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Energy Use in Rural Kenyan Households: A Case Study on the Welfare Impact of Rural Electrification

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ABSTRACT

Rural electrification can, potentially, enhance the welfare of households if the scarcity of inefficient fuels and/or a rise in income facilities inter-fuel substitution towards electricity use. This research aimed to analyse the rural energy use patterns and gauge the welfare impact of rural electrification on households. Descriptive techniques and non-parametric statistics were used to evaluate the inter-fuel substitution to more efficient fuels. Further, regression analysis was used to gain insights into the factors that influence the level of electricity consumption. The analysis shows that firewood is the main energy source in the study area. Further, inter-fuel substitution is hampered by unfavourable electricity tariffs and costly electric appliances for cooking. Although connected households enjoy social benefits attributed to electricity use, its consumption in the study area is low, and the range of electricity-dependent activities is narrow. The findings suggest that there is a need, in the short run, to sustain current efforts to increase wood fuel supply and its end-use efficiency as part of the solution to the rural energy crisis. For electricity to be the major source of energy, the Kenya Power Company should work out a tariff structure that encourages its adoption and consumption. In addition, the Kenyan government should initiate appropriate tax exemptions and subsidies towards wood-fuel-saving devices and relevant electric cooking appliances. Moreover, rural electrification should be treated as an infrastructural project, requiring modification of Rural Electrification Program expansion so that connections are made in those rural areas where the expected electricity demand level and growth appear promising. However, the government should heavily subsidize community standalone solar photovoltaic systems projects to ensure that economically vulnerable communities access electricity service.

1. Introduction

1.1 Background

Energy use pervades every aspect of human life. In the early stages of the development process, it is observable that there is the substitution of commercial energy for muscle in agricultural, industrial, and domestic tasks. Modernization of the economy, in the wake of technological advancement, necessitates an increase in more convenient, cleaner, and efficient forms of energy. For this reason, commercial energy consumption per capita is widely used as an indicator of the economy's level of development (Amann, 1969). Unfortunately, many studies indicate that wood fuel is the major energy source for rural households in developing countries but there exists surplus demand (Ghosh, 1984). The recommendations for energy crises cited in these studies revolve around afforestation, rural electrification, and efficient end-use of wood fuel as the countries transit to renewable sources of energy that have a premium on lower economic and environmental costs. More fundamentally, a wide and systematic review of experiences in Asia and Pacific countries indicates that on average, electricity access interventions increase households' income, working time, and employment status (United Nations ESCAP, 2021).

Nevertheless, an evaluation study by the World Bank (2008) on the welfare impact of rural electrification across some Latin American, East Asia, and African countries indicates that (i) a larger share of benefits of rural electrification goes to the non-poor (ii) the dominant use of electricity in rural areas is lighting and television sets and (iii) electricity is rarely used for cooking. However other studies demonstrate that being connected to electricity matters in improving rural welfare as electricity access facilitates an increase in rural incomes (Bensch et al. 2012, Adu et al 2018). Indeed, it is possible to gauge the benefits of electricity connection by analysing the multiplier effects along the causal chain from rural electrification connection to economic activities undertaken (Köhlin et al. 2011, ADB 2020, Bayer et al. 2020, Kumar et al. 2018).

The varied perspectives on the usefulness of electricity connection in improving rural welfare point to a possible correlation between the drivers of rural electrification and the ultimate household benefits that accrue from accessing electricity. From an economic viewpoint, electricity demand is derived from demand. Consequently, efforts to get an electricity connection are expected to be preceded by established economic activities that require motive power. On the other hand, electricity supply may create its demand which, unfortunately, may not be linked to any economic activity. For that reason, a review of the welfare of rural electrification may need to be regional-specific if it is to inform policy. Such a review should therefore map out the link between the evolution of electricity connection and the pattern of energy use and/or inter-fuel substitution in a given area of study.

1.2 Energy Situation in Kenya

Kenya covers an area of 582,646 km2 with a population of 48 million people (GoK, 2018). The government targets to have universal access to electricity by 2030. Kenya has a diversified power sector with energy sources ranging from crude oil, wood fuel, and other renewable energy resources, especially geothermal, wind, and solar. Biofuels constitute the main principal source of energy in Kenya, accounting for 62.5% of the total energy supply as in Table 1.

Table 1: Total Energy Supply/Demand in Kenya, 2021

Energy Supply		Consumption	
Coal	2.1%	Coal	3.5%
Oil	18.5%	Oil products	28.7%
Wind, Solar	15.8%	Electricity	5.1%
Biofuels and waste	62.5%	Biofuels and waste	62.7%

Source: International Energy Agency https://www.iea.org/countries/kenya

By 2018, Kenya's electricity generation capacity was about 2670 MW with a peak demand of 1,841 MW. As of 2021, the main sources of electricity were Geothermal (40.7%), Hydro (29.7%), Fossil fuels (10.2%), Biofuels (2%), Wind (16.2%), and Solar (1.3%). Given the relatively high percentage of hydroelectricity to total electricity supply, periodic shortages in rainfall precipitate the government to resort to privately owned thermal power to bridge the capacity gaps.

High population growth over time has resulted in increased wood-fuel consumption and its scarcity often precipitates excessive deforestation and undesirable ecological effects (Various Kenya's development plans; World Bank, 1978). The low-income levels of rural households and the rising costs of commercial energy hamper individual's capacity to transition to efficient fuels. To address the wood-fuel crisis in rural areas, 1987 Kenya's National Energy Policy and Investment Plan recommended interventions geared toward encouraging domestic fuel substitution, provision of electricity services to all parts of the country, and promoting energy conservation. The earmarked programs to achieve these objectives included afforestation, rural electrification, and the development of energy-saving devices.

1.3 The Status of Rural Electrification in Kenya

Since independence, the government has embarked on vigorous rural electrification programs to supplement dwindling supplies of wood fuel and improve people's welfare through opening up opportunities in commercial, industrial, and social activities (Various Development Plans and Medium-Term Plans). The historical thread of rural electrification in Kenya has had three facets. The government's initial efforts to electrify rural areas were subsumed in amenity schemes. The term "amenity schemes" refers to sub-economic areas concerning rural electrification where marginal costs exceed revenue receipts. The then Kenya Power and Lighting Company (KPLC) was to set aside 1% of its gross sales revenue to provide capital subventions and subsidised operations to supplement government funds for the schemes.

The second phase of rural electrification, as documented in 1974 -78 Development Plan, was in form of the establishment of the Rural Electrification Programme (REP) in 1973 through a loan agreement between the Kenya government, the Swedish government, and the Tana River Development Company. The objectives of the REP were to (i) provide electricity to all district headquarters, (ii) bring electricity to the rural markets to facilitate the development of industrial and commercial activities, and (iii) take electricity to the rural people so as to raise their living standards. These objectives were similar to those of the amenity schemes. In 1983, KPLC increased its contribution to rural electrification to 2% of its gross sales revenue.

The third facet of rural electrification has been the Last Mile Connectivity Program which was introduced by the government in 2015. The program aimed to improve access to electricity in slums and rural areas in Kenya, targeting universal electricity access by 2022. The program has four phases, each geared to specific action points to improve electricity access. For instance, in the first phase, the government gave priority to connecting households located within 600 metres of an existing transformer by reducing the electricity connection fee from USD 398 (Ksh 35000) to USD 171 (Ksh15000) for households in communities covered under the programme. In the National Energy Policy of 2018, the government indicated that by June 2016, 68.4% of public facilities targeted for electrification in the country had electricity connections under the Programme. Overall, the household electricity connection to the national grid is impressive as Kenya Power reports that by 2017. the domestic consumers' connection was close to 6 million. However, most of the connected households are in urban and pre-urban areas. As Moner-Girona. et al (2019) note, that electricity in rural areas remains low. Yet, rural areas are characteristically poor but provide the means of livelihood for the majority of the population. Rural electrification can therefore be an effective tool of social-economic development for rural households. Taking electricity to rural areas increases fuel choices and offers rural households a cleaner and more efficient fuel alternative. However, the eventual transition to efficient fuels is linked to the socio-economic conditions of households. It is therefore important to examine how electricity fits the rural energy use patterns and its effects on the welfare of rural households.

Rural electrification is a heavy capital investment. It ties up large capital resources for a lengthy period as initial revenue receipts are not enough to meet operational costs and to recover capital costs. Rural electrification in Kenya is largely funded by multilateral agencies in addition to contributions from the Kenya Power Company. As per the Report of Auditor General on Rural Electrification Programme for the year ending 30th June 2019, the cumulative contribution from the government, development partners, and the connected entities was Ksh 80,196,860, 000.

The opportunity cost of these investment outlays is high. Further, basic needs are yet to be met in most rural areas, (Kenneth, et al. 2015). To make rational investment choices in improving rural welfare, an evaluation of the realizable impact of the rural electrification programme is vital if these long-term heavy investments are to be justified. Potentially, the provision of electrical energy will enable rural households to substitute electricity for wood-fuel and kerosene for cooking and lighting respectively because it is delivered at home, does not have to be stored, is clean to use, and is highly versatile. By contrast, firewood is bulky, time-demanding in gathering, and smoky in use. Therefore, a transition towards electricity use constitutes welfare improvement.

In addition to stimulating industrial and commercial activities, electricity connection has potential socio-economic and psychological benefits to households. Electricity availability may positively improve reading habits, health standards, and general awareness. Electricity connection enhances information dissemination through radio and television sets. The superior quality of lighting and ironing eliminate some of the drudgery of women's work. With the availability of refrigerators, food storage is improved and diseases, particularly among infants, may be reduced (Foley, 1989). Electricity connection may also raise motivation and optimism which are important gradients of innovation. Given the huge potential benefits of rural electrification, amid heavy investment associated with the programme, it is important to examine whether, for a rural area with an electricity connection, the identified benefits of rural electrification are being realized.

1.4 Operational Definitions

In the foregoing discussions in this study, the terms "welfare", "economic benefits", "social benefits" and "psychological benefits" are frequently used. However, these terms acquire slightly different meanings depending on the context in which they are used in economics literature. For this reason, it is important to clarify how the terms are used in the study

.

Welfare

The microeconomic approach to welfare analysis is framed within normative economics (Layard, 1987; Baumol, 1977). Positive theory gives an insight into the way economic units interact. Policies are meant to influence this interaction and their formulation borrows from normative theory which describes the welfare function. The use of the phrase "welfare" in the context of this study stems from this microeconomic set-up, the emphasis being put on economic aspects that lead to the well-being (happiness) of individuals in society. Thus, welfare is the level of well-being attained by an individual. We can hardly talk about the amount of welfare an individual has achieved but one can observe any changes in his/her wellbeing. An individual welfare is improved if his/her choice set is expanded and/or its feasibility is increased.

Social, Economics and Psychology Benefits

It is rarely possible to completely disentangle the economic from social or psychological benefits. In the cost-benefit analysis, economic benefits are those that lead to efficiency (cost minimization) whereas social benefits accrue to society if the equity is improved (Irvin, 1978). In an evaluation of welfare programs, benefits that are quantifiable and tangible are regarded as economic benefits whereas those that are not, are taken to be social benefits (Sen,1981; World Bank, 1975). The latter classification stresses on delineation of those aspects of the program that result directly to income from those others that contribute to the overall wellness of an individual. The use of the phrase "social-economic" in the context of this study adopts this definition. However, some aspects of the Rural Electrification Programme (REP) are not covered by this forgoing definition. For instance, how do we treat externalities? Furthermore, individuals may feel that a certain program is beneficial to them yet they cannot rationalize their feelings (say, electricity availability is just taken as an indication of "better things to come). For purposes of this study, these benefits outside the scope of the socio-economic realm are considered to be of a psychological nature.

2. Theoretical Framework

2.1 Theoretical Framework

Welfare is a multifaceted concept that encompasses the wellness of an individual. In assessing the welfare impact of rural electrification, the building blocks of the argument is that getting connected allows a rural household to substitute electricity for less-efficient fuels and hence increase both production and allocative efficiency in her/his economic activities. Indeed, the element of inter-fuel substitution may be mirrored by the amount of electricity used, which is a good proxy for the level of economic activities a household undertakes once connected. For this reason, this study is anchored on conventional basic demand theory and the premise is that electricity pricing, household income, and individual preference for existing forms of energy, collectively influence the energy transition towards electricity use by rural households.

2.2 Determinants of Inter-fuel Substitution

Pricing of electricity

Electrifying a remote rural area requires subsidized tariffs because low-income households cannot pay a price that fully reflects the high unit costs of rural electrification. Since subsidization implies extra drain on public funds, care must be taken not to subsidize the wealthy households. The tariff structure administered may have different effects on different households depending on their incomes. If the existing tariffs make the electricity service to be enjoyed only by well-off households, then the electricity service reinforces the inequality in the rural areas. The focus of the study, in this case, was to investigate the incentives offered by the prevailing tariff structure.

In addition, the second-best considerations affect the electricity use. The pricing of related goods influences the various ways electricity is put to use. For instance, the subsidy offered to kerosene consumers may prevent households from shifting to electricity use in cooking and lighting. Similarly, the prices of electrical appliances may be so high that they are infeasible in consumer's choice preference. There is, therefore, a need to analyse how the prices of related goods affect the electricity use by rural households.

Income and Electricity Use

The level of income is an important factor that influences house energy transition. As disposal income increases, people are likely to substitute electricity for biofuels and kerosene due to its cleanness and efficiency. Theoretically, there is some income threshold below which people cannot afford to purchases electrical appliances, make regular bills payment and raise connection fees. An analysis of income distribution and pattern of energy use can lead one to ascertain the income level at which the use of electricity use is opted for. Such an analysis is also useful in giving insights into two other issues:

i. Does the use of electricity lead to declining use of other forms of energy and at what rate does each fuel consumption change with income variation?

ii. Do non-users of electricity use wood-fuel saving devices?

The concern of the first issue is whether electricity availability in rural areas leads to less wood-fuel and kerosene consumption. The second issue attempts to investigate whether it is economic or non-economic reasons that explain inter-fuel substitution.

Role of Lifestyles in Inter-Fuel Substitution and Electricity Use

Besides the household's income and the tariff structure, other factors potentially affect electricity use. The quality of housing, level of education, family size and age distribution, and household activities matter in terms of the amount of electricity used by a household. Whether a household lives in a mud-walled house or a stone building indirectly affects electricity use. Due to safety concerns associated with electricity connection, a household in a mud-walled house may prefer to build a better house before applying for an electricity supply. The size of the family determines the level of food requirements and thus the amount and type of energy fuel for cooking. The age distribution in the family is likely to influence the household's energy preferences. The level of education is related to sensitivity to the cost of living, general awareness about life, and drive towards profit-making activities.

Monetization of women's labour and overall well-being in a nuclear family formation can lead to the replacement of inefficient forms of energy. For instance, a woman in formal employment may wish to spend as little time as possible doing household chores and any appliances that can save her some time is welcome. In addition, social stress is common with working mothers and entrainment appliances become a convenient tranquilizer. Conspicuous consumption is identified with modernisation. The poor may purchase electrical appliances to prove their self-worth, yet forgo their real needs such as decent housing, better sanitation, and education facilities. By and large, this study used household size and dietary patterns as proxies of lifestyle in seeking to understand how it facilitates inter-fuel substitution and electricity use.

2.3 Conceptual Issues

Electricity supply in rural areas has been broadly set for two target groups: those engaged in productive economic activities and households (World Bank, 1978). Electricity is said to be productively used if firms cut costs and expand production (Grogan, 2018). Connected households are expected to enjoy the versatility, efficiency, and cleanness of electricity in cooking and lighting in addition to new benefits of ironing and refrigeration. Further, the households that access electricity are expected to experience the social and psychological benefits that are largely associated with electricity connection. While such categorization may be useful in certain contexts, say in formulating the tariff structure, it is good to avoid such dichotomy in assessing the welfare impact of rural electrification due to the apparent overlap in electricity usage by rural households. Over and above the housework, there are farming activities that require electricity that a rural household can undertake. If he/she has the necessary facilities (or there exist means to access them), electricity supply will enable him/her to process the agricultural produce, irrigate the farm, process animal feeds, and provide the heating system for poultry activities. All these undertakings contribute to rural household welfare.

Electrification in Response to Demand

Electricity is an intermediate product. A rural household, for instance, will need electricity for motive power for processing animal feed if zero-grazing activity is feasible and profitable. Thus, if rural electrification is demand-oriented, then it is likely that the whole process will be undertaken in various stages that are time-sequenced. Initially, only a few isolated households may demand electricity. They would access electricity through individual-owned batteries and generators. The number of households who want electricity service may increase and neighbouring individuals may find it economical to use one large generator to connect their homesteads. If the local demand increases further, the households may opt for a microgrid extended from a “village” generator. Finally, the load density may improve to the extent that electrification from an interconnected grid becomes feasible and economical. Rural electrification in Kenya is a public policy-oriented programme. There is a possibility that if its expansion is not phased in a way that electricity connection is demand-oriented, rural households may not take full advantage of electricity availability.

3. Methodology

The research methodology combined sample survey and content observation to allow comprehensive information from the area of study. For results to be generalizable and take into account the resource constraints, a sample survey was considered an appropriate tool. But for an informed description of the nature of the fuel-saving devices, the quality of housing, economic activities being undertaken and types of electric cooking devices used, content observation became necessary. The household was used as the unit of analysis. Rural households in the area of study have plots of land that are numbered. Since plot numbering does not follow any physical logical sequence, systematic random sampling was carried out using a list of plots gathered from a map of the Githunguri ward. There were 396 households with freehold titles. The sample size was determined by postulating that at least of quarter of households of the households in Githunguri are connected to electricity. Therefore, 100 households were targeted for the interview. An interview schedule (containing sections on socioeconomic status, patterns of energy use, extent of electricity use, and perception of welfare improvement) was administered to the sampled households.

Though the fieldwork was fairly successful, some difficulties were encountered which reduced the effective sample to 80 households. Another challenge was that of suspicion. Issues on socioeconomic status invoked fear that the researcher was a government official or a blatant spy. This sometimes led to non-responsiveness or aggressive conduct on the part of the respondent. Moreover, in some cases where the response was good, the interviewer was prone to strategic bias when the respondent interpreted the event as an educational programme.

Quantification of fuel consumption also posed another difficulty. Households do not record the units of energy consumption/expenditures nor are the fuels’ containers standardized. For instance, kerosene is usually bought in bottles and plastic containers and the interviewer had to see the containers to estimate the monthly fuel consumption. For firewood, many households buy in stacks of different sizes, which had to be standardized to an approximate weight of 100 kilogrammes. Exact levels of electricity consumption were also hard to determine as some of the connected households do not keep copies of their electricity bills. Different tariff rates notwithstanding, the amount of kilowatts used was estimated from the recollection of monthly electricity payments.

The survey was carried out in the Githunguri ward which is characteristically a rural set-up. Here, agricultural activity is dominant and the production process is highly labour intensive. The Githunguri town was connected to the national grid in the late 1960s through a programme of an amenity scheme. Githunguri ward is about 35 miles from Nairobi and is part of the larger Githunguri sub-county. Comparably, electrification in this Ward is more developed than in any other ward in the sub-county. It has 761 land plots. The plots numbered T.1 to T.396 are freehold in nature with an average measurement of 0.22 hectares. The plots numbered T.397 to T.502 constitute the Githunguri Township with an average hectarage of 0.039. The rest of the land plots are those leased from the County of Kiambu with leasehold periods that range between 33 to 66 years.

Hypotheses, Model Specification and Data Analysis

The introduction and theoretical framework sections in the study highlights some key factors that influence inter-fuel substitution towards electricity use and how electrification can, at least theoretically, affect rural households' welfare. These factors formed the background of the working hypotheses which were tested using the survey findings. The specific hypotheses were:

i. Inter-fuel substitution towards electricity use in the Githunguri is income-progressed.
ii. Electricity replaces inefficient fuels for connected households.
iii. Scarcity of fuel influences use of energy-saving devices.
iv. Dietary patterns affect electricity consumption.
v. Social economic benefits, attributed to electricity use, accrue to connected households'
vi. Electricity access is a priority for rural households.

To test these hypotheses, both qualitative and quantitative methods were required as a result of which descriptive techniques and nonparametric analysis were used in the data analysis. The importance of individual fuels and the transition up the "energy ladder" was illustrated by the tabular analysis of fuel consumption across different income groups. Since we predicted, prior, that the nature of the income distribution for the entire Githunguri household is asymmetric, the Kruskal-Wallis method was thus useful in testing whether the differences in monthly fuel consumption for the income groups are significant. Further, we used the chi-square statistic to test whether the non-usage of wood fuel-saving devices should raise concern, depending on the expectations.

Given the versatility of electric energy, a close relationship between the level of electricity consumption and rural welfare was anticipated. Regression analysis was thus used to analyse the significance of the factors that influence the level of electricity consumption.

The hypothesized model was:

$Y_i = \beta_0 + \beta_1 X_I + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \mu_i$ where;

Y_i – Monthly quantity of electricity used in kilowatt hours

X_I – Household size

X_2 – Number of electrical appliances in use

X_3 – Monthly expenditure on charcoal

X_4 – A dummy variable indicating the whole or non-whole grain diet

X_5- Monthly expenditure on Liquefied Petroleum Gas (LPG)

μ_i - Error term

The choice and measurement aspects of these variables need some explanation. Banking on the principle that inter-fuel substitution towards electricity use is income-progressed, we expected the income elasticity of inter-fuel substitution to be higher between electricity, charcoal, and LPG. Monthly expenditures on charcoal and LPG constitute the fuels' prices from the consumer vantage point. For instance, households are more concerned with not only what a bag of charcoal costs but on how long the bag will meet the intended use. Further, income earnings are likely to influence the amount of energy consumption. Beyond the income threshold for a household connection, income earnings were expected to influence the diversification of electricity use and therefore, its consumption. Diversification of electricity use was expected to be reflected through the stock of electric appliances. Thus, the number of electric appliances was taken as a good proxy of the link between income earnings and the level of electricity consumption.

Since the versatility of electricity may facilitate the establishment of new electricity-using activities, household size is an important factor to be considered in fuel consumption. For instance, a connected household that decides to chop animal feeds with an electric gadget may require extra man-hours of labour.

If labour is in short supply, the availability of family members will determine whether or not electricity will be used in animal feed production. In addition, individual needs of household members imply that a large-sized household will consume more electricity than a small-sized household

Finally, the typical food of rural Kenyan is “Ugali” (a paste-like mixture of boiling water and maize flour) and or “githeri” which is a whole grain meal consisting of a boiled mixture of maize and beans. The latter requires a long period of cooking and thus substantially higher energy inputs.

4. Empirical Results and Study Findings

This section presents the survey findings per the hypotheses outlined in Section 2. The section starts by examining the energy use patterns and factors that influence inter-fuel substitution and ends by analysing determinants of electricity consumption in the area of study.

3.1 The Inter-Fuel Substitution

Income and Energy Use Pattern

Economic theory stipulates that inter-fuel substitution towards efficient fuels is income progressed due to Engel's effects of income growth and household propensity towards better well-being. To test whether this is empirically true, we evaluated the relative importance of each fuel for individuals in different income groups as illustrated in the following table.

Table 2: Income and Energy Use Patterns

Y	n	% of Total Energy Use					Ave. Exp.	Ave. Cons.
		F	C	K	L	E		
0 - 5000	24	63.13	24.24	12.63	0	0.00	293	1936
5001-10000	19	57.13	28.95	12.88	0	0.66	306	1996
10001-15000	21	35.15	49.67	13.53	0	1.65	314	2096
15001-20000	10	19.25	53.29	15.83	6.79	4.84	350	2344
20001-25000	5	3.61	43.14	6.17	27.26	19.74	496	2470
Over 25000	1	0	13,75	0	24.34	61.90	880	2617

Y- Net Income Ksh/Month F- Firewood C- Charcoal K- Kerosene L- LPG E-Electricity Ave. Exp. – Average Energy Expenditure Ave. Cons.- Average Energy Consumption
Conversion: Firewood- 16mj/kg Charcoal- 30mj/kg Kerosene- 35mj/kg LPG- 45.5mj/kg Electricity- 3.6mj/kwh

There are notable facts from Table 2. Firewood is the most used fuel by the low-income group (Ksh 0 - 10000) and it is primarily used for cooking. Households in the medium income group (Ksh 10001-20000) depend on charcoal for half of their energy needs. For the upper-income group (Over 20000), charcoal, LPG, and electricity – in that order- constitute the major energy sources. By and large, energy consumption and expenditure increase with the rise in income, and therefore energy, as a good, is income elastic. This finding confirms that inter-fuel substitution towards electricity use is indeed income-progressed.
To examine this observation further, we analysed how each fuel consumption varies according to income categories.

Table 3: Average Monthly Fuel Consumption, Household Size and Dietary Pattern across income groups

Income	Fuel Consumption (mj)					Household size	Ave. Dietary Pattern
	F	C	K	L	E		
0 - 5000	1224	470	245	0	0	7.354	0
5001-10000	1148	578	257	0	13.52	7.47	0
10001-15000	737	1041	284	0	14.62	6.8	0
15001-20000	451	1249	371	159	113	6.3	1
20001-25000	80	936	134	592	428	5.4	1
Over 25000	0	360	0	637	1620	4	1

*The dietary pattern is denoted by a dummy variable: 0 for “Githeri “and 1 for “Ugali”

The Kruskal -Wallis test on the whether the differences between the fuel averages are significant, indicates: H = 18019 chi-squared (α = 0.05) = 9.494 chi-squared (α = 0.01) = 13.29

These results show that the null hypothesis that the individual fuel consumption averages across income groups are the same, is rejected at 5% and 1% levels of significance. As Table 3 indicates, firewood consumption decreases consistently with an increase in income whereas LPC and electricity uptake increase with the rise in income. Charcoal and kerosene consumption initially increases with the rise in income and then decreases. Thus, better household incomes result in inter-fuel substitution towards more efficient fuels. This energy use pattern is well explained by the end-use of the individual fuel type. Among the sampled households whose monthly income was below Kshs 15000, firewood and charcoal were used for cooking, and “Githeri” constituted a major part of their diet. Those households who earned at least Kshs 15000 substituted LPG for firewood and charcoal for cooking. Therefore, for fuels that are income elastic, high energy consumption is an indicator of an increase in rural households’ welfare.

Firewood Scarcity and the use of Energy Saving Devices

The dictums of utility and profit maximization suggest that the scarcity of a good induces bidding up of price and subsequent increase in its production. The findings in the area of study show that firewood is scarce and is largely a market good. A bag of charcoal costs between Ksh 1000 to Ksh 1200 whereas a 100-kg stack of firewood costs Ksh 3000. Theoretically, one would expect households to be using wood-fuel-saving devices and/or opt for more efficient fuels. Table 4 summarizes some scientific tests carried out on the efficiency of wood fuel devices:

Table 4: Summary of Jiko Efficiency Tests

Stoves	Fuel	NHV	FC	T	EW	Eff.
Open-fire	Wood	4200	2.25	10	0.19	7.6
Jiko	Charcoal	7000	0.44	90	0.25	16.5
Modern Jiko	Wood	4200	0.55	25	0.10	18.7
	Charcoal	7000	0.17	18	0.09	34

NHV – Net heat value (kilocalories/kg) FC – Fuel consumption (kg) T- Time taken to boil 1 kg of water
EW- Evaporated water (kg) Eff. – Efficiency in %
Source: L.Bodria and F. Sangiorgi “Wood burning stoves and their efficiency: The case of Kenya” in Renewable Sources of Energy. Vol. 1 No. 1 1983.

`Given the efficiency scores of the two types of jikos, as articulated in Table 4, we hypothesized that scarcity of firewood motivated households to use modified jiko. Table 5 presents the general observations of the usage of energy-saving devices.

Table 5: Households using improved devices

	Firewood	Charcoal
Observed frequency	7	47
Expected frequency	57	62

It is noticeable from Table 5 that the usage of improved devices is higher for charcoal than for firewood (76% and 12% respectively). One possible reason for this could be that, by the time a household can afford the improved firewood jiko, he/she would have made the transition to charcoal which is a cleaner and more efficient source of energy. The validity of this explanation rests on specifying the period a household takes before it reaches the income threshold on which charcoal replaces firewood. Since our data is cross-sectional, we are trapped in its fixed effects bias and therefore remain inconclusive on the matter.

Alternatively, the low usage of improved firewood jiko was possibly due to its relatively high price. Modern charcoal stoves cost Ksh 500 whereas improved firewood stoves cost Ksh 800 on average. To assess how plausible this explanation is, we investigated how usage of devices varies according to income categories:

Table 6: Income and Usage of Energy saving devices

	Firewood		Charcoal	
Income	Observed	Expected	Observed	Expected
0 - 5000	2	23	5	13
5001-10000	2	17	12	15
10001-15000	2	12	17	20
15001-20000	0	4	17	20
20001-25000	1	1	4	5
Over 25000	0	0	1	1

We used the chi-square statistic to determine whether the observed frequencies significantly differ from the expected frequencies. The results are presented below:

Table 7: Chi-square tests of goodness of fit

	Firewood	Charcoal
Chi-square	43.94	7.002
df	2	3
Significance ($\alpha = 0.05$)	5.99	7.82
Coefficient of contingency	0.66	0.32

The lack of firewood-saving device usage is significant and negatively correlated with increased income. However, the scarcity of firewood does not motivate households to use modified jikos. The low usage of these devices can be attributed to the cost and unavailability of firewood-saving devices, as many respondents had difficulty understanding the specific device the interviewer was referring to.

Electricity Use and Inter-fuel Substitution

Given the versatility and efficiency of electricity, a connected household is expected to substitute it for inefficient fuels. We then expected that the average monthly energy consumption for less efficient fuels to be higher among non-users of electricity. Table 8 presents the average fuel consumption for connected and non-connected households.

Table 8: Average monthly non-electric fuel consumption (mj)

	Connected households [13]		Non-Connected households [67]	
	Fuel consumption (mj)	No. of Users	Fuel consumption (mj)	No. of Users
Firewood	720	3	1284	54
Charcoal	951	13	1006.4	49
Kerosene	153.8	6	301	67
LPG	718	5	530.8	3

Average fuel consumption for firewood, charcoal, and kerosene is higher for non-connected households. All connected households use charcoal and their comparably low consumption is due to the use of modified jko (energy-saving device). Therefore, electricity connection does not replace the use of charcoal and firewood for cooking. For connected households, electricity replaces kerosene for lighting. This observation is confirmed when we evaluated the end-use electricity for connected households as shown in Table 9.

Table 9: Electricity Application

Application	No. of Users	Percentage
Cooking	0	0
Space heating	0	0
Refrigeration	4	31
Lighting	13	100
Ironing	5	38
Radio	13	100
Television Set	10	77
Water heating	2	15
Agricultural activity	1	8

As shown in Table 9, electricity is widely used for lighting, radio, and television sets. Since, as we saw in Table 8, LPG consumption is higher for connected households, inter-fuel substitution peaks itself to LPG for cooking. Nevertheless, most non-connected households indicated that they would use electricity for cooking, lighting, and motive power for agricultural activities if they were to be connected.

Given the scarcity of firewood, the non-usage of electricity for cooking for connected households raises concern. Most of the connected households (70%) who don't use electricity for cooking indicated that imported electric cookers are expensive as their prices range from Ksh 20000 and above. Those households who had bought locally manufactured cookers found them unreliable due to safety concerns and frequent mechanical breakdowns after a short period of their use.

The Pricing Effect on Electricity Consumption

A connected household preference for a certain fuel over another in a particular end-use (say, the choice of electricity over LPG in cooking) is dependent on the expectations of future prices of the fuel and its complementary goods. More than half of connected households were fearful that electricity would go up if electricity was to be used for cooking. We, therefore, concluded that connected households do not use electricity for cooking because they feel that any rise in electricity tariffs and prices of electric cookers will be hard to accommodate in their budgets, given their prevailing incomes.

Role of Lifestyle in Inter-Fuel Substitution

The last two columns of Table 3 illustrate how the type of food and household size correlate with income level. The household size is higher for low-income households whose common diet is “githeri”. The issue of concern here is whether the household size and dietary pattern relate to fuel consumption. Given that inter-fuel substitution is income progressed, it is clear from the table that small-sized households use efficient fuels and their food choices have low energy requirements. This observation leads us to conclude that household size is income dependent and diets that mostly require high energy inputs are inferior goods. Thus, inter-fuel substitution, household size, and diet choice are interrelated.

Electricity Supply: Is it a Priority?

The concept of rural development presupposes fiscal interventions whose converging effects improve the living standards of the households. In making choices of the appropriate macro interventions, amidst resource constraints, consumer sovereignty has to be beckoned to reveal the rural households’ choice preference. In evaluating the welfare impact of rural electrification, it is then imperative to assess the relative importance given to electricity supply. The hypothesis here is that in a given project's choice set, the electricity supply will be revealed superior to other infrastructural projects.

Restricting ourselves to what is generally taken to constitute basic needs, the choices availed to sampled rural households included: Education, Medical care, Good housing, Electricity, energy-saving devices, Reliable water supply, and Tarmac roads. Since adequate income earnings enable welfare improvement and enhance the opportunities to utilize infrastructural projects for productive purposes, the choice preference pattern was analysed according to income status.

Table 10: Revealed Preferences Pattern of Projects by Rural Households across Income levels

	Average listing preference pattern					
Income	0 - 5000	5001-10000	10001-15000	15001-20000	20001-25000	Over 25000
Education	1	2	2	2	2	4
Medicare	2	1	1	1	1	3
Housing	3	4	3	3	3	2
Electricity	6	6	5	4	6	5
Energy Saving devices	7	7	7	6	7	7
Water	4	3	4	4	4	2
Road	5	5	6	7	5	1

*The numbers indicate the ranking of most cited project preference for each income category with most preferred indicated as 1

On average, medical care, education, shelter, and reliable water respectively scored highly in households’ choice preferences. Electricity preference only came ahead of the choice of energy-saving devices. We note that despite the firewood crisis, households didn’t indicate access to energy-saving devices as a major priority. To assess the rationality of the overall preference pattern, respondents were asked whether their welfare had improved in the last five years. Those who responded in the affirmative associated their welfare improvement with house improvements, construction of cemented floors for zero-grazing structures, education of their children, and access to piped water. The low pricing of agricultural produce and escalating cost of living were the cited reasons for welfare deterioration by some households. We, therefore, note that electricity supply does not rate favourably when compared with other infrastructural projects.

3.2 Low use of electricity

From the foregoing findings in section 3, it is notable that the energy ladder picks itself up to LPG consumption for cooking whereas, for connected households, electricity replaces kerosene for lighting. In addition, electricity is hardly used as motive power for agricultural activity contrary to the perceived and intended uses of the government and households respectively. Consequently, consumer demand for electricity is saturated at very low levels of consumption.

Given the wood-fuel scarcity in rural areas and the heavy government investment in rural electrification, it was imperative to investigate what constraints inter-fuel substitution towards electricity as captured by a narrow range of electricity use and its low consumption. To determine factors that influence electricity consumption in the area of study, we regressed the amount of electricity consumed on Household size (X_1), Number of electrical appliances in use (X_2), Monthly expenditure on charcoal (X_3), A dummy variable indicating the whole or non-whole grain diet (X_4) and Monthly expenditure on LPG (X_5). The regression results are summarized as follows:

Table 11: Regression Results

Adjusted R Square	0.9245			
F-statistic	28.02	Sig.(0.01201)		
	Coefficients	Standard Error	t Stat	P-value
Intercept	49.5	58.2	0.85	0.152
Household size	10.1	8	1.25	0.833
No. of electrical appliances in use	3.5	0.5	7.55	0.007
Monthly exp. on charcoal	-0.1	0.3	-0.15	0.549
Dietary Pattern	14	38	0.36	0.097
Monthly exp. on LPG	0.16	0.202	0.836	0.053

The estimated model is Yi = 49.5 + 10.1XI + 3.5X2 - 0.1X3 + 14X4 + 0.16X5. The identified causal variables explain 92.5% of the variation in household electricity consumption. Based on the F-test for goodness of fit ($p < 0.05$), the linear multiple regression model captures well the relationship between household electricity consumption and the explanatory variables. The household size (XI), the dietary pattern (X4), the Monthly expenditure on charcoal (X3), and the monthly expenditure on LPG (X5) don't matter (both at 1% and 5% level of significance) in explaining household electricity consumption. The regression coefficient for the number of appliances ($\beta = 3.5$, $p < 0.01$) underscores the critical role of appliance affordability in driving electricity consumption. Thus, the regression analysis shows that the number of electrical appliances significantly affects electricity consumption, indicating that not only does income progression facilitate inter-fuel substitution but also that non-affordability of electrical appliances is a barrier to transition to electricity use in cooking.

3.3 The Non-connection to Electricity Supply

The analysis of the non-connectivity of households to the national grid in this study was fraught with difficulties. The distribution of interconnected grid systems in the area of study did not reflect geographical sequence. The sampled households indicated that the extension of the electricity grid is largely a political process. Most of the non-connected respondents stated that the grid line was far and the connection fees were prohibitive. Referring to Table 2, it is noticeable that the level of income does not deter connection to electricity supply apart from the very poor (Ksh 0 - 5000). However, income level determines the diversification of uses of electricity to those who are connected. Thus, household electricity connection is largely explained by how close the grid line is to the residence.

5. Conclusions

The survey findings on the rural energy use pattern and inter-fuel substitution are summarized as follows. First, inter-fuel substitution towards efficient fuels, in the area of study, is income progressed. This is consistent with economic theory and supports the findings of Leach (1992) on energy transition. However, inter-fuel substitution is not consistent along the energy ladder, as it peaks itself to LPG for cooking. The second conclusion is that though firewood is scarce in rural areas, the use of related energy-saving devices is limited. The high cost and non-availability of firewood-saving devices explain their low usage. Subsequently, any intervention in solving the firewood crisis in rural areas should explore appropriate subsidies to encourage the use of firewood-saving devices.

Thirdly, electricity is not used for cooking and hardly replaces firewood and charcoal. Indeed, electricity is widely used for lighting, radio, and television sets. The non-usage of electricity for cooking is largely explained by the high prices of imported electric cookers and the low reliability of locally manufactured cookers. This suggests that interventions focusing on subsidizing appliances could have a direct impact on energy use patterns. A related aspect is that the block increasing rates of electricity tariffs does not encourage electricity consumption but rather induces consumers to “conserve and thus pay less”. Finally, electricity service is not a priority for rural households. Indeed, households in the area of study associate electricity with better broadcasting reception and superior quality of lighting. They would opt for better medical care, improved education facilities, and reliable water supply if they were to choose which public projects to start in their area. The salient observation here is that it is the existence of electricity-dependent activities that raise the need for electricity availability and not the other way around. These findings have some bearing on the basic needs approach to rural development (Streeten, 1981) that households associate welfare improvements with accessibility to public projects that relate directly to their pressing needs. Thus, any government intervention to improve rural welfare will only succeed if it targets addressing the basic challenges facing the households.

6. Policy Implication

Rural areas in Kenya, like many other regions, vary widely in terms of farming practices, socioeconomic status, and infrastructure development. However, they share common characteristics: a firewood crisis, lower living standards compared to urban areas, and economies that are largely agricultural. Any policy aimed at these areas should take a comprehensive approach that addresses these key issues. Based on the findings of this study, the following recommendations are made:

i. Addressing the Firewood Crisis: To mitigate the firewood shortage in rural areas, the government should offer strong incentives for afforestation in the short term. These could include, among other measures, providing free tree seedlings and offering technical extension services.
ii. Promoting Firewood-Saving Devices: As household income increases, many rural households substitute charcoal for firewood. The government should introduce tax exemptions on firewood-saving devices to make them more affordable and accessible, especially for low-income households.
iii. Encouraging the Use of Electricity for Cooking: To facilitate the shift towards using electricity for cooking, the government could implement an appliance subsidy program that reduces the upfront cost of electric cookers by, for example, 50%. This would help address affordability concerns and encourage more households to adopt electricity for cooking.
iv. Integrating Rural Electrification with Infrastructure Development: For electricity to have a meaningful impact on rural incomes, the government should integrate rural electrification into a broader infrastructure development plan. This would involve prioritizing the installation of high-power grid lines and transformers in rural areas with promising electricity demand and potential for economic growth.

v. Subsidizing Solar Solutions for Remote Areas: In areas where connecting to the grid is not feasible or unlikely to stimulate economic activity, the government should provide heavy subsidies for community-based standalone solar photovoltaic systems. This would ensure that economically vulnerable communities still have access to electricity.

7. Limitations of the study

Although the study findings are valuable, the sample size of 80 households limits the ability to generalize the results to other rural areas in Kenya. Future research should focus on larger, more diverse samples to validate these findings. Additionally, cultural preferences, such as the popular use of 'githeri' in cooking, influence energy choices and should be explored in future studies.

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Conflict of interest statement

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