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ABSTRACT

This study aimed to assess the households' woodfuel sources and their utilisation technologies in Mt. Elgon and Cherang'any Hills Water Towers in Kenya. The two ecosystems were purposively sampled based on various factors, which included diverse ecological conditions and population densities. A total of six counties out of the eleven were sampled based on homogeneity to the ecosystem. The most notable reasons for preferring certain species over others were: species availability, fast growth, good burning characteristic, provision of good timber, and ease of propagation among others. The paper concludes that most households in Mt Elgon and Cherang'any Hills water towers depend on woodfuel for their energy requirements and exotic species were the most preferred. Therefore, there is a need to domesticate national legislation to enhance sector sustainability.

Keywords: *biomass, woodfuel, household energy sources, cookstove, preferred tree species*

INTRODUCTION

Biomass is a primary energy source in Kenya, accounting for over 68% of total energy and over 90% of rural household energy needs [1]. The main sources of biomass energy for cooking and heating are charcoal, fuelwood and agricultural residues. According to the Ministry of Energy (MoE) [2], besides being the standard cooking fuel for the majority of Kenyan households, firewood and charcoal (woodfuel) are also important energy sources for learning and service institutions and small-scale rural industries such as tobacco curing, tea drying, brick making, fish smoking and bakeries.

Though there has been an attempt to promote clean energy sources, their consumption has been low as 19%, 3%, 14% and less than 1% of the Kenyan population considering liquefied petroleum gas, electric cooker, kerosene and alternative cooking technologies (biogas, ethanol and solar) as their primary fuel respectively [2]. Though households use multiple energy sources, it is evident that energy proportions consumed from clean sources are much lower compared to non-clean energy sources, especially solid biomass energy. Over-reliance on solid biomass energy sources, especially charcoal and firewood, are increasingly contributing to deforestation. A study in Ethiopia established that the collection of wood harvesting for woodfuel purposes was the second cause of forest degradation next to agricultural land expansion [3]. This is more prevalent in the arid and semi-arid regions where 40 to 70% of woodfuel used in Kenya is produced, yet such regions are characterised by less than a 4% productivity rate due to poor regeneration and vegetation growth rates [4]. Therefore, as sustainable biomass energy productions continue to decline by 0.5%, its demand is increasing by 2.7% [4]-[5]. This has led to the unsustainable harvesting of woodfuel in protected water towers in Kenya [6].

The principal drivers of increasing biomass energy demand are population growth, lack of access to affordable energy substitutes and the growing incidence of poverty among Kenyans [7]. Therefore, the energy resource is threatened by the interaction of a multiplicity of factors such as population pressure, rural-urban migration, unstable fossil fuel prices, unaffordable cost of alternatives, lack of access to alternative energy sources, ineffective legal and regulatory framework, competing land uses, inefficient production and utilisation technologies, increased frequency of extreme weather patterns and unemployment. As a result, Kenya has faced an increased biomass energy supply deficit from 56% to over 60.5% in the last two decades [4],[8]. Biomass energy supply and demand imbalance are exerting considerable pressure on the remaining forest and vegetation stocks, especially in protected water towers. This has accelerated the processes of land degradation, exacerbating climate change and reduced food production leading to increased famine and increased vulnerability of marginalized people to the impacts of climate change. This is negatively affecting the country's ability to attain Sustainable Development Goals (SDGs), especially SDG7, 13 and 15 which can support resilient communities [9]. For the country to deal with these challenges, there is a need for effective regulation of the woodfuel sector, which has remained a challenge facing the government [10]. However, to be effective, policies and regulationsy need to be strongly supported by context-sensitive, verifiable, timely and accurate data [11].

Therefore, the study's objective was to assess the status of woodfuel energy utilisation and intervention initiatives in Mt. Elgon and Cherang'any Hills ecosystem in Kenya. The information generated will enhance the formulation and implementation of evidence-based policies.

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METHODOLOGY

Study Area

A baseline survey on energy sources was conducted in Mt. Elgon and Cherang'any Hills Ecosystems. The study area covered 11 counties (Busia, Kisumu, Siaya, Bungoma, and Trans-Nzoia in Mt. Elgon ecosystem; and Elgeyo Marakwet, Pokot West, Uasin Gishu, Kakamega, Vihiga and Nandi in Cherang'any Hills ecosystem. Mt. Elgon is one of Kenya's five main water towers, with an estimated population of over 1.5 million, covering 236,505 ha on the Kenyan side [12]. The vegetation in the ecosystem can be classified into four; open woodland, tropical moist, bamboo and afro-alpine. Cherang'any Hills cuts across Trans-Nzoia, West-Pokot and Marakwet counties and covers over 120,000 ha. It comprises 12 forest blocks, which maintain great plant diversity of relatively undisturbed, disturbed and secondary forests as well as swamps and riverine forests together with natural glades [13].

Sampling Procedure

Purposive sampling within the two ecosystems was done based on household populations in Mt. Elgon and Cherang'any Hills ecosystems based on the 2009 population census data. A total of 6 Counties (Kisumu, Bungoma, Kakamega, West-Pokot, Uasin-Gishu and Nandi) out of the 11 counties were sampled based on homogeneity to the ecosystem. With different percentage household distribution in each of the counties within the ecosystems, a sample of 401 households in 42 sub-counties representing the population was randomly sampled (Table 1) and calculated based on Equation 1 [14]. The Confidence level (95%) and margin of error (3.5%) were used to calculate the sample size of the whole population in Mt. Elgon and Cherang'any Hills ecosystems.

$$\eta = \frac{z^2 * p(1-p)/e^2}{1 + \left(\frac{z^2 * p(1-p)}{z^2 N} \right)} \quad (1)$$

where, *Population Size = N*
Margin of error = e (e is a percentage, put into the decimal form)
Z-score = is the number of standard deviations a given proportion vary from the mean).
p = Confidence level

Table 1 Sample size per county in Mt. Elgon and Cherang'any Hills ecosystems

Ecosystem	CL-95% ME-3.5%				
	County	Household population	% Household Distribution per county	Number of Household	No. of sub-counties
Mt. Elgon	Kisumu	226719	17	67	7
	Bungoma	321628	24	95	10
	Kakamega	355679	26	105	11
Cherang'any Hills	Pokot West	93777	7	28	3
	Uasin Gishu	202291	15	60	6
	Nandi	154073	11	46	5
	Total	**1354167**	**100**	**401**	**42**

CL –Confidence level; ME- Margin of error

Data Collection Tools

Household surveys, Key Informant Interview (KII) and Focused Group Discussions (FGDs) were conducted within the selected ecosystems. Combinations of qualitative and quantitative tools were developed for energy baseline data collection activities. For the household survey, the information gathered were sources of energy commonly used for heating and lighting, the most preferred tree species as woodfuel, accessibility levels, and technologies used in the conversion and utilisation of woodfuel. The KII targeted officials of the Kenya Forest Service, extension officers from the ministries of Agriculture, Energy and Environment, local administration and non-governmental organizations. The captured information on KII included main sources of energy, quantities of wood energy supplied from the forest and charcoal production techniques. FGDs were held at the sub-county/village level and involved representatives of Community Forest Associations (CFA) Community-Based Organizations (CBOs) and user groups who provided on the most preferred energy sources and concerns of access and use of different sources of energy.

Data Analysis and Reporting

The baseline survey data was analyzed using SPSS and MS excel. Data was coded in SPSS and in the case of "check all that apply" question (where respondents were required to give more than one response, data was recorded in multiple columns, with one each column representing one answer option, including 'do not apply'. The chi-square test of fit was used to test if there were significant differences in frequencies for different energy types, tree species and accessibility levels.

RESULTS AND DISCUSSIONS

Sources of Energy for Heating and Lighting

Firewood, charcoal, briquettes, agricultural residues, kerosene, Liquefied Petroleum Gas (LPG), sawdust/sawmill residues, biogas, electricity and other sources of energy, including solar were the main sources of energy used by households for heating/cooking and lighting within the water towers (Table 2). The chi-square test of fitness indicated statistically significant differences in the frequencies of respondents using different fuel sources for heating ($\chi2(9) = 201.623$, $P < 0.001$) and lighting ($\chi2(9) = 154.903$, $P < 0.001$) in Mt. Elgon and Cherang'any Hills water towers. The majority of respondents were using firewood (91.7%) for heating and electricity (48.5%) for lighting, while the minority were using agricultural residues for heating (2.2%) and sawdust (0.0%) for lighting (Table 2). Within the water towers, 89.3 and 91.7% of respondents in Mt Elgon and Cherang'any Hills water towers, respectively use firewood for heating. In Mt. Elgon water towers, 20.6% and 8.3% of respondents use LPG and electricity for heating, compared to 12.4% and 3.9% in Cherang'any Hills water towers, respectively. However, the use of kerosene for heating was slightly higher (50.1%) in Cherang'any Hills water towers compared to Mt. Elgon Water towers (45.5%). The chi-square test of association indicated that the source of energy for heating (age ($\chi2(5) = 15.473$, $P = 0.068$) and lighting (($\chi2(5) =$

10.462, P = 0.351) were not significantly associated with the counties in which the respondents reside. However, 100% of respondents in West-Pokot were using firewood as the main source of heating energy compared to 84.9% in Kisumu, who were using the same. Over 30% of respondents were using kerosene and electricity for lighting in all counties (Table 2).

As stated by FGDs and KII, charcoal was mainly used for heating/cooking, mostly in urban areas. West Pokot County produces a lot of charcoal, but most of it (90%) is sold to towns like Kisumu, Eldoret, Nairobi, Kitale and Bungoma, which confirms why the majority of the households use firewood more for heating/cooking. Energy prices are a major determinant of the choice of fuel type a household chooses. Firewood was the most preferred source of energy among the households because of its availability, familiarity and most importantly, because it costs much less compared to other energy sources.

It was also noted from FGDs and KII that there were no considerable relationship among the education levels, type of household homes and energy sources used. The level of income plays a big role in the type of energy used, as those with a stable source of income are faster to adopt energy alternatives. However, this was not the case with households in WestPokot as households with a monthly income of over Kenya Shillings (KShs) 40,000 (equivalent to USD 312 on 6th March 2023) still preferred firewood for cooking. This could be explained by the ease of accessibility of firewood, its familiarity and most importantly, because it costs much less as compared to other energy sources [15].

Table 2 Sources of energy used for heating/cooking and lighting in Mt Elgon and Cherengani Water Towers in Kenya

Source of Energy	Uses	Response in Mt Elgon Water Tower (%)					Response % in Mt Cherengani Tower (%)			Average Response (%)
		Kakamega	Kisumu	Bungoma	Mean	West Pokot	Nandi	Uasin Gishu	Mean	
Firewood	Heating	98.1	84.9	85	89.3	100	96.4	85.6	94	91.7
	Lighting	8.9	17.5	9.2	11.9	17.1	0.0	2.2	6.4	9.15
Charcoal	Heating	50.3	81.4	51.6	61.1	50.4	36.8	44.5	43.9	52.5
	Lighting	5.2	4.6	6.5	5.4	10	2.3	3.4	5.2	5.3
Briquettes	Heating	8.4	14.6	9.2	10.7	0.0	8.0	9.6	5.9	8.3
	Lighting	0.0	2.5	0.0	0.8	0.0	0.0	4.6	1.5	1.2
Agricultural residues	Heating	2.1	0.0	4.3	2.1	1.3	2.0	3.3	2.2	2.2
	Lighting	1.8	0.0	3.6	1.8	1.0	0.0	0.0	0.3	1.1
Kerosene	Heating	22.4	27.0	19.2	22.9	16.3	18.4	26.3	20.3	21.6
	Lighting	47.3	54.8	34.5	45.5	65.6	39.9	44.8	50.1	47.8
LPG	Heating	11.6	29.6	20.6	20.6	8.2	17.4	11.5	12.4	16.5
	Lighting	1.4	0.0	3.5	1.6	2.9	1.8	0.0	1.6	1.6
Saw dust/ saw mill wastes	Heating	2.6	10.6	1.0	4.7	0.0	5.3	0.0	1.8	3.3
	Lighting	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biogas	Heating	3.3	1.2	10.3	4.9	4.3	0.0	8.2	4.2	4.5
	Lighting	0.0	0.0	8.6	2.9	4.4	0.0	6.4	3.6	3.2
Electricity	Heating	6.0	9.5	9.3	8.3	4.6	3.4	3.6	3.9	6.1
	Lighting	42.6	48.4	53.4	48.1	31.3	59.8	55.2	48.8	48.5
Any other (Specify)	Heating	19.1	26.4	24.6	23.4	7.6	20.8	26.6	18.3	20.9
	Lighting	24.2	33.5	30.3	29.3	23.3	26	33.4	27.6	28.5

The identified energy sources concur with the energy sources mentioned by Takase et al. [4] in their comprehensive review of energy scenarios and sustainable energy in Kenya. Firewood and charcoal are the most predominantly used energy sources for heating. This is because they are relatively cheaper, available and require less skills and knowledge as people of all ages and education levels can use them. However, continued charcoal production through selective harvesting of trees has led to forest degradation, deforestation and loss of biodiversity [16]. Contrarily, the use of firewood may not be causing deforestation as most firewood is usually collected from fallen wood or from sources that would already be felled for other purposes [17]. However, continuous collection of firewood increases gender parity as mostly women and children spend most of their time walking longer distances fetching firewood instead of engaging in other meaningful activities like attending schools and other income generating activities [18]. The use of LPG and other sources, including solar heaters has been increasing in the past two decades, though this progress may be hampered with ever increasing taxes in Kenya [19]-[20].

Kerosene, electricity and other sources of energy, especially solar were the main sources of energy used for lighting in Kenya. This concurs with the report by Energy and Petroleum Regulatory Authority [19]. However, with increasing rural electrification, reduced cost of electricity, increasing cost of kerosene due to adulteration levies and availability of reliable off-grid solar systems, Wagner et al. [15] and Baek et al. [21] predict that electricity and solar will overtake kerosene as the main source of lighting, especially in rural areas. This is expected to reduce the use of 'dirty lamps' that includes gas lamps, kerosene-powered lamps, biogas lamps, candles and firewood [15].

Preferred Sources and Tree Species of Woodfuel

Preferred sources of woodfuel in Mt. Elgon and Cherang'any

The study identified the main sources of woodfuel as being on-farm indigenous trees, on-farm exotic trees, planted woodlots, purchasing from the market, sawmills, gazette forests, trust land and other sources like along riverine. The chi-square test of fit indicated a statistically significant difference in the proportions of respondents that obtained firewood ($\chi2(7) = 109.064$, $p = 0.021$) and charcoal ($\chi2(7) = 98.972$, $p = 0.013$ from different sources. The majority (66%) of respondents get firewood from on-farm exotic trees, while the majority (45%) of respondents purchase charcoal from markets (Table 3). In terms of counties, 100% and 92% of respondents in West-Pokot County get firewood and charcoal from on-farm indigenous forests, respectively. Obtaining firewood from exotic trees on farms is an indicator of sustainable firewood harvesting as they only use fallen wood and leftovers from wood cut for other purposes and even encouraging on-farm tree planting [17].

However, it may indicate overexploited indigenous tree species in the neighborhood. This is because when nearby indigenous vegetation is overexploited and to the point of extinction, people fetch firewood from farms to save energy and time that would be spent walking long distances to fetch firewood from indigenous forests is unsustainable [22]. On charcoal, the study concurs with a review by Ndegwa et al. that over 67% of households using charcoal in Kenya purchase it from the market [23]. This may be because most charcoal users reside in urban regions, and they neither have trees nor are allowed to produce charcoal. However, over relying on indigenous trees in WestPokot County is unsustainable. Though this overreliance may be due to the availability of indigenous trees on farms as the county is in semi-arid regions, vegetation has poor regeneration and slow growth.

Table 3 Preferred sources of firewood and charcoal in Mt Elgon and Cherang'any Hills Water Towers of Kenya

Source of woodfuel	Uses	Response in Mt Elgon Water Tower (%)				Response in Cherang'any Hills Water Tower (%)				Average Response (%)
		Kakamega	Kisumu	Bungoma	Mean	West Pokot	Nandi	Uasin Gishu	Mean	
On-farm indigenous trees	Firewood	25	78	61	55	100	25	14	46	51
	charcoal	26	35	38	33	92	7	3	34	34
On-farm exotic trees	Firewood	48	47	75	57	71	74	82	76	66
	charcoal	33	13	26	24	38	12	54	35	29
Planted woodlots	Firewood	34	20	0	18	0	21	2	8	13
	charcoal	25	3	1	10	4	5	0	3	6
Purchase	Firewood	25	42	25	31	0	24	18	14	22
	charcoal	31	70	45	49	4	64	57	42	45
Saw mills	Firewood	3	0	0	1	0	0	0	0	1
	charcoal	2	0	0	1	0	0	0	0	1
Gazetted forests	Firewood	10	0	4	5	0	5	0	2	3
	charcoal	5	0	0	2	0	0	2	1	1
Trust land	Firewood	0	0	0	0	4	0	0	1	1
	charcoal	0	0	1	1	8	0	0	3	2
Other sources	Firewood	1	0	0	0.3	0	5	0	2	1
	charcoal	13	9	15	12	0	19	0	6	9

Tree species preferred for firewood and charcoal

The results showed that exotic tree species were the most preferred for planting on the farms for firewood and charcoal, with Eucalyptus spp (18.50%) being the most popular species, followed by Grevillea robusta (12.20%) and Cupressus lusitanica (10.66%) (Table 3). The three most preferred indigenous species were Markhamia lutea (7.35%), Croton macrostachyus (2.99%) and Albizia coriara (2.91%) (Table 3). The chi-square test of fit indicated that there were statistically significant differences in respondents' frequencies on different preferred tree species for firewood and charcoal in Mt. Elgon and Cherang'any Hills water towers ($\chi2(14) = 396.032$, $P < 0.001$), with the majority (18.4) and minority (0.6%) of respondents indicating Eucalyptus spp. and Euphorbia tirucali were their preferred species.

The preference for different species, as summarized in Table 3, was based on species availability, fast growth, good burning characteristic, provision of good timber and ease of propagation. Exotic species were most preferred based on the short time period the species took to grow and the ease of processing compared to the indigenous species. Indigenous species were not preferred because communities attach more value to indigenous species as opposed to exotic species and therefore, they were not cutting them for firewood.

Table 3 Preferred tree species for woodfuel and potential reasons for preference

Species	Frequency (%)	Plant type	Reasons for preference
Eucalyptus Sp.	18.4	Exotic	Easily/locally available, produces branches good for firewood, burns well and retains heat, easy to split, cheap to acquire, early maturity, easily grows (coppice) after cutting, faster to grow, grows tall and produces branches, Economical to use
Grevillea robusta	12.4	Exotic	Can be used as a source of timber, charcoal, firewood and shade; easily available and economical, burns with high heat intensity (Produces more heat), doesn't produce a lot of smoke, dries fast, matures fast, easy to split, easy to light, produces high-quality charcoal
Cupressus lusitanica	13.8	Exotic	Easy to propagate, grow and matures faster, branches dry fast, burn with ease; good flame; Cheap to acquire, produce less smoke and ash, easy to cut and split
Markhamia lutea	5.1	Indigenous	Easily accessible, burns for long, dries faster, produces high-quality charcoal and firewood that light fast, easy to intercrop, easy to split, grows fast
Mangifera indica	2.9	Exotic	Available and produces firewood and charcoal of high quality, burns for long, dries quickly, easy split, the branches are easy to lit, produce less smoke when dried well
Persea americana	1.6	Exotic	Available, burns for long, dries fast, early maturity, easy to split, easy to maintain, produces the quality of charcoal
Acacia mearnsii	4.5	Exotic	Best for Charcoal and fuelwood burns for a long time, grows and matures fast to produce marketable firewood and charcoal, cheap and easy to acquire, high market demand for its charcoal and firewood, which produces less smoke, easy to harvest and process and lights easily, the seedling is more available compared to other species so that makes the farmers grow them
Pinus patula	2.0	Exotic	Easy to split, dries fast, produces less smoke, early maturity, and easy to split, firewood burns fast, it has the worst charcoal, so farmers only use it for firewood, the farmers plant them purposely for timber and the branches are used as firewood, they are cheap to maintain because one can intercrop with other crops, e.g., maize, beans
Croton macrostachyus	2.9	Indigenous	Readily available; burns for long, easy to light; dries fast and easy to split, matures faster, produces high-quality charcoal and timber
Albizia coriara	1.8	Indigenous	Available, produces quality charcoal and firewood, burns for long, dries fast, easy to spilt, good source of heat
Psidium guajava	0.7	Indigenous	Dries fast, easily available, naturally growing, not easily consumed with fire, Easy to prune branches for firewood, Produces good quality charcoal
Jacaranda mimosifolia	0.7	Indigenous	Easy to light, easy to be spilt, easily accessible/available, fast-growing, Produces quality of charcoal and firewood
Ficus sycomorus	1.1	Indigenous	Easily available, burns for long, easy to split, lights fast, produces firewood and quality charcoal
Acacia Spp	1.2	Indigenous	Easy to grow, has high heat intensity, produces high-quality charcoal and firewood, easy to light, has many branches which can be used as firewood, Readily available
Euphorbia tirucali	0.6	Indigenous	Dry fast, grows fast as such easy to replant, a good source of heat, grows naturally, readily available

Within the water towers, Eucalyptus species and Cupressus lusitanica, with a response rate of 18.1 and 21.2%, were the most preferred tree species to be planted for woodfuel in Mt Elgon and Cherang'any Hills water towers, respectively. However, there were variations on the most preferred tree species to be planted for woodfuel within counties. Eucalyptus species were the most preferred species in Kakamega (22.2%), Bungoma (20.1%) and Nandi (18.5%). Cupressus lusitanica, Markhamia lutea and Acacia meansii were preferred in West-Pokot (25.8%), Kisumu (13.8%) and Uasin Gishu (26.9%), respectively (Table 4).

The findings of these studies contradicted earlier findings like Ndegwa et al. [16] and Namaswa et al. [24] that indicated a preference for indigenous tree species, especially Vachellia species for firewood and charcoal. The FGDs and KII explained that the trend seems to be shifting to exotic tree species. This is due to the on-farm tree planting initiatives being undertaken in the counties under study to curb deforestation (which has led to the destruction of most indigenous tree species). This proves the argument that eucalyptus has better calorific values and can compete with preferred species for charcoal and firewood production [25]. This trend is being encouraged by field officers for a freehold land tenure system that enhances the ability of the landowner to enjoy tree rights as well as intensive on-farm tree planting [24].

Accessibility to Firewood and Charcoal

Regarding accessibility, firewood and charcoal were relatively accessible across all the Counties surveyed. In all sampled counties, an average of 33% of households indicated that firewood was easily accessible, 29% indicated it was accessible, while only 15% indicated it was hardly accessible (Table 5). A different trend was noted for charcoal, with 38% of households confirming that charcoal was accessible while 32% said it was hardly accessible. Charcoal may not be easily accessible because it was sold at high prices of up to Kshs. 1200 (USD 9.5 as at 6th March 2023) per sack in some areas (Figure 1). The condition has been exacerbated by the presidential moratorium in 2018 that banned charcoal production in Kenya's public forests, a situation that has led to increased scarcity of the commodity [26]-[27]. In addition, the distance travelled to fetch firewood is mostly less than 2 km (79%) (Figures 2 and 3), however, there are places within the counties studied that fetched firewood from up to a distance of more than 5 km but this was

Table 4 Dominant species preferred per water tower and county for woodfuel

Tree Species	**Response in Mt Elgon Water Tower (%)**				**Response in Cherengani Water Tower (%)**			
	Kakamega	**Bungoma**	**Kisumu**	**Mean**	**West-Pokot**	**Nandi**	**Uasin Gishu**	**Mean**
Eucalyptus Sp.	22.2	20.1	12	18.1	16.81	18.	20.8	18.7
Markhamia lutea	10.5	5.9	13.8	10.1	0.0	0.0	0.0	0.0
Cupressus lusitanica	9.5	9.5	0.0	6.3	25.8	17.7	20	21.2
Grevillea robusta	9.5	17.5	7.1	11.4	9.7	14.3	15.4	13.1
Persea americana	5.6	4.1	0.0	3.2	0.0	0.0	0.0	0.0
Croton macrostachyus	4.6	0.0	0.0	1.5	0.0	12.6	0.0	4.2
Psidium guajava	3.9	0.0	0.0	1.3	0.0	0.0	0.0	0.0
Mangifera indica	3.6	5.3	8.5	5.8	0.0	0.0	0.0	0.0
Pinus patula	3.3	4.1	4.6	4	0.0	0.0	0.0	0.0
Ficus sycomorus	0.0	6.2	0.0	2.1	0.0	0.0	0.0	0.0
Albizia coriara	0.0	5.6	5.3	3.6	0.0	0.0	0.0	0.0
Jacaranda mimosifolia	0.0	0.0	3.9	1.3	0.0	0.0	0.0	0.0
Euphorbia tirucali	0.0	0.0	3.5	1.2	0.0	0.0	0.0	0.0
Acacia mearnsii	0.0	0.0	0.0	0.0	0.0	0.0	26.9	9.0
Vachellia Spp	0.0	0.0	0.0	0.0	0.0	0.0	6.9	2.3
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

minimal (3%). The distance may keep on increasing as the firewood resources become scarce. However, this can be sourced through the development of on-farm woodlots.

Table 5 Accessibility to firewood and charcoal

Accessibility	Accessibility of firewood	Accessibility of charcoal
Not accessible	2%	8%
Hardly accessible	15%	32%
Accessible	29%	38%
Easily accessible	33%	13%
Most easily accessible	21%	9%

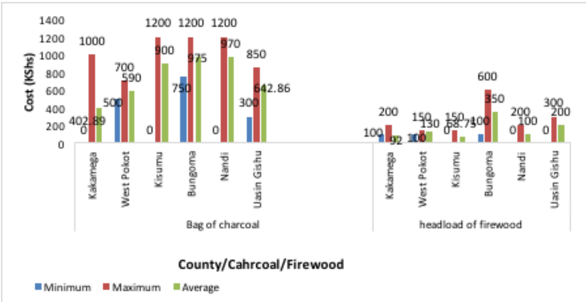

Figure 1 Average woodfuel prices in Mt. Elgon and Cherang'any Hills water towers in Kenya

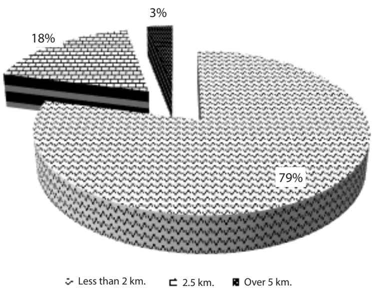

Figure 2 Overall firewood transport distance

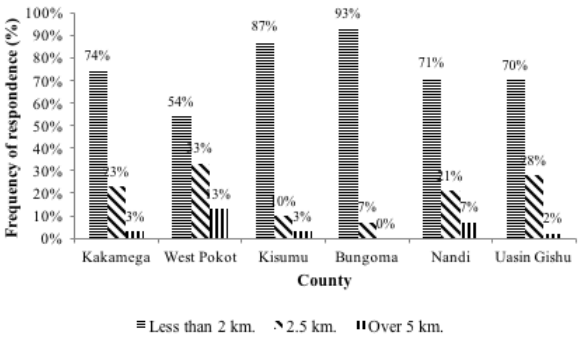

Figure 3 Firewood transport distance within counties

Woodfuel Conversion and Utilisation Technologies

Charcoal conversion technologies

Figure 4 indicates that over 95% of respondents in the study areas use earth mound kiln for charcoal production. The chi-square test of fit indicated that the earth mound kiln is the most dominant charcoal production technology in Mt. Elgon and Cherang'any Hills water towers ($\chi 2(4) = 201.631$, $P < 0.001$). The results concur with studies by Siko et al. which reported that over 99% of charcoal producers in Kenya still use traditional earth mound kilns with less than 14% wood to charcoal conversion efficiency [28]. This may because the technology has no upfront investment cost except kiln preparation labor, requires minimal operating skills and does not require transportation as it can be constructed near sources of wood. However, low conversion efficiency means more wood is required per unit of charcoal produced, leading to high deforestation rates as a result of massive waste [29]. They also take longer carbonization time and have high greenhouse gas emissions. Despite the enactment of charcoal rules to ensure sustainable production through the adoption of improved and more efficient technologies, charcoal production in Mt. Elgon and Cherang'any Hills is still produced unsustainably.

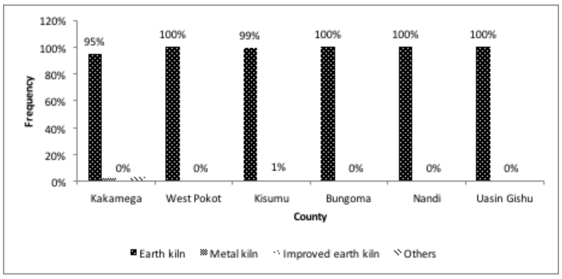

Figure 4 Charcoal production technologies in Mt. Elgon and Cherang'any Hills Water Towers

Woodfuel utilisation technologies

The study identified four categories of cookstoves that were being used; they include three stone open fire stoves, traditional metallic charcoal stoves, improved charcoal cookstoves and improved firewood stoves (Table 6). The chi-square test of fit indicated that there was a statistically significant difference in the proportions of respondents using different woodfuel cookstoves, with three stone open fire (78% of respondents) being the most dominant.

The results concur with other studies that found that despite various projects and programmes advocating for the adoption of improved cookstoves, three stone open fire cookstove remains dominant [24],[30]. Three open stone fire cookstove is preferred by many households because it has no upfront investment cost, people have gained skills and experience in using it because of its long time use, it can accommodate cooking pots of different sizes and it can be used to heat houses during cold weather. However, three stone open fire cookstoves have lower efficiency that translates to higher fuel consumption and increased household expenditure for those that purchase firewood from the market [24]. In addition, three stone open fire cookstoves have high levels of indoor emissions and particulate matter that can lead to premature death, among other respiratory complications [31].

Table 6 Cooking technologies in Mt Elgon and Cherang'any Hills Water Towers in Kenya

Cooking technology	Response in Mt Elgon Water Tower				Response % in Mt Cherang'any Hills Water Tower (%)				Average Response (%)
	Kakamega	Kisumu	Bungoma	Mean	West Pokot	Nandi	Uasin Gishu	Mean	
Three stone open fire stove	88	77	80	82	77	69	74	73	78
Traditional metallic charcoal stove	4	34	8	15	8	36	23	22	19
Improved charcoal stove	4	38	20	21	17	5	3	8	15
Improved firewood stove	10	6	2	6	25	2	2	10	8
Others	2	0	5	2	0	10	0	3	3

CONCLUSION AND RECOMMENDATIONS

Firewood and charcoal are the main sources of energy used for heating/cooking in Mt Elgon and Cherang'any Hills water towers. Due to the high dependence on these resources, the sustainability and environmental effects need to be considered, as most people are still using inefficient conversion and utilisation technologies. This is important to avoid jeopardizing the existence of very important water towers in Kenya. This is however, resulting in an increase in the utilisation of alternative energy options offered by other resources, including solar and wind energy.

Despite kerosene and electricity being the main sources of energy used for lighting by households in Mt Elgon and Cherang'any Hills water towers ecosystem, some noticeable households are still using firewood, charcoal, briquettes and agricultural residues for lighting. Burning these fuels for long time, especially in inefficient technologies with huge amounts of smoke, may cause indoor air pollution that is detrimental to human health. Households in Mt Elgon and Cherang'any Hills water towers are shifting their preferences for woodfuel species from indigenous species that were originally thought to be superior in terms of energy values and availability to exotic species.

The recommendations for the future thrust of the energy sector may be summarized as follows:

1. Increasing the contribution of renewable energy in the overall national energy supply mix, including the use of biogas, briquettes and solar for cooking and lighting, should be encouraged and promoted by county and national extension officers in Mt Elgon and Cherang'any Hills water towers. These initiatives can be supported through active private-sector involvement.

2. County governments in Mt Elgon and Cherang'any Hills water towers in Kenya should enact, domesticate legislative and regulatory framework to guide various energy sub-sector elements such as charcoal, wood energy supply, and institutional reforms within their regions. This may also include the adoption of improved and efficient conversion and utilisation technologies.

3. Provide incentives for individuals, businesses and industry to increase wood fuel by encouraging on-farm forestry, solar energy, and adopt the use of energy efficient stoves and fireplaces.

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