring the efficiency and scalability of tree nurseries and planting tree seedlings on the acquired land. According to the KTDA fuelwood establishment guide, developing one acre of eucalyptus plantation requires approximately Ksh 24,000 (Annex 4). This involves the development of individual nurseries as opposed to the purchase of prepared seedlings. This suggests that financial resources play a crucial role in enabling the establishment and expansion of fuelwood plantations.

Forest cover was statistically significant with a negative coefficient of -0.780 (** $p < 0.05$). The results suggest that as the proportion of forest cover increases, the area of factory land planted decreases. This could imply that factories located in counties with higher forest cover may be relying on external sources for fuelwood supply and thus may be hesitant to establish new plantations. In contrast, those in counties with less forest cover may be encouraged to establish plantations for a sustainable energy supply. Similar findings were reported by Kahare (2019), who noted that the increased demand for fuelwood by factories adversely affected forest cover, leading these factories to seek alternative sources of energy.

Table 5.2: OLS regression estimates for the proportion of land planted

Variable	Coef.	Std. Err.
Age of the factory	0.331	0.245
Population density	0.023	0.0134
Users of briquettes	6.391	8.280
Proportion of forest cover	-0.780**	0.428
Access to credit	0.541**	8.067
Size of the factory	0.301	0.006
Prob > F = 0.0000 R-squared = 0.8973 Number of obs = 67		
Statistical significance at *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$		

5.1.3 Comparison of energy mix used in factories

The analysis compared tea factories using an energy mix (briquettes and fuelwood) with those that solely used their own fuelwood. The factories were assessed based on the proportion of forest cover, land acquired, and land planted and harvested, as indicated in Figure 5.1.

Tea factories that did not use an energy mix had a higher forest cover in their counties (19.21%). In contrast, those factories that used energy mix had an average forest cover of 18.24 per cent. This suggests that factories not using briquettes had significant forest cover available for fuelwood, making them less inclined to switch to briquettes or establish their own wood plantations. Tea factories using an energy mix acquired a larger proportion of land (63.06%) compared to those not mixing (50.77%). Factories using briquettes planted 78.89 per cent of their land, while those that did not use briquettes planted 73.5 per cent of their land. Additionally, factories not mixing harvested a greater proportion of their plantations (35.51%) compared to those mixing (24.37%). These results imply that the 11.14 per cent disparity arises because those not mixing relied solely on fuelwood as their energy source for heating in their boilers.

Figure 5.1: Comparing tea factories using energy mix and those not mixing



Most of the tea factories that acquired 60 per cent or less of their target land had a higher proportion of land planted, as depicted in Annex 1. In contrast, those factories that exceeded their targets in land acquisition recorded a lower proportion of planted land, as indicated in the scatter plot (Annex 1). The findings suggest that while factories are motivated to acquire more land, the proportion of planted land remains lower. This implies that factories could focus on acquiring only the specified target area of land and planting it, aligning with each factory's available resources and energy demands, thereby optimizing resource allocation.

5.2 Energy Mix in KTDA Tea Factories

Another key objective of this study was to determine the key factors that define the energy mix frontiers for the KTDA factories. The analysis considered two transitions: the proportion of briquettes to total energy and the use of fuelwood from own plantation.

5.2.1 Proportion of briquettes to the total energy used

The size of the factory and the amount of fuelwood harvested were key determinants influencing the proportion of briquettes to total energy used (Table 5.3). The results suggest that larger factories are more likely to use more briquettes than their smaller counterparts. As tea factories expanded their processing capacity, their energy demand grew, necessitating an increased energy mix ratio. This shift facilitates the integration of briquettes into their energy mix to meet their energy needs. Similar findings were reported by Šūmakaris et al. (2021), who revealed that firm size positively correlates with the adoption of energy-efficient technologies as alternative energy sources to fuelwood. Larger firms benefit from economies of scale, which simplifies the implementation and sustainability of such technologies.

As the amount of fuelwood harvested by tea factories increased, the proportion of briquettes to total energy decreased by 3.9 per cent. The results suggest that factories used briquettes when the amount of fuelwood harvested was low, acting as a compensatory mechanism regardless of the associated costs. However, as the plantations matured, a smaller proportion of briquettes was used. These findings align with Kagombe et al. (2020), who reported that the 2018 logging moratorium resulted in a fuelwood shortage, causing most tea factories to begin using briquettes for co-firing.

Table 5.3: Tobit model estimates for the proportion of briquettes to total energy

Variable	Coef.	Std. Err.
Age of the factory	-0.011	0.007
Size of factory	0.071 (0.012) **	0.044
Before and after the first harvest of fuelwood	-0.039 (0.06) *	0.994
R-squared = 0.5092 Number of obs = 458		
Statistical significance at ** $p < 0.05$, * $p < 0.1$		

5.2.2 Proportion of fuelwood from own plantation

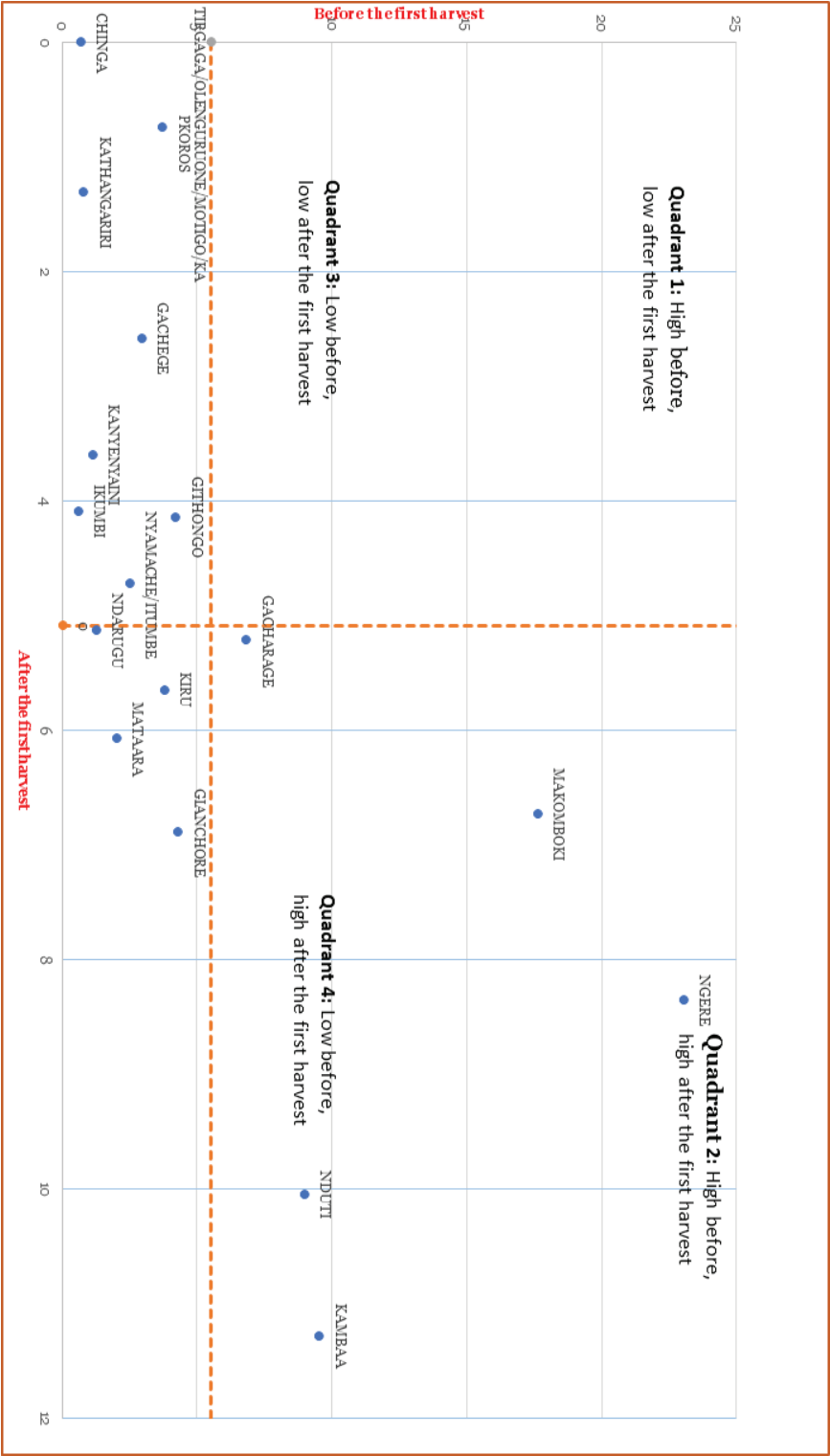
The proportion of mature trees harvested was statistically significant at 0.51 ($p < 0.05$), as illustrated in Table 5.4. The findings indicate that factories that harvest mature trees produce more fuelwood compared to those that harvest trees that have not yet reached the 6-8-year maturity period. This disparity is partly due to the premature harvesting of trees. Similar observations have been reported in other studies. For example, Kagombe et al. (2015) found that some factories exhibited extremely high harvesting rates compared to planting, resulting in the cutting of trees before they reached the 6-year maturity mark.

Table 5.4: Tobit model estimates for the proportion of own wood to total energy

Variable	Coef.	Std. Err.
Age of the factory	0.037	0.068
Size of factory	0.005	0.004
Proportion of mature trees harvested	0.151 (0.03) **	0.994
R-squared = 0.646 Number of obs = 458		
Statistical significance at ** $p < 0.05$, * $p < 0.1$		

The scatter plot (Figure 5.3) illustrates the behaviour of tea factories before and after the first harvest of fuelwood in 2021. The analysis of the second quadrant reveals factories that maintained a high level of briquette usage both before and after harvesting their plantations, such as Kambaa and Ngere tea factories, which consistently relied on briquettes even after they began harvesting from their fuelwood plantations. In contrast, most tea factories are located in quadrant three, where briquette usage remained low before and after their fuelwood harvest. This pattern suggests a low adoption rate of briquettes among these factories. The limited use of briquettes can be attributed to a preference for available traditional fuel sources. Finally, quadrant four includes tea factories such as Nduti and Kambaa, where the use of briquettes was initially low before the first harvest but increased thereafter, likely due to the lower volumes of fuelwood harvested by some factories, necessitating the integration of briquettes for co-firing.

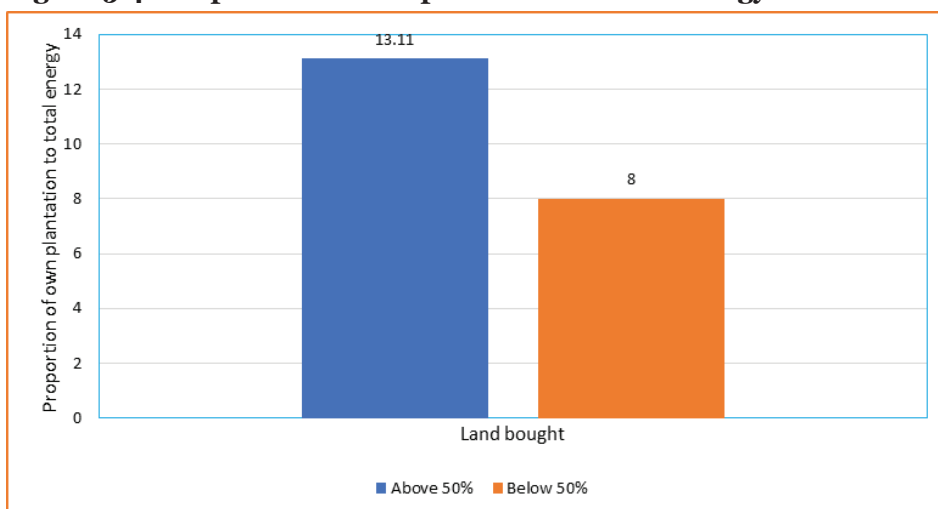
Figure 5.3: Proportion of briquettes to total energy



5.3 Transition Path for KTDA Tea Factories in Kenya

To achieve a sustainable fuelwood supply, the tea factories established a target for acquiring 620 acres of land, requiring each factory to obtain at least 103 acres annually. Further, harvesting was to commence after the sixth to the eighth year of planting, in accordance with KFS guidelines. As shown in Figure 5.4, tea factories that acquired less than 50 per cent of the target land generated only 8.0 per cent of their energy from their plantations. In contrast, those that met 50 per cent of the target produced 13.11 per cent of their energy from their plantations. These results indicate that the proportion of energy generated from their plantations was low for both groups. A report from KTDA on wood fuel plantations highlights that for factories to transition to their fuelwood fully, meticulous planning, strategic execution, and ecological sustainability are essential in assessing the suitability of the acquired land according to the established KFS guidelines. This approach will ensure long-term health and viability of the plantation.

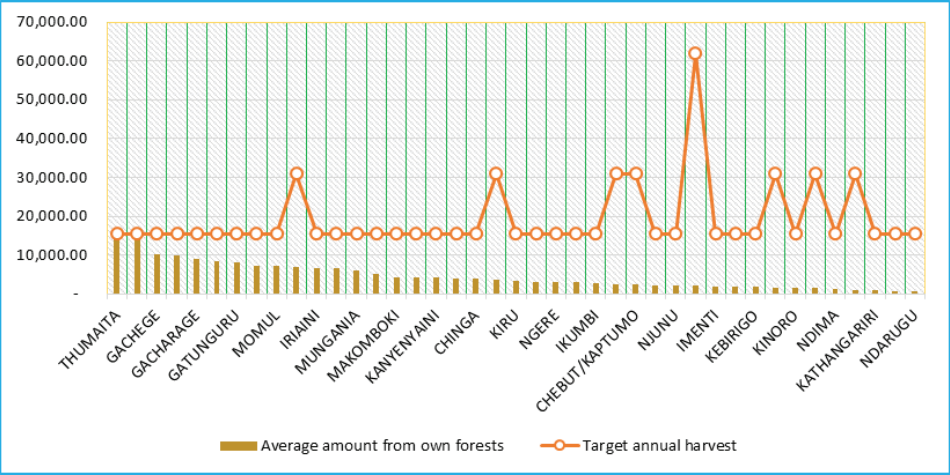
Figure 5.4: Proportion of own plantation to total energy



The study also examined the amount of fuelwood harvested from the factories' own plantations (Figure 5.5). According to the KTDA key performance indicators (KPIs), each acre is expected to produce 150 cubic metres of fuelwood. The findings revealed that only Thumaita and Kambaa tea factories met their targets for fuelwood production. Other factories, such as Gatunguru, Maatara, Gacharage, Kimunye, and Gachege, managed to generate over 50 per cent of their fuelwood from their plantations. The remaining factories harvested below 50 per cent of their fuelwood from their plantations. The KTDA report titled 'Ndemi Wood Fuel Plantation Tree Growing Assessment Report' notes that various factors contribute to the lower-than-expected fuelwood harvests from factory-owned plantations. Species-site matching suitability is crucial, as planting the right species in the appropriate environment significantly impacts growth and yield. Additionally, using the correct variety of eucalyptus seedlings ensures that the

trees are well-adapted to local conditions, promoting healthy development. Soil testing is essential to identify nutrient deficiencies or other soil conditions that might hinder tree growth, allowing for targeted interventions. Effective pest and disease management is critical to prevent damage that could reduce the quantity and quality of the harvest. Notably, timely coppicing, which involves removing old growth to encourage new shoots, is necessary to maintain the vitality and productivity of eucalyptus trees. Addressing these factors comprehensively could lead to more successful fuelwood production in the future.

Figure 5.5: Fuelwood from own plantation



6. Conclusion and Policy Recommendations

6.1 Conclusion

The overall objective of this study was to determine how the tea industry in Kenya is integrating adaptive forest management and transitioning to alternative energy sources. The tea sector in Kenya presents a significant opportunity for a substantial shift in energy usage, moving from traditional firewood to establishing own plantations and adopting biomass briquettes. This transition is particularly promising due to the economic importance of tea exports and the considerable energy requirements in tea production. The study establishes key priorities for tea factories to identify the transition path and achieve the desired energy mix, which includes reaching the targeted acquisition of 620 acres for rotational harvesting, establishing eucalyptus plantations on the acquired land, and supplementing firewood with 30 per cent of briquettes. To integrate adaptive forest management within the tea industry, the study identifies the key findings listed below.

- (i) Achieving the required energy sourcing: The findings indicate that tea factories tend to harvest less from their plantations. Additionally, factories that acquire more land than their target often plant a smaller proportion of it, highlighting potential inefficiencies in land use. These observations suggest that while there are ongoing efforts to transition to alternative energy sources, there remains a need to optimize both land acquisition and planting strategies to enhance the sustainability and efficiency of energy sourcing in these tea factories.
- (ii) Factors influencing the energy mix in KTDA tea factories: The analysis of factors influencing the energy mix in KTDA tea factories revealed that larger factories and those engaging in significant fuelwood harvesting are more likely to incorporate a higher proportion of briquettes into their energy mix. The study also indicates that the proportion of briquettes used is low, often below 5.0 per cent, reflecting a slow adoption rate and potential barriers to the more extensive integration of briquettes.
- (iii) The transition path for the KTDA tea factories in Kenya: The transition path for KTDA tea factories towards achieving self-sufficient fuelwood supply reveals that, despite the 620-acre land acquisition target, most factories are struggling to meet their fuelwood production goals. Factories that acquired less than 50 per cent of the target land size produced only 8.0 per cent of their energy needs from their own plantations, while factories that attained at least 50 per cent of the target managed 13.11 per cent. Further, only two factories achieved their fuelwood production targets, whereas others fell short. Therefore, an effective transition to self-sufficient fuelwood necessitates improved planning, strategic execution, and ecological management, including optimal species-site matching, soil testing, pest control, and timely coppicing. These measures are crucial for enhancing fuelwood yield and addressing the current energy supply shortfalls.

6.2 Recommendations

Based on the findings, the paper recommends the following policy implications to achieve optimal energy sourcing and transition to alternative energy sources in Kenya's tea industry.

- (i) Plant fast-growing and high-calorific-value tree species: Prioritizing the planting of fast-growing and high-calorific-value tree species, such as eucalyptus, is crucial for efficiently meeting the energy needs of tea factories. Additionally, selecting tree species that match the specific conditions of each site, such as *Eucalyptus grandis*, ensures optimal growth and productivity. These species offer rapid maturity, providing a quicker return on investment and ensuring a steady fuelwood supply. Furthermore, their high calorific value means they produce more energy per unit of wood, making them highly efficient for tea processing operations. The use of fast-growing species also supports sustainable forestry practices, as these trees can be harvested and replanted in cycles, ensuring a continuous supply without depleting natural forests. This approach balances the immediate energy needs with long-term environmental sustainability.
- (ii) Enhance access to financial support: Offer incentives or subsidies for tea factories to incorporate briquettes into their energy mix, especially for those experiencing significant energy deficits. These incentives could help alleviate the initial costs of transitioning to briquettes, making it more viable for factories to adopt this alternative energy source. By doing so, factories can reduce dependence on traditional fuelwood, improve energy efficiency, and contribute to more sustainable operations. This strategy not only aids the factories in managing their energy needs more effectively but also aligns with broader environmental and economic goals.
- (iii) Enhanced strategic planning and implementation: KTDA tea factories could prioritize improved strategic planning and implementation to achieve a self-sufficient fuelwood supply. This involves focusing on acquiring and optimally planting the necessary land area, ensuring species-site matching, conducting thorough soil testing, and practising timely coppicing. Factories ought to consider establishing more realistic acquisition and planting targets that align with their operational capacity. These measures will enhance fuelwood yields, address existing energy supply shortfalls, and facilitate a sustainable transition towards self-sufficiency.

References

- Ajzen, I. (1985), "From intentions to actions: A theory of planned behavior". In J. Kuhl and J. Beckmann (Eds.), *Action control: From cognition to behaviour* (pp. 11–39). Springer-Verlag.
- Dincer, I. (2000), "Renewable energy and sustainable development: A crucial review". *Renewable and Sustainable Energy Reviews*, 4(2): 157–175. [https://doi.org/10.1016/S1364-0321\(99\)00011-8](https://doi.org/10.1016/S1364-0321(99)00011-8).
- Gatimbu, K.K., Ogada, M.J., and Budambula, N.L.M. (2020), "Environmental efficiency of small-scale tea processors in Kenya: An inverse data envelopment analysis (DEA) approach". *Environment, Development and Sustainability*, 22(4): 3333–3345. <https://doi.org/10.1007/s10668-019-00348-x>.
- Hesselink, L.X.W., and Chappin, E.J.L. (2019), "Adoption of energy efficient technologies by households – Barriers, policies and agent-based modelling studies". *Renewable and Sustainable Energy Reviews*, 99(July 2018): 29–41. <https://doi.org/10.1016/j.rser.2018.09.031>.
- Irfan, M., Elavarasan, R. M., Hao, Y., Feng, M., and Sailan, D. (2021), "An assessment of consumers' willingness to utilize solar energy in China: End-users' perspective". *Journal of Cleaner Production*, 292:126008. <https://doi.org/10.1016/j.jclepro.2021.126008>.
- Jackson, A., Grösche, P., Rehdanz, K., and Schröder, C. (2019), "Drivers of renewable technology adoption in the household sector". *Energy Economics*, 81: 216–226. <https://doi.org/10.1016/j.eneco.2019.04.001>.
- Kagombe, J., Kiprop, J., Langat, D., Cheboiwo, J., Wekesa, L., Ongugo, P., Mbuvi, M. T., and Leley, N. (2015), Socio-economic impact of forest harvesting moratorium in Kenya. In *KEFRI is ISO* (Vol. 9001, Issue August). www.kefri.org.
- Kahare, S.G. (2019a). Impact of Fuelwood Consumption By Three Tea Factories on-Farm Tree production in Kangema Sub-County, Muranga County, Kenya.
- Kahare, S. G. (2019b). Impact of Fuelwood Consumption by Three Tea Factories on Environment and on-Farm Tree Production in Kangema Sub-County, Murang'a County, Kenya. 8(6), 1058–1062..
- Kahare, S.G. (2019b). Impact of fuelwood consumption by three tea factories on. 8(6), 1058–1062.
- Kibet, J., and Letema, S. (2022), "Environmental impacts of energy usage in selected tea factories in Kenya". *Journal of Modern Green Energy*, December. <https://doi.org/10.53964/jmge.2022007>.

- Kimani, M.N., Makindi, S.M., and Aboud, A.A. (2020), "Knowledge and awareness determinants of renewable energy technologies: A cross sectional study of rural residents from Njoro Constituency". *IOSR Journal of Environmental Science Toxicology and Food Technology*, 14(8): 25-30. <https://doi.org/10.9790/2402-1408042530>.
- KNBS (2023), Kenya's Economic Survey 2023. https://investmentpromotion.go.ke/sites/default/files/2023-07/Economic-Survey-2023_2.pdf.
- Kumar, K.R., Dashora, K., Krishnan, N., Sanyal, S., Chandra, H., Dharmaraja, S., and Kumari, V. (2021), "Feasibility assessment of renewable energy resources for tea plantation and industry in India - A review". *Renewable and Sustainable Energy Reviews*, 145 (July 2020):111083. <https://doi.org/10.1016/j.rser.2021.111083>.
- Li, H.X., Edwards, D.J., Hosseini, M.R., and Costin, G.P. (2020), "A review on renewable energy transition in Australia: An updated depiction". *Journal of Cleaner Production*, 242: 118475. <https://doi.org/10.1016/j.jclepro.2019.118475>.
- Magu, D.M. (2019), Determinants of the likelihood of adoption of concentrated solar power technology by tea factories in Kenya.
- Mburugu, P.N., and Gikonyo, N. (2019), "Factors influencing utilization of solar energy in Kenya industries: The case of tea processing factories in Meru County". *International Academic Journal of Information Sciences and Project Management*, 3(4): 304–326. http://www.iajournals.org/articles/iajisp_m_v3_i4_304_326.pdf.
- Mose, G.N., Mbeche, R., and Ateka, J. (2015), "Institutional innovations for smallholder agricultural production systems in Kenya: A case of smallholder tea subsector". *European Journal of Sustainable Development*, 5(3): 461–475. <https://doi.org/10.14207/ejsd.2016.v5n3p461>.
- Mosly, I., and Makki, A. A. (2018), "Current status and willingness to adopt renewable energy technologies in Saudi Arabia". *Sustainability (Switzerland)*, 10(11). <https://doi.org/10.3390/su10114269>.
- Nordman, E.E., and Nordman, E.E. (2014), Scholar works @ GVSU energy transitions in Kenya's tea sector: A wind energy assessment energy transitions in Kenya's tea sector.
- Oduor, N., and Githiomi, J. K. (2012), "Strategies for sustainable wood fuel production in Kenya". *International Journal of Applied Science and Technology*, 2(10):21–25.
- Rawlins, J., and Ashcroft, M. (2013), "Small-scale concentrated solar power - A review of current activity and potential to accelerate deployment". *Carbon Trust*, March, 50. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/191058/small_scale_concentrated_

solar_power_carbon_trust.pdf.

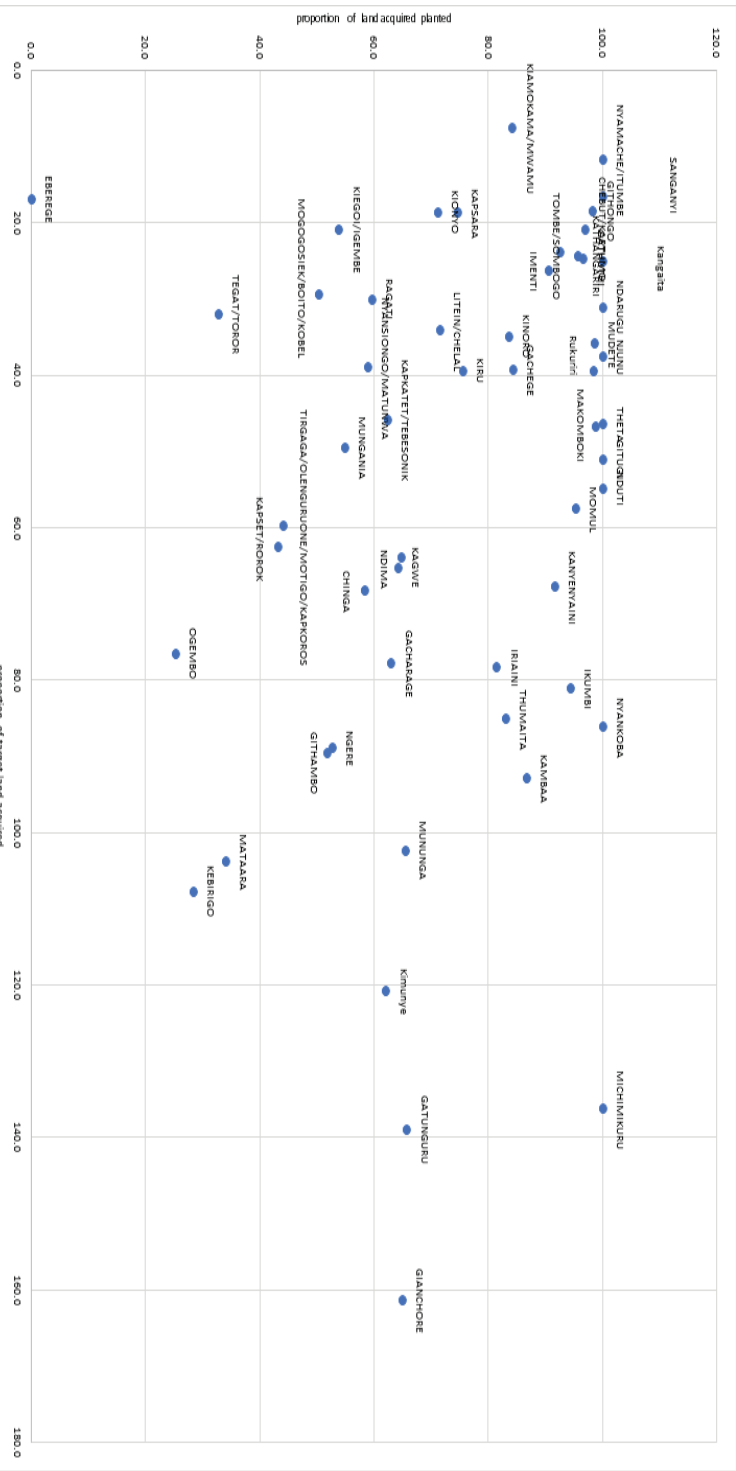
- Republic of Kenya (2018), A report on forest resources management and logging activities in Kenya: Ministry of Environment and Forestry. Nairobi: Government Printer (Issue April).
- Rogers, E.M (1983), "The change agent". *Diffusion of Innovations*, 105–117. <https://doi.org/10.4324/9781315263434-16>.
- Šumakaris, P., Korsakienė, R., and Ščaulovs, D. (2021), "Determinants of energy efficient innovation: A systematic literature review". *Energies*, 14(22): 1–20. <https://doi.org/10.3390/en14227777>.
- Suryani, A., Bezama, A., Mair-Bauernfeind, C., Makenzi, M., and Thrän, D. (2022), "Drivers and barriers to substituting firewood with biomass briquettes in the Kenyan tea industry". *Sustainability (Switzerland)*, 14(9). <https://doi.org/10.3390/su14095611>.
- Tu, J.C., and Yang, C. (2019), "Key factors influencing consumers' purchase of electric vehicles". *Sustainability (Switzerland)*, 11(14). <https://doi.org/10.3390/su11143911>.

org/10.3390/su1143863.

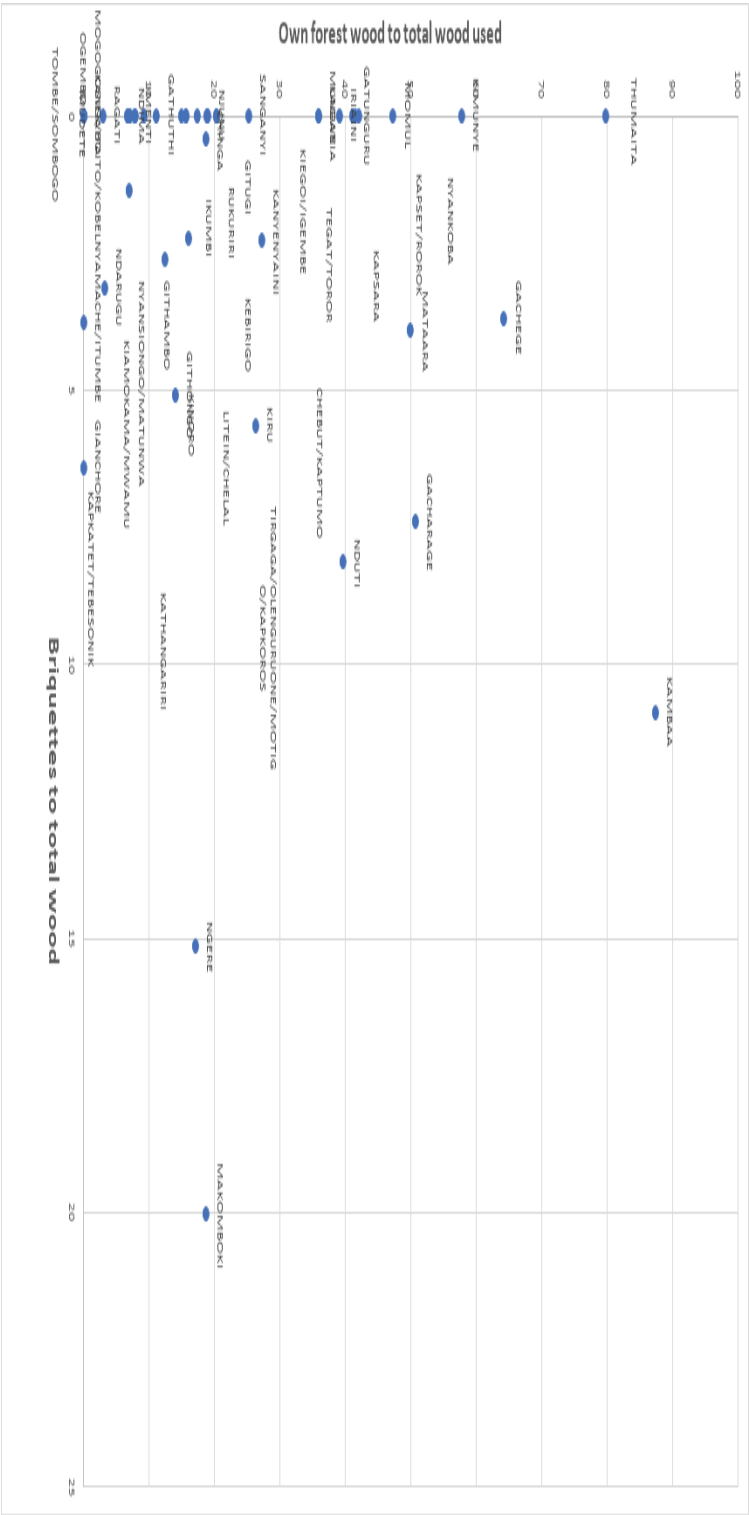
United Nations Environment Programme (2019), Of sugarcane briquettes and charcoal value briquettes and charcoal value. Wambughu, O. (2013), “A review of a successful unsubsidized market-based rural solar development initiative in Laikipia District, Central Kenya”. *International Journal of Renewable Energy Development*, 2(3): 151–164. <https://doi.org/10.14710/ijred.2.3.151-164>.

Annex

Annex 1: Comparison between the land acquired and the planted land portion by KTDa factories



Annex 2: Comparing the 70/30 ratio and own fuelwood ratio to total energy



Annex 3: List of KTDA-managed tea factories per factory

County	Mother factory	Satellites	Total
Kericho	Litein	Chelal	7
	Tegat	Toror	
	Kapkatet	Tebesunik	
	Momul		
Bomet and Nakuru	Kapkoros	Tirgaga, Motigo, Olenguruone	9
	Mogogoseik	Kobel, Boito	
	Kapset	Rorok	
Trans Nzoia	Kapsara		1
	Total		
Kakamega and Vihiga	Mudete		1
Nandi	Chebut	Kaptumo	2
	Total		
Kiambu	Kambaa		6
	Kagwe		
	Theta	Ndarugu	
	Mataara		
	Gachege		
Murang'a	Gatunguru		10
	Kanyenyaini		
	Kiru		
	Githambo		
	Gacharage		
	Ngere		
	Nduti		
	Ikumbi		
	Njunu		
	Makomboki		

Nyamira	Kebirigo		8
	Nyansiongo	Matunwa	
	Sanganyi		
	Nyankoba		
	Tombe	Sombogo	
	Gianchore		
Kisii	Kiamokama	Rianyamwamu	6
	Nyamache	Itumbe	
	Ogembo	Eberege	
	Total		
Meru	Imenti		7
	Githongo		
	Kinoro		
	Kionyo		
	Michimikuru		
	Kiegoi	Igembe	
Tharaka-nithi	Weru		1
	Total		
Nyeri	Ragati		5
	Chinga		
	Gathuthi		
	Iriaini		
	Gitugi		
Nyeri/kirinyaga	Ndimba		1
	Total		
Kirinyaga	Kangaita		4
	Thumaita		
	Mununga		
	Kimunye		
Embu	Mungania		3
	Rukururi		
	Kathangariri		
	Grand Total		71

Annex 4: Plantation establishment and maintenance costs



KTDA
KENYA TEA DEVELOPMENT AGENCY (MS) LIMITED
KTDA FARMERS BUILDING | P.O. Box 30213 GPO 00100 Nairobi
Tel: +254 20 221441/2/3/4, 331053, 340570 | Fax: 254 020 211240
E-mail: info@ktdateas.com | Site: www.ktdateas.com

PLANTATION ESTABLISHMENT AND MAINTENANCE COSTS (GUIDE)

AREA: 1 ACRE SPACING: 2.5 M BY 2.5 M ROTATION: 6-8 YEARS
Rainfall: > 900 mm

	Activity	Unit	Quantity	Unit Price Ksh	Amount (Ksh)
INPUTS	Seedlings	No.	600	10/-	6,000
	Fertilizer DAP	Kgs	12	70/-	840
	Confidor(Anti termite)	Litres	1	2500/-	2500
Sub Total					8,340
LABOUR	Land preparation/tractor	1 acre	-	4000-7000	7,000
	Staking out	Mandays	4	200	800
	Pitting	Mandays	600 holes	2-3	1800
	Planting	Mandays	600 seedlings	2-3	1800
	Complete weeding	Mandays	8 days	200	1,600
Sub Total					10,500
2 nd Weeding	Complete weeding	Mandays	8 days	200	1,600
3 rd Weeding	Spot weeding	Mandays	8 days	200	1600
Sub Total					3,200
TOTAL COST (Ksh)					24,540/=

Cost can be lowered by applying the following: -

1. Develop own nursery as opposed to purchase of prepared seedlings.
2. Mechanized ploughing of virgin lands is recommended to break the hard pan to encourage faster root development hence early maturity.
3. Use of chemical (herbicides) instead of weeding after the first year; (this cheaper than manual weeding).
4. Accounting data/records of any activity should be maintained to this guide the process, for future reference and audit purposes.
5. Shamba system should be applied to check weeding and cleaning costs.
6. The recommendations herein are only to guide cost for upper limit, otherwise can be much lower. All cost for each land parcel must be recorded for future reference and for audit purposes.

PLANTATION ESTABLISHMENT AND MAINTENANCE COST ESTIMATES

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