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Research Article

Relationship Between Income-earned from Sale of Woodfuel and Volume Extracted from Gazetted Forests of Koibatek Zone, Kenya

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Abstract

Approximately 2 billion people globally rely on woodfuel, that is, firewood, and charcoal to meet their energy needs. The average annual consumption of woodfuel per capita in Africa is 0.89 cubic meters, which is 67.0% of the total energy consumed. In Kenya, 68% of the total energy consumed is woodfuel. Although woodfuel contributes significantly to Kenya's economy, the relationship between the income-earned from selling woodfuel and the extracted volume is largely unexplored. This paper set out to investigate this relationship with particular interests in the gazetted forests of Koibatek Zone in Kenya. The research study used a cross-sectional descriptive design. All the eight gazetted forest blocks within the zone were purposively selected and, stratified random sampling was used to sample 384 woodfuel extractors as respondents within the zone. The primary data collection means included: review of woodfuel extraction registers of licenses, survey of 384 woodfuel extractors, key informant interviews with eight forest officers, eight focussed group discussions, and analysis of satellite images. Secondary data were obtained through critiquing documents of policies, office files, and journals. Data were analyzed using descriptive statistics (i.e., crosstabs and percentages), simple linear regression and Pearson chi-square tests. Qualitative information was tabulated and coded, and the tabulated data was analyzed. It was found that the income-earned through the sale of woodfuel has a significant ($p < 0.05$) connection with the volume of woodfuel harvested in the gazetted forests. Income-earned from sales could explain approximately 53.1% variation in volume of extracted woodfuel ($R^2 = 0.531$). It was thereby concluded that the amount of woodfuel extracted has a direct significant relationship with income-earned from the sale of woodfuel. It is thus recommendable that the training of woodfuel extractors should be done concerning the laws in place, and the use of sustainable forest management and agroforestry practices should be provided to the extractors. The results of this research are crucial for policymakers at the energy and forestry levels in developing practices that sustain the harvesting and utilization of woodfuel.

Keywords

Woodfuel, Volume, Income-Earned, Gazetted, Zone

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1. Introduction

The global population of woodfuel users is approximately two billion individuals [7]. The world population relying on woodfuel was equivalent to 38 percent population in 2015 [3]. Woodfuel accounts for approximately 10-15 percent of the total global annual primary energy, which is used directly and or converted into thermal energy in both developing and developed countries [9]. World Bank defined woodfuel to comprise of firewood and charcoal, is the most common energy source in most developing countries [9]. Additionally, utilization of woodfuel has been increasing in developed nations as well [22]. The Food and Agriculture Organization reported that the global amount of woodfuel produced in 2016 was 1.86 billion m^3 with Africa alone consuming 673 million m^3which was 36%. Further to that, extraction of woodfuel has increased due to its commercialization of the commodity [7]. Nevertheless, the Energy Sector Management Assistance Program indicated that woodfuel is usually undervalued in terms of its production costs and the quantities retrieved [5].

According to World Energy Council, Africa's annual woodfuel consumption is highest worldwide, averaging about 0.89 m^3per capita [25]. The percentage of primary energy use in Africa is contributed by woodfuel, ranging from 61% percent to 86% percent, with residential households consuming between 74 percent and 97 percent of this energy [25]. Another research showed that woodfuel accounts for almost 90 percent of the overall energy supply in Sub-Saharan Africa [8]. Furthermore, the authors noted that in nations such as Burundi, Rwanda, as well as the Central African Republic, more than 90 percent of primary energy is by woodfuel [8]. the annual revenue generated by charcoal production alone is estimated at approximately USD 60 million in Rwanda (2 percent of the GDP) and USD 450 million in Kenya [18]. Commercialization of woodfuel has grown significantly, generating substantial income for both urban and rural households in Africa [5]. According to projections, woodfuel and municipal waste are expected to be the leading sources of energy in Africa by 2035, accounting for 51-57% of total energy consumption [9]. Despite the increased commercial importance of woodfuel in African economies, a scarcity of information exists about the connection between the amount of income generated and the quantity of woodfuel being exploited.

The research was conducted in the gazetted forests of the Koibatek Forest Zone, which is part of the Mau Forest complex in Kenya. The Mau Forest Complex has been severely degraded, with its forest cover reduced to a drastic level over time [2]. The Government of Kenya has recorded that the Mau Forest complex, which, in addition to being a central water catchment, covers an area of about 400,000 hectares, is the largest closed-canopy forest block in East Africa. Koibatek Forest Zone, which has 8 gazetted forest blocks, covers 510.08 km^2 or 12.75 percent of the total area of the Mau Forest Complex, which is located on the eastern boundary of the Mau Forest Complex. The Zone comprises natural forests of 27,996.5 hectares and 19,416.3 hectares of forest plantations [2].

Nevertheless, these gazetted forests have been subjected to greater pressure from illegal logging, woodfuel collection, grazing, and unplanned harvesting of other forest products. Gazetted forests within Koibatek Zone were also found to be highly vulnerable to degradation as woodfuel and other forest products, such as timber and grass, continue to attract high demand [12]. The connection between income generation and the volumes of woodfuel harvested, however, has received minimal research attention in such forests. This research, therefore, sought to establish the correlation between the income-gained and the volumes of woodfuel harvested in the gazetted forests of the Koibatek Forest Zone in Kenya.

2. Literature Review

The use of woodfuel globally is not only economically lucrative but also enriches the rural population, especially in comparison to oil [1]. In addition, woodfuel combined with bagasse, makes up 10-15 percent of the global annual primary energy demand. They have also indicated that there is an escalating environmental trade in woodfuel, with European trade being approximately 50 petajoules annually. However, the study did not determine the monetary value of the international woodfuel trade, and thus, there is a need to conduct a further study to establish this value. According to IEA, approximately 2 billion individuals worldwide rely on traditional biomass as their primary energy source, with firewood and charcoal being the primary sources [9]. However, the nature of these supplies is unspecified in terms of whether they are traded locally or internationally. In the initial report by Europen Union (EU) on energy poverty in nine EU countries, the highest prices for woodfuel were found in Greece and Germany. However, countries such as Ireland, Spain, Catalonia, Italy, and Austria had relatively medium prices, while Croatia, Romania, and Slovenia had the lowest prices [6].

Woodfuel prices in eight EU countries increased between 2011 and 2014, without specifying individual prices [23]. The study acknowledge that it is challenging to obtain data on the woodfuel pricing trend in EU countries and that there is no clarity on whether the prices are based on supply-side or demand-side factors [23]. Therefore, establishing specific prices for woodfuel will be of utmost importance, as this will help determine the income-earned through the sale of woodfuel.

Amidst the rising urban demand for and the market expansion of woodfuel in Africa, studies emphasized that increased demand in cities and towns provides a potentially significant income-generating activity [4]. The study further revealed that over 120,000 to 140,000 people were directly employed by woodfuel trade in Sub-Saharan Africa in 2008. The eco-

nomic contribution of the charcoal sector in Tanzania alone was approximately USD 650 million, which was 5.8 times the combined dollar value of coffee and tea production in the country. Also, the woodfuel trade benefited both urban and rural households by generating direct income [4]. As illustrated, the value of woodfuel in Malawi accounted for 3.5 percent of the country's GDP [19]. The authors state that, in Sub-Saharan Africa, the majority of firewood collection and trade deals with dead plant material. Furthermore, the charcoal industry in Africa has experienced steady growth of approximately 3 percent per year since the early 2000s, with urbanization being attributed as the primary reason for this increase in charcoal production and trade [19].

Approximately 200-300 transporters and 2,000 charcoal vendors are involved in woodfuel business, mainly those in towns, who feed about 300,000 individuals [4]. This implies that one of the significant sources of income for households in rural Africa, particularly those with access to urban markets, is the production of charcoal. The monetary value of charcoal in 2007 was USD 8 billion, supporting more than 7 million individuals in Sub-Saharan Africa [1]. The market size of charcoal in Africa is estimated to be between $9.2 billion and $24.5 billion annually, which demonstrates that this process is economically significant.

The value of woodfuel supplied in Kenya is estimated to be Ksh 4.8 billion, derived from gazetted forests, and 24 million m^3spilled in farmlands [10]. According to author, the costs of charcoal traded in Kenya annually is estimated at USD 450 million, whereas [18], the charcoal industry in Kenya is estimated at Ksh 30 billion with over 200,000 people being directly employed in its production. The industry also pays over Ksh5 billion in taxes, which enables it to provide 80 percent of urban homes and 34 percent of rural homes with energy. Research conducted indicated that firewood and charcoal have been a significant source of livelihood for rural households in Kenya [12]. Besides, the woodfuel industry in Kenya employs approximately 18,000 individuals, comprising 7,000 loggers and 8,000 charcoal manufacturers, most of whom are based in poor farming communities in the countryside. Therefore, the importance of woodfuel trade in the economic growth of rural areas in Kenya cannot be underestimated. Income has been identified as one of the key factors in the exploitation of forest resources [12, 18], however, studies lack detailed information about the links between the income generated from selling firewood and charcoal and the volume harvested. This demonstrates the necessity of researching the impact of the income a household receives on woodfuel sales versus the volume of woodfuel harvested.

The Kenyan government loses approximately Ksh 5.1 billion in taxes due to tax evasion by charcoal industries, primarily attributed to the lack of effective legal and policy systems [14]. This reduction is provided as 16 percent of the statutory tax on the earned income. The charcoal subsector in rural regions, including Kitui, Narok, and Kajiado, provides sustenance for nearly 2.5 million people, offering basic amenities such as food, clothing, and education, while employing approximately 200,000 producers, 2,700 transporters, and 500,000 vendors [13]. In Kenya and Rwanda, the significant influence of the woodfuel trade is evident in both urban and rural settings. The situation, as observed in charcoal production cannot be maintained and may eventually result in the greater exhaustion of the already delicate forests and woodlands [18]. Although research illustrates charcoal sector as a part of the informal sector, it is the most significant source of employment in Kenya, with an estimated 700,000 people employed in it and 2.3-2.5 million dependents supporting them. However, little is known about the relationship between the amount of income generated from the sales of woodfuel and the amount by volumes of woodfuel extracted from the forests.

3. Materials and Methods

The research design applied in this study was a cross-sectional descriptive research instrument, which facilitated the exploration of woodfuel extraction activities at the gazetted forest blocks in the Koibatek Forests Zone. The first stage entailed purposively selecting all the blocks of gazetted forests across the Koibatek Forests Zone. Interviews with a randomly sampled of woodfuel extractors and purposively conducted interviews with the forest officers were carried out to determine socio-economic factors that influence woodfuel extraction. Secondary data of the number of permits and licenses for annual woodfuel extraction have been compiled and utilised to estimate the quantity of woodfuel extracted. Koibatek Forest Zone has eight gazetted blocks of forests. All eight blocks of the forest were purposely chosen. The sample size of 384 woodfuel extractors was determined using Kothari's formula from an estimated population of 7,200 and proportionately distribution across the eight forest blocks. The forest officers, ecosystem conservators, and other key informants was selected for interviews through purposive sampling.

The data used was primary, and this was gathered through the licensing and permits profile study, with a target of Monthly Fuel Licenses (MFLs) and firewood stack licenses issued annually. Two methods were used to estimate the amount of woodfuel collected by the people: counting headloads and the number of firewood piles stacked. In the production of charcoal, the quantity of sacks used was multiplied by 40 kg per sack, taking into account the change in weight due to volume, using a specific density of 180 kg/m^3 (the density of preferred tropical hardwood charcoal). Observations and photographs recorded the extraction and transportation of woodfuel activities. Both qualitative and quantitative approaches have been employed in the data analysis. The SPSS software was used to analyze quantitative data, involving descriptive statistics, chi-square tests, and simple linear regression. Results were presented in the form of tables, figures, and photographs. The data collection instruments

in the study were pre-tested to ensure their reliability and validity. Specialists in the field of interaction of forestry and energy evaluated the content validity. The study maintained ethical standards by obtaining informed consent from Kenya Forest Service, ensuring the anonymity of respondents, and ensuring that their participation in the survey was free and voluntary.

4. Results and Discussion

4.1. Relationship Between Revenue from Licensing and Woodfuel Extraction

Based on the research findings, the Government of Kenya (GoK) in Kenya describes three types of woodfuel extraction permits: the Monthly Fuel License (MFL) which is at the rate of Ksh 100 for 1 headload daily annually, the commercial clear felling or salvaging license that is charged at the rate of Ksh 2,000 per cubic meter (firewood stack) and, the annual charcoal production licenses which all depend on how many charcoals you produce. As an example, the license of up to 10,000 bags is Ksh 50,000, the license of 10,001 to 20,000 bags is Ksh 200,000, and the license of the number of bags of 20,001 to 50,000 costs Ksh 500,000. Nevertheless, it should be mentioned that production of charcoal in the gazetted forests has also been prohibited [24]. This means that revenue earned in the extraction of woodfuel in gazetted forests is capped on the issuance of firewood collection licenses.

Table 1. *Average annual volume of firewood collected from Koibatek Forests Zone and Consequent revenue.*

Type of licence	Frequency	Average annual Volume in M^3	Average Annual Revenue (Ksh)
Stacks	1,076	3,230	603, 614
MFLs	107,564	9,358	306, 803
Total		12,588	910, 417

Source: Field data, 2025

According to data collected in Table 1 above, an average annual volume of firewood collected from Koibatek Zone is 12,588m^3 out of which 3,230m^3 is firewood headloads and 9,358m^3 is firewood stacks. The consequent annual revenue from sale of the firewood was found to be Kshs 910,417 where Kshs 603,614 were received in the annual licensing of firewood stacks and Kshs 306,803 in the cumulative annual MFLs. It is observable that licensing of firewood stacks yielded more income than headloads. The research results are similar to estimates that the annual amount of revenue obtained through woodfuel produced in Kenyan gazetted forests being Kshs 4.8 billion [13]. Additionally, the study established that no revenue was generated from charcoal production in the gazetted forests, and this fact agrees with the Republic of Kenya, which regarded charcoal production in the gazetted forests as an illegal activity [24]. Table 2 provides a summary of the linear regression analysis, which has the independent variable as revenue gained by KFS and the volume of woodfuel collected as a predictor.

Table 2. *Summary of Linear Regression of Revenue collected on Volume of woodfuel Extracted within Gazetted Forests.*

	B	SE_b	β	
Constants	2.077	0.758	--	
Main Effects				
Revenue gained	0.640	0.877	0.544	
R				.544
R Square				0.296
Adjusted R Square				0.294
R Square Change				0.315
Model F Change				158.239

	B	SE_b	β	
Model Summary df				1,376
Sig. F Change				0.000
T Values				12.579

Note: Dependent variable, Volume of woodfuel N=377
The significance levels p<0.05

Source: Field Survey data, 2025

The linear regression model in Table 2 indicates that the value of 0.296 of R^2 shows that annual revenue from firewood within Koibatek Forests Zone explains 29.6 percent of the changes in the volume of woodfuel harvested. Adjusted R^2 of 0.294 indicates that there is a slight decrease in predictive abilities (0.002), implying great generalization ability of the model. It was revealed that there was a statistically significant and positive relationship between the volume of the woodfuel extracted and revenue collected (beta = 0.544, p < 0.05). The coefficient of 0.544 and standard error of 0.877 with 95 percent confidence limits mean that an increase in revenue collected by one unit brings about an increase in the volume by activating the woodfuel extracted by a range of between 0.544 and 0.877m^3. It was observed that the t value of this relationship (T = 12.579) was significant at p < 0.05, and as such, it implies that revenue collection is significantly important in predicting the volume of woodfuel that is harvested in the gazetted forests.

4.2. Estimated Annual Volume of Woodfuel Extracted Within Gazetted Forests

To establish the estimates on the supply of woodfuel in the gazetted forests, the researcher used annual licensing data of firewood extractors and the respondents' data on illegally production and sold charcoal.

a) Volume of Firewood Extracted annually

Table 1 above shows that the average annual volume of firewood collected from the gazetted forests within Koibatek Zone was done by:

1) Multiplying each firewood stack by 3m^3 [11]. Therefore; 1076 stacks multiplied by 3m^3 gave 3230m^3 of firewood.
2) Each firewood headload measures 25kg or an average of 0.087m^3 [17]. Therefore; an estimated annual number of firewood headloads of 107,564 multiplied by 0.087m^3 gave 9,358m^3 of firewood collected.

Thus, the total annual volume firewood collected was found to be 12,588 cubic metres. Logging of firewood, especially the exploitation of natural forests, can possibly have a severe ecological impact, such as degradation of species and biodiversity loss [21]. The paper also finds that the result of increased income in Kenya is leads to rise in the extraction of firewood from gazetted forests. This is because more income boosts the purchasing power and allow residents access to the necessary firewood collecting licenses. This, however, contradicts FAO who stated that households tend to migrate from traditional firewood to Liquefied Petroleum Gas (LPG) and electricity when their income rises [7].

b) Estimated annual Volume of Charcoal Produced

An estimation of how much charcoal was produced annually in the gazetted forests of Koibatek was done by first establishing how many producers are involved in the production of charcoal in these forests. Then, the quantity of charcoal that was produced by each producer per event was evaluated. Next, a computation of the number of events of production per month and per year was done.

Researchers have discovered that Kenya charcoal manufacturers tend to package their goods in sacks of about 40 kg [17].

Table 3. *Number of Sacks of Charcoal Produced at a Time within Gazetted Forests.*

Number of Sacks at a time		**Frequency (f)**	**fx**
No of sacks	**Mid-Points (x)**		
0-1	0.5	3	1.5
1-5	3	36	108
6-10	8	8	64
11-15	13	1	13

Number of Sacks at a time		Frequency (f)	fx
No of sacks	Mid-Points (x)		
		∑f=48	∑fx=186.5

Source: Field Survey, 2025

Equation 1: Number of Sacks of Charcoal produced in a single time

$$\text{Mean number of sacks} = \frac{\sum fx}{\sum f} = \frac{186.5}{48} = 3.9 \text{ sacks of charcoal} \quad (1)$$

As depicted in Table 3, the research conducted shows that the average quantity of sacks of charcoal that the 48 interviewed producers can produce simultaneously is about 186.5 sacks of charcoal. Given that the gazetted forests in Koibatek Forest Zone are reported to have 895 charcoal producers, one can find that there are always 3,480 sacks of charcoal being produced at any one time, as shown in Table 4.

Table 4. *Number of Sacks of Charcoal Produced within Koibatek Forests Zone.*

No. of sacks per event		Charcoal Producers		Total No. of Sacks of Charcoal
Range	*Average*	*%*	*No.*	
0-1	0.5	6.3	56	28
1-5	3	75	671	2,013
6-10	8	16.7	149	1,192
11-15	13	2	19	247
Total	-	100	895	3,480

Source: Field Survey, 2025

Table 5. *Percentage of Charcoal Producers on the Times of Charcoal Production per Month.*

Sacks Charcoal Per Event	% of Producers within the Times per month			
	1	2	3	4
0-0.9	0.0	33.3	33.3	33.3
1-5	38.9	47.2	11.1	2.8
6-10	25.0	62.5	12.5	0.0
11-15	100.0	0.0	0.0	0.0
Total	35.4	47.9	12.5	4.2

Source: Field Survey, 2025

The frequency of charcoal production by various groups of producers appears in Table 5. It indicates 35.4%, 47.9%, 12.5%, and 4.25% of producers are involved in the activity once a month, twice a month, three times a month, and four times a month, respectively. Upon consideration of production frequency, considering the size of charcoal production in

sacks, it was found that among those who produce less than one sack per time, 33.3% produce twice a month, 33.3% produce thrice a month, and 33.3% produce four times a month. Out of the producers that produce 1-5sacks, a quarter of the producers produce monthly, 62.5% produce bi-monthly, and another 12.5% take part in the production 3 times a month. On the side of producers who produce between 11 and 15 sacks, 100 percent of them make just once a month. Generally, most of the charcoal players in the gazetted forests in the Koibatek forest zone produce charcoal two times a month (47.9%) and others once-a-month (35.4%).

Table 6. *Estimated Number of Sacks of Charcoal burned per Month within Gazetted Forests.*

Cohorts of Sacks of Charcoal	Sacks of Charcoal per Month				Total
	1	2	3	4	
0.1-0.99	0	18.5	27.7	37.0	83
1-5	783	1900.3	670.3	225.5	3,579
6-10	298	1490.0	447.0	0	2,235
11-15	247	0	0	0	247
Total	1,328	3,408.8	1,145	262.5	6,144

Source: Field Survey, 2025

As indicated in Table 6, most of the charcoal (3,408.8 sacks) was made by people who practiced the activity every two months. Production of charcoal that had between 1 and 5 sacks per event amounted to 3,579 sacks in a month, but those events that resulted in the production of 6-10 sacks provided 2,235 sacks monthly. Approximately 6,144 sacks of charcoal were generated monthly in the gazetted forests in the Koibatek Forests Zone.

A sack of charcoal weighs about 40 Kg [17]. Hence, it would be estimated that the total weight of 6,144 sacks of charcoal manufactured monthly in the gazetted forest blocks of Koibatek Forests Zone is around 245,760 kg. This translates to an approximate weight of 2,949,120 kg of charcoal annually. Using volume conversion where $1m^3$ of charcoal weighs 180 kg, the resultant estimated annual volume of charcoal produced therefore be about $16,384m^3$.

Estimated Annual Volume of woodfuel

The analysis in part (i) and (ii) revealed that the annual volume of woodfuel extracted from gazetted forests of Koibatek Zone is $28,972m^3$ whereby firewood collection accounted for $12,588m^3$ and charcoal production accounting for $16,384m^3$. Therefore, though it is illegal within gazette forests, volume of charcoal produced was found to be more than volume of firewood collected. This observation coincides with that of the report released by the Ministry of Environment, identifying that even Kenyan forests were consumed, making 16,506,498 tonnes worth of charcoal that went past the number of firewood that was 15,111,180 tonnes [11]. Charcoal is usually preferred over firewood since it is lighter to transport and contains more energy [21]. This implies that the volume of illegal operations of charcoal making was large, and hence, the laws controlling the extraction of forest products in these regions were not perfectly observed.

Estimated annual income earned from Sale of Woodfuel extracted from Koibatek Forests Zone

A systematic method was used to determine the amount of income obtained during the sale of woodfuel. This entailed investigations on where the wood fuel extracted in gazetted forests was to be used, as well as the units in which the wood fuel was to be measured when it is being sold, and the cost incurred in every unit of measurement.

Table 7. *Purpose for Woodfuel Extraction within Gazetted Forests of Koibatek Zone.*

Category of Woodfuel	% of Total respondents on purpose for woodfuel extraction		
	Domestic	Commercial	Total
Firewood	77.1	28.9	100.0
Charcoal	62.5	37.5	100.0

Category of Woodfuel	% of Total respondents on purpose for woodfuel extraction		
	Domestic	Commercial	Total
Mean Total	66.8	33.2	100.0

Source: Field Survey, 2025

Table 7 reveals that the woodfuel was mostly extracted to cater to domestic purposes as indicated by 66.8% of the respondents, whereas 33.2% of the respondents extracted woodfuel for commercial purposes. Therefore, there is a significant income population who extracted woodfuel in pursuit of income from sale of the commodity

Table 8. *Linear Regression of Income Earned Sale of Woodfuel and Volume of woodfuel Extracted.*

	B	SE_b	β	
Constants	982	1031	--	
Main Effects				
Income from Sale		868	1194	
R				.729
R Square (R^2)				0.531
Adjusted R^2				0.528
R Square Change				0.315
Model F Change				158.24
Model Summary df				1,139
Sig. F Change				0.000
T Values				12.503

Note: Dependent variable, Volume of woodfuel N=140
The significance levels p<0.05

Source: Field Survey data, 2025

Table 8 indicates that a regression model is used and is in the form of Equation 2 which predicts income earned as follow:

$$Woodfuel\ volume\ =\ 982\ +(1031\times\ Income\ earned).$$

The relationship between Income earned and the volume of the woodfuel extracted per day. The results have the R squared = 0.531 and the adjusted R squared = 0.528 (F = 158.239, p < 0.05, df = 1,139), and as it is seen, the reduction of the ability of the model to predict the values is minimal, just 0.003. As the decrease in the predictive power is lower than the value of 0.075, the given regression model is highly generalizable to the general population. R^2 = 0.531 implies that 53.1 percent of change in the volume of woodfuel harvested in gazetted forests can be attributed to the income derived in the sale of the woodfuel. Significant relationship of positive nature between income earned and volume of woodfuel extracted was established (p < 0.05, 1.194). With a 95 percent degree of certainty, the model will indicate that the volume of woodfuel extracted rose between 0.868m^3 and 1.194m+3 as a result of income that was generated by the sales of the fuel. t-value (T = 12.503) was significant at p < 0.05; hence income earned is a major determinant of the amount of woodfuel extracted in the Koibatek Forest Zone. This study has concurred with [12, 18] who emphasized that revenues generated in the sale of woodfuel highly contribute to the increased harvesting of woodfuel in most African countries. In addition, it corresponds with reports that the purpose for issuance of firewood's Monthly Fuel Licenses (MFLs) to registered members of the Community Forest Association (CFA) in gazetted forests is mainly for domestic uses [15]. However,

nothing prevents the licensees from selling the firewood harvested, provided they collect the firewood in the forest only once a day.

Table 9 shows the Pearsons chi-square tests on the purpose for which woodfuel is collected from gazetted forests of Koibatek Zone.

Table 9. Chi-Square Tests Statistics for Category of Woodfuel and Purpose for Extraction.

	Value	Df	Asymp. Sig. (2-sided)
Pearson Chi-Square	53.920[a]	2	.000
Likelihood Ratio	53.396	2	.000
Linear-by-Linear Association	52.362	1	.000
N of Valid Cases	384		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 2.81.

Source: Field Survey Data, 2025

The results of the Pearson Chi-Square test, tabulated in Table 9 ($X^2 = 53.920$, $P < 0.05$), show that there is a significant association between the category of woodfuel to be extracted, and the purpose to which it is to be extracted in the gazetted forests of the Koibatek Zone. The overall extraction of firewood and charcoal is, however, more commercially oriented, with the sales of charcoal being a major aspect of the business. The findings are consistent with published results which state that the total amount of woodfuel that is extracted annually in Kenya through both home and commercial purposes in the mixed forests is 31,617,678 tons [16]. In addition, woodfuel is commonly refined into charcoal, which makes transportation easy and increases its energy content [15]. Moreover, projections indicates that the market value of woodfuel harvested in Kenya's gazetted forests is about Ksh 4.8 billion per year [13]. Table 10 indicates measurement units and the estimated costs per unit of firewood and charcoal manufactured by the gazetted forests of Koibatek Forest Zone to be used for commercial government purposes.

Table 10. Measuring Units and Costs per Units of Woodfuel within Gazetted Forest Blocks.

Type of Woodfuel	Measuring Unit	Approximate Cost (Kshs) per Unit
Firewood	Split/round 1m piece	20
	Headload	400
	Donkey load	900
Charcoal	40kgs Sack	1200

1 USD = Ksh. 130 in 2025 [20]
Source: Field Survey, 2025

Table 10 shows some of the different measuring units of firewood and the average cost of sale within Koibatek Forest Zone. Firewood was sold was follows: a 1-meter piece of firewood at a cost of Kshs 20; a back/headload firewood was also sold at a price of Kshs 400; a donkey load of firewood costs Kshs 900 and a sack of charcoal weighing approximately 40kg at Kshs. 1200. Back/head load is the most widespread unit of measurement for firewood among the firewood sellers. This is in line with the Government of Kenya, which stipulates that one headload of firewood should be harvested in gazetted forests every day under the Monthly Fuel Licenses [11].

Table 11. Coefficients for Regression Model for Income Earned and Volume of Woodfuel Extracted Within Gazetted Forests.

Model	Standardized Coefficients	Unstandardized Coefficients		T	Sig.
	Beta	B	Std. error		
Constant		982	0.248	3.96	0.000
M^3	0.729	1031	0.082	12.5	0.000

Source: Field Survey Data, 2025

In Table 11, the coefficients (B) are shown as 0.982 and 1.031, which have a p-value of less than 0.05. The regression model using these non-standardized coefficients thus takes the form of Equation 2.

Equation 2: Regression Model for Predicting Income-earned from Volume is as follows:

$$Income\ earned\ (Kshs) = 982 + (1031 \times Volume)$$

Therefore, with an estimated annual volume of 28,972m^3 of woodfuel from Koibatek Forests Zone, the predicted annual income earned can be calculated as follows:

$$Income\ earned\ (Kshs) = 982 + (1031 \times 28{,}972) = Kshs.\,29{,}871{,}114 \quad (2)$$

The predicted annual income earned from sale of woodfuel collected from gazetted forests within Koibatek Forest Zone is Kshs. 29,871,114. The results indicates that the woodfuel business is a very profitable venture since out of the volume collected revenue that goes to government was found to be Kshs. 910,417 annually. This income collected from the sale of woodfuel was high and instrumental in improving the standard of living for populations clustered near the forests. This is a complementary study to [18], who valued the annual supply of woodfuel obtained through the gazetted forests in Kenya at Ksh. 4.8 billion. In addition, the income results of trading woodfuel as a significant influence on the amount of woodfuel extracted; however, the authors did not measure the amount of income earned as a result of this trade [24].

5. Conclusions

The research established that the revenue raised by selling the woodfuel contributes immensely towards the quantity of woodfuel obtained during the harvesting of the gazetted forests in Koibatek Zone. The Kenya Forest Service (KFS) receives significant income in the form of licenses and permits issued to collect firewood in specific forests. Such licenses form a chain of traders, where the woodfuel extractors either sell all or half of the firewood they gather to traders with yards in the local areas or directly to households. Consequently, these extractors make money by selling the wood fuel they collect. In addition, charcoal burning is also illegal and occurs in the Dyed forests of Koibatek. These forests will be used to produce charcoal, which is sold in urban regions with high demand, thereby bringing money to the producers, transporters, and retailers in the towns. Charcoal and firewood produced in gazetted forests are a lucrative trade, and thus there is a high demand for woodfuel. To curb this, this study suggests that policymakers (KFS, County Governments) should harmonize their licensing regulations to crack down on the illegal woodfuel trade. Additionally, woodfuel extractors are proposed to be categorized into two groups: domestic and commercial. It is also advisable that business owners consider innovating new and improved methods of value addition to woodfuel, which may lead to an increase in income while reducing the amounts being extracted from the ground. The increased monitoring of gazetted forests by forest rangers, especially at night and on weekends, will also be necessary to reduce charcoal production and the extraction of firewood without a civil license. Moreover, the monitoring of the extraction and transport of firewood by licensed extractors should ensure that only dry wood is collected, and the authorized quantities of firewood are removed from the forests. Lastly, education and empowerment of local forest communities to establish on-farm forestry systems should be achieved through sustainable woodfuel extraction practices, agroforestry, and effective land management.

Abbreviations

CFA	Community Forest Association
ESMAP	Energy Sector Management Assistance Program
EU	European Union
FAO	Food and Agricultural Organization
FGD	Focussed Group Discussion
GDP	Gross Domestic Product
GoK	Government of Kenya
IEA	International Energy Authority
Ksh	Kenya Shilling
KFS	Kenya Forest Service
LPG	Liquified Petroleum Gas

MFL	Monthly Fuel Licence
USD	United States Dollar
WEC	World Energy Council

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Author Contributions

Keith Kipngetich Rono is the sole author. The author read and approved the final manuscript.

Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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Research Field

Keith Kipngetich Rono: Woodfuel Energy development, Electricity Conservation and Management, Environmental Impact Assessments and Auditing, Urban Environmental Planning and Management, Climate Change Mitigation, Indigenous Knowledge Systems