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Research Article

Effects of Income and Price on Household's Charcoal Consumption in Three Cities of Tanzania

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More than 80% of the urban and periurban population in Tanzania depend on charcoal as their main source of energy for cooking. This charcoal is supplied from natural forests, mainly Miombo woodlands, and the high charcoal consumption is a main trigger for deforestation, forest degradation, and climate gas emissions. The country's urban population is increasing at an annual rate of 5-6%, and better understanding of the urban demand for charcoal is of high interest regarding the country's energy development, climate mitigation, and land use. We surveyed 360 households situated in the Tanzanian cities Dodoma, Morogoro, and Mtwara and analyzed statistically the impacts of household income, charcoal prices, and household size on the per capita charcoal consumption. For the total sample, statistically significant elasticities were found to be 0.03, −0.13, and −0.62 for per capita income, charcoal price, and household size, respectively. In the low-income group, the elasticities of charcoal price and household size were found to be statistically significant with the values of −0.44 and −0.59, respectively, whereas in the middle-income group, the household size was the only statistically significant variable, with elasticity −0.81. In the high-income group, we got statistically significant elasticities of 0.17 for per capita income and −0.44 for household size. These results are based on small samples and should be followed up by larger surveys.

1. Introduction

Of the about 4 billion m^3 of wood annually extracted from forests worldwide, approximately 50% is used for energy production, and for Africa, this share is 90% [1]. According to Bonjour et al. [2], biomass energy remains the main source of energy to about 2.8 billion people worldwide, in which about 780 million people are from sub-Saharan Africa [3]. About 17% of the global use of wood for energy is converted to charcoal, and particularly in developing countries, charcoal consumption is rising as a consequence of increasing demand in urban centers [4–7]. Several studies, e.g., AFREA [8] and FAO [1], report that unsustainable wood harvesting and charcoal production and consumption cause forest degradation and deforestation as well as high emissions of greenhouse gases (GHGs) along the charcoal value chain. These studies also report that charcoal produced from sustainably managed forests and using improved kiln and cooking technologies could significantly reduce the net emittance of GHGs, thereby contributing to climate mitigation while also increasing the access to energy and food and providing income-generating opportunities.

In Tanzania, more than 90% of the biomass energy consumption comes from forest sources in the form of charcoal or firewood [9–14], and charcoal is the most common energy for cooking in more than 80% of the country's urban and periurban population [1, 15–17]. Charcoal has several comparative advantages to wood for cooking in urban and periurban areas in Tanzania, like higher energy content, cleaner burning, less bulkiness, easier transport, and higher accessibility [18–20]. In 2018, the population of mainland Tanzania was 52.6 million with a growth rate of 3.1% p.a.[21], and in 2015, the urban population was about 18 million growing at 5-6% p.a. [22]. The rate of electrification in Tanzania is increasing, and by 2016, about 17% of the rural population and 64% of the urban population had access to electricity [13]. However, mainly because of high costs and irregular supply, few households use solely electricity for cooking, even in urban areas.

The increased demand for charcoal leads to increased wood harvests which in turn cause severe deforestation, forest degradation, and environmental impacts such as loss of biodiversity and increased emission of climate gases [15, 16, 23–29]. Forests occupy approximately 55% of the area of Mainland Tanzania [12, 30–32], and according to Nyamoga et al. [33], about 49% of this land area is affected by either light, moderate, or heavy soil erosion. The annual rate of deforestation and land degradation in the country is estimated to be 1.1% [30, 34]. The Tanzanian land use has both national and international concerns, due to the country's extremely rich biodiversity values and importance, and deforestation and land degradation have negative impacts to both biodiversity, climate mitigation, and human well-being [29, 35–37]. The annual GHG emissions from different land use changes in Tanzania in 2014 are estimated to be 208 million metric tons of carbon dioxide equivalent (MtCO2e), and the total GHG emissions for Tanzania in 2014 was 286 MtCO2e, with 73% coming from the land use change and forestry sector and with agriculture, energy, waste, and industrial processes contributing 17%, 7.8%, 1.6%, and 0.5%, respectively [29].

Although several studies such as by Faraji et al. [38], Fisher et al. [39], Hofstad [25], Hosier and Kipondya [40], Hosier et al. [41], Mwampamba [11], and Schaafsma et al. [42] have quantified household charcoal consumption and showed its economic, social, and ecological importance in Tanzania at village, regional, or national levels; very little research has been done regarding testing statistically what are the main determinants of this consumption. In fact, D'Agostino et al.' study [43] is the only econometric study of charcoal consumption behavior in Tanzania we have come across. They analyzed socioeconomic determinants of charcoal expenditures of more than three thousand Tanzanian urban and rural households based on household expenditures data collected in two nationally representative panel surveys conducted by Tanzania's National Bureau of Statistics. Their study had household expenditures on charcoal as dependent variable, and the statistical tests confirmed three main hypotheses for the use of charcoal. The first was that as household income increases, charcoal expenditures increase; the second was that as household size increases, charcoal expenditures increase (this hypothesis was confirmed only for urban households); and the third hypothesis was that rural households spent less money on charcoal than urban households.

Two conclusions in D'Agostino et al.' study [43] were particularly important for our study, the first being (p. 479) "Although charcoal has now become the fuel of choice for the vast majority of urban households in Tanzania, the socioeconomic determinants of charcoal choice and expenditures remain poorly understood. This omission is regrettable because it makes clear that government regulations of charcoal production and expenditures are not based on comprehensive information on actual socioeconomic trends that determine fuel choice at household level. Curbing the surge in charcoal consumption is important for managing forests and protecting poor households against sudden price shocks." The second conclusion refers to the fact that price of charcoal was not included as explanatory variable in the statistical analyses in D'Agostino et al. [43] and their corresponding statement (p. 480): "Future studies of charcoal consumption should extend and modify our initial approach. One promising direction for research is to collect data on local charcoal prices and estimate price elasticity of demand. This is particularly important for urban areas, where domestic production of charcoal is not possible, for the most part, but the fuel is still available on local markets. Detailed price data could inform policy by showing how households respond to price hikes." A third motivation factor for us was the high GHG emissions in both the production and consumption of charcoal in Tanzania and the emittance of health-damaging gases amidst the local urban users of charcoal reported in the FAO [1].

The abovementioned high economic and population growths as well as the high urbanization rate in Tanzania made it particularly important to get more reliable estimates on how income per capita and price of charcoal may influence the urban charcoal consumption. Such estimates can rather easily be combined with already existing prognosis on population growth, urbanization rate, economic growth, and forest resource development in Tanzania, thus providing socioeconomic consistent analysis of likely future developments of the charcoal consumption and its environmental and economic impacts and information for improved policy making in the country.

On this background, the main objective of this study is to provide improved empirically based information on magnitude and strength of the main economic factors driving urban household charcoal consumption in Tanzania. The study is focused on quantifying and statistically testing how this consumption is affected by charcoal price, per capita income and household size.

2. Methodology

2.1. Theory and Hypotheses. Prior studies conducted in Tanzania, Uganda, Zambia, and Sudan show that per capita charcoal consumption in urban areas is much higher than in rural areas and that it depends on a diverse set of factors including availability and reliability of alternative energy sources, income, as well as the price of charcoal relative to alternative energy sources [10, 11, 15, 16, 25, 28, 39, 43, 45].

Mainstream economic theory about consumption behavior is based on the assumption of rational choice, i.e., that

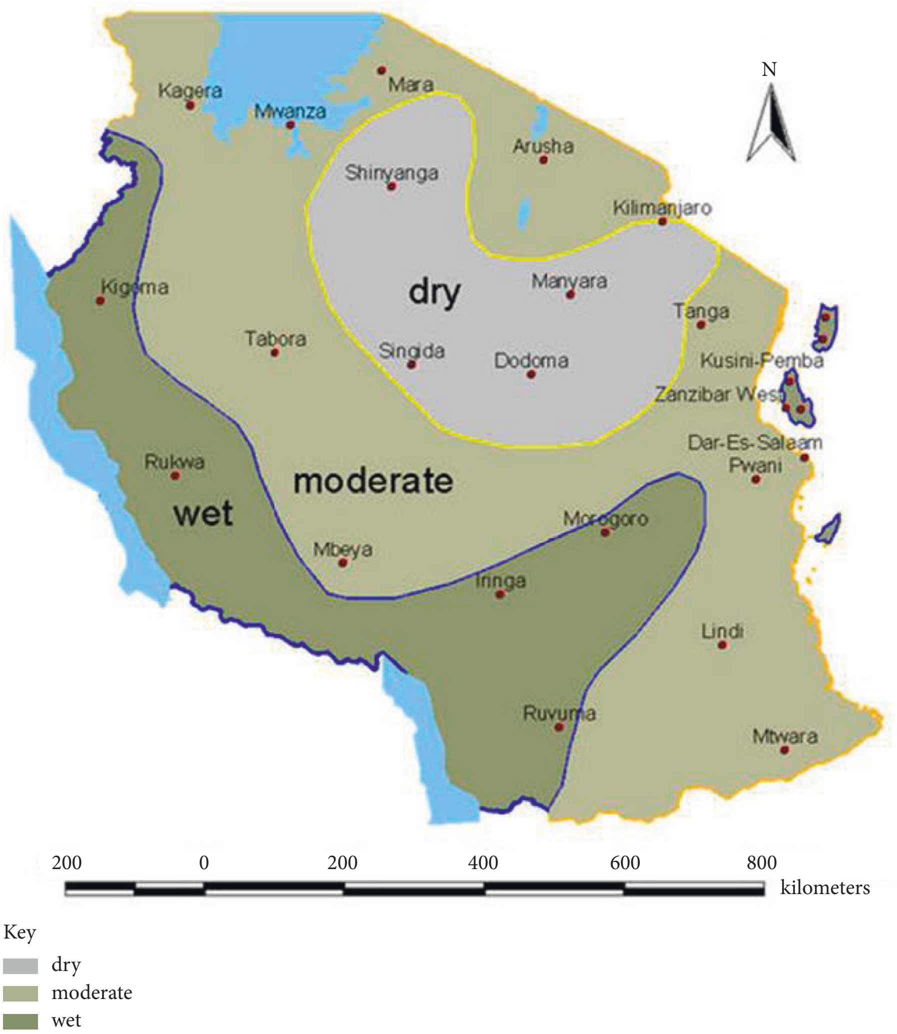


FIGURE 1: Map of Tanzania showing the location of Mtwara, Morogoro, and Dodoma and the main climate zones (source [58]).

choices are made individually or collectively based on the highest expected utility or return [46, 47]. Individuals tend to choose the best option from a range of alternative choices available [48–50], although the rationale of such choices may be different when made at the individual compared to the collective level. In this study, we consider charcoal consumers as rational decision makers. We assume that the theoretical behavior model underlying the study is based on economic theory of household demand as described by Becker [51], i.e., a household allocates its income on expenditures (food, housing, energy, travels, and school fees) to get as high utility (or welfare) as possible given the constraints set by the household income and the prices of goods and services. Formally, we assume that a household maximizes utility, conditional on household income I and prices for various energy sources ($p1$ for charcoal, $p2$ for gas, and $p3$ for electricity) and other commodities and services (po). This theory implies (e.g., Varian [47, 52]) that the short-term demand di for charcoal consumed in household i is $di = di$ ($p1$, $p2$, $p3$, po, I), with the hypotheses that di decreases with increasing $p1$ and increases with increasing $p2$ and $p3$ and all other factors assumed equal. The impact of increased I can, according to economic theory, be either positive or negative depending upon charcoal being an inferior good or not. We have here initially used the energy ladder theory, which postulates that households will shift to more advanced and clean energy types as income increases [53], implying decreased di with increasing I. In addition, we use the microeconomic theory of economies of scale to justify the hypothesis that the quantity of charcoal used per person in a household for cooking is a decreasing function of the number of household members. This relationship is empirically documented in many charcoal consumption studies in Tanzania, as shown in the study by Greyson and Solberg [54].

Thus, our initial hypotheses for the statistical analysis are that the urban household charcoal demand for cooking increases with increasing $p2$ and $p3$ and decreases with increasing $p1$, I, and the number of household members, all other factors equal.

2.2. Data Collection. Many charcoal studies have already been conducted in the study by Dar es Salaam [25, 38, 40, 43, 55–57], and it was, therefore, decided to select the three urban regions of Dodoma, Morogoro, and Mtwara as study areas. These regions were chosen because they are located in different climatic zones and in varying directions from Dar es Salaam, the main charcoal market and business center in Tanzania (Figure 1). Dodoma is the capital of Tanzania and currently houses among others the country's Parliament, all ministerial offices, and two new universities, all of which have contributed to changing the socioeconomic conditions of the region. Morogoro and Mtwara are located within the Miombo woodland area where charcoal production is highly prominent. Mtwara has seen economic expansions in recent years due to discovery and exploration of natural gas as well as huge investments in cement production and establishment of new colleges and a university.

The data for the analysis were collected in field surveys during the period June–September 2015 in each of the three urban centers, and 120 households from each center were interviewed. The households were selected to represent respondents from low-income, middle-income, and high-income categories in a two-stage approach. First, in each of the three urban areas, the population was divided into different income levels by classifying the city wards and streets into three groups reflecting, respectively, the low, middle, and high-income households. This classification was done in close collaboration with local government officials in order to capture the actual income distribution within the cities. In the second stage, the households in the selected wards and hamlets were assigned numbers using the population registry in the local leaders' offices, and the respondents were then drawn randomly in each street until sufficient numbers of respondents were provided in each income class. Based on the income reported in the interviews, the households were categorized into the following three income classes: low income consisting of households with income less than TZS 3,000,000 per annum, medium income comprising households with an income between TZS 3,000,000 and 10,000,000 per annum, and high income containing households with income greater than TZS 10,000,000 per annum. The average exchange rate in 2015 was 2085 TZS per USD.

Among other questions in the survey, we asked about the price of charcoal per given unit (bag, sack, or tin), amount of charcoal consumed per month, week, or day, total annual or monthly income, and the size of the household. The questionnaire used in the survey is shown in Appendix 1. If possible, the head of households was interviewed, but in his or her absence, we interviewed any available member in the household who was above 18 years, knowledgeable, and familiar with the required household data on income, household composition, economic activities, and the daily or monthly consumption of charcoal and other types of energy consumed in the household. Our field data show that most of the respondents were females, probably because they spend more time at home than the males. In case the interviewee felt he did not get sufficiently good information about the household expenditures, he communicated with the head of the household through phone call in order to acquire as reliable data as practically possible. During interviews, it was observed that many households particularly in the low and middle-income groups buy charcoal in smaller units than bags, depending on their immediate needs and financial situation. We recorded the units of charcoal as presented by the interviewee and then converted the reported consumption into standard unit "normal bags," assuming 50 kg per "normal bag." Some households reported business consumption of charcoal, but we excluded these commercial usages, leaving only charcoal consumed at the household level in the analyses.

The urban population of Dodoma, Mtwara, and Morogoro in 2014 was totally about 800000 and represented about 10% of the urban population in Tanzania [59].

2.3. Statistical Specifications. The original dataset was first checked for outliers by performing influence measures tests. Altogether, 27 observations were removed because of missing values or abnormalities. The statistical analyses were thus done using 333 households in the whole sample, of which 71 (21%) were high-income households, 142 (43%) were middle-income households, and 120 (36%) were low-income households.

As household charcoal consumption is likely to increase with the number of household members, possibly introducing heteroscedasticity in the econometric estimation, we used per capita charcoal consumption as dependent variable and, correspondingly, income per capita (household member) as independent variable. We also included number of household members as independent variable to reflect possible economies of scale in the cooking. Prices of alternative energy sources (electricity, kerosene, or gas) were excluded because very few of the respondents reported the use of those sources for cooking. Logarithmic transformation was used because it gave higher R^2 and better normal distributions of the independent variables than no transformation. The final econometric equation thus became

$$\log \mathrm{C} = a + b1 \log P + b2 \log I + b3 \log H + \varepsilon, \qquad (1)$$

where C is the per capita consumption of charcoal (kg per capita per year), P is the price of charcoal (TZS per kg), I is the annual per capita income in the household (TZS per year per person), H is the number of persons per household, a, b_1, b_2, and b_3 are the coefficients to be estimated, and ε is the error term.

The data were analyzed using R program, version 3.2.5, 2016-04-14 [60]. To check for heteroscedasticity, the Breusch–Pagan test (lmtest and NCV test) in R was used.

3. Results

3.1. Overview of the Collected Data. In Table 1, mean values and standard deviations of the collected data on consumption, income, charcoal price, and household size are presented for the whole sample and the three income groups. Figures 2–9 show box-plots of the samples, in which the dark horizontal line shows the median value, the low and high line of the green box show, respectively, the value of the 25% and 75% sample quartiles, the two outer lines show the low and high sample value which are, respectively, plus/minus 1.5

Table 1: Transformed and untransformed mean values and standard deviations (SD) of the data input used in the regression analysis for the total sample and distributed on income classes (C, P, I, and H as defined in equation (1)).

			Consumption (C)	Income (I)	Price (P)	Household size (H)
Log-transformed	Mean	All	4.83	13.72	6.14	1.58
		Low income	4.82	12.53	6.17	1.53
		Medium income	4.85	13.96	6.04	1.56
		High income	4.80	15.24	6.29	1.70
	SD	All	0.51	1.18	0.37	0.44
		Low income	0.52	0.69	0.36	0.45
		Medium income	0.53	0.94	0.36	0.45
		High income	0.45	0.61	0.37	0.35
Untransformed	Mean	All	141.90	1,766,337	496.79	5.31
		Low income	141.92	346,735	510.14	5.07
		Medium income	146.05	1,349,851	446.17	5.28
		High income	133.58	4,998,634	575.48	5.77
	SD	All	72.50	2,338,354	198.11	2.23
		Low income	74.97	257,798	193.63	2.21
		Medium income	76.24	841,334	175.32	2.39
		High income	59.65	3,160,864	220.69	1.85

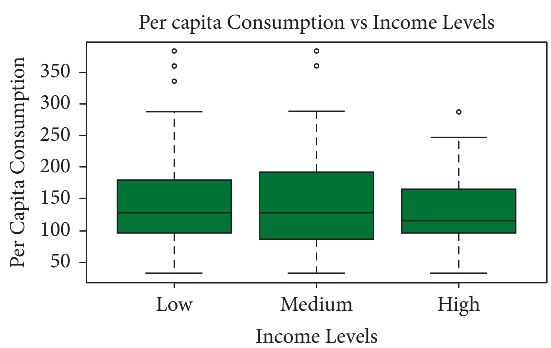


Figure 2: Box-plot of per capita charcoal consumption (y-axis in kg/person per year in the three main income samples (x-axis in TZS per year)).

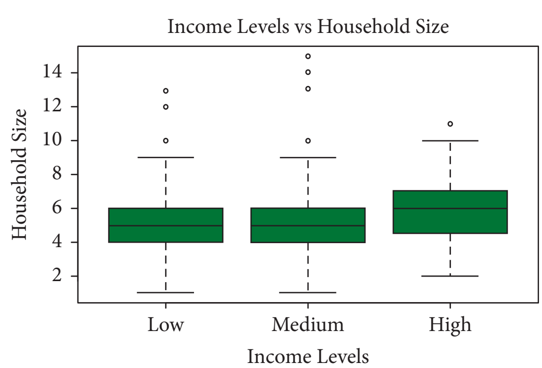


Figure 3: Box-plot of household size (y-axis in number of persons per household) in the three income samples (x-axis).

standard deviations from the mean, and the dotted circles show all sample values which are outside this range.

Per capita charcoal consumption varies from 32 kg to 384 kg being on average lowest in the high-income group and highest in the medium income group (Figure 2), having lowest variation in the high-income group (Table 1, Figure 2), and being some lower in Morogoro region compared to the other two regions (Figure 6). For the total sample, the average number of persons per household is 5.31 (Table 1), with largest average household in the high-income group (Figure 3). The price of charcoal varies considerably between the three regions, with the average price in Morogoro being about double of the Mtwara price (Figure 4). The per capita income variations within and between the three household income groups are shown in Figure 5 and depend upon the observed data of income per household and number of persons per household. With our fixed lower limits for the medium and high household income groups (Section 2.2),

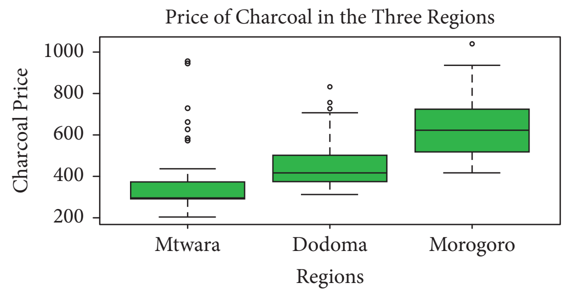


FIGURE 4: Box-plot of price of charcoal (y-axis in TZS/kg) in Dodoma, Morogoro, and Mtwara (x-axis).

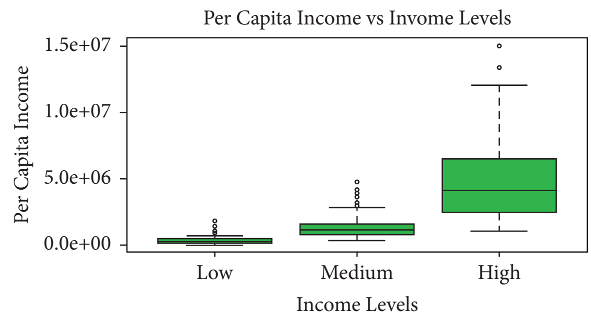


FIGURE 5: Box-plot of per capita income (y-axis in TZS) in low, medium, and high-income samples (x-axis).

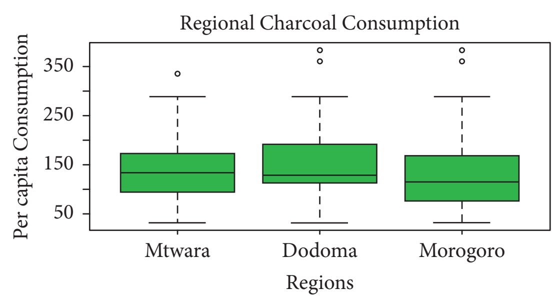


FIGURE 6: Box-plot of per capita charcoal consumption (y-axis in kg per year) in Dodoma, Morogoro, and Mtwara (x-axis).

TABLE 2: Regression results of full sample and three income level samples.

	Total sample ($n = 333$)		Low income ($n = 120$)		Middle income ($n = 142$)		High income ($n = 71$)	
	Coefficients	SE	Coefficients	SE	Coefficients	SE	Coefficients	SE
Intercept	6.138***	0.472	7.689***	1.075	8.490***	1.891	2.628	1.583
Per capita income	0.034*	0.020	0.061	0.066	−0.159	0.108	0.167*	0.094
Price of charcoal	−0.130**	0.063	−0.442***	0.102	−0.024	0.108	0.057	0.135
Household size	−0.621***	0.055	−0.590***	0.082	−0.814***	0.081	−0.440**	0.160
Adjusted R^2	0.3162		0.414		0.3279		0.2195	
F-value	52.17		29.12		23.92		7.564	

***Significant at level $\alpha = 0.01$; **significant at level $\alpha =$ at 0.05; *significant at level $\alpha = 0.10$.

the per capita income difference is highest in the group with the highest household income.

The average per capita charcoal consumption differences between regions are highest in the low-income group (Figure 7). Figure 8 shows that the average price of charcoal is lowest in the medium-income group and that the average per capita income and per household income are rather equal in the three regions with the exception that Mwanza has fewer very rich households than the other two regions. Figure 9 shows that in Dodoma, the average price of charcoal is highest for the low-income group, whereas in the other two regions, the average charcoal price is about equal between the three income levels and has a larger variation.

The testing group means using Tukey multiple pairwise-comparisons HSD [61] gave significant differences at 0.05 probability level for per capita income in different regions

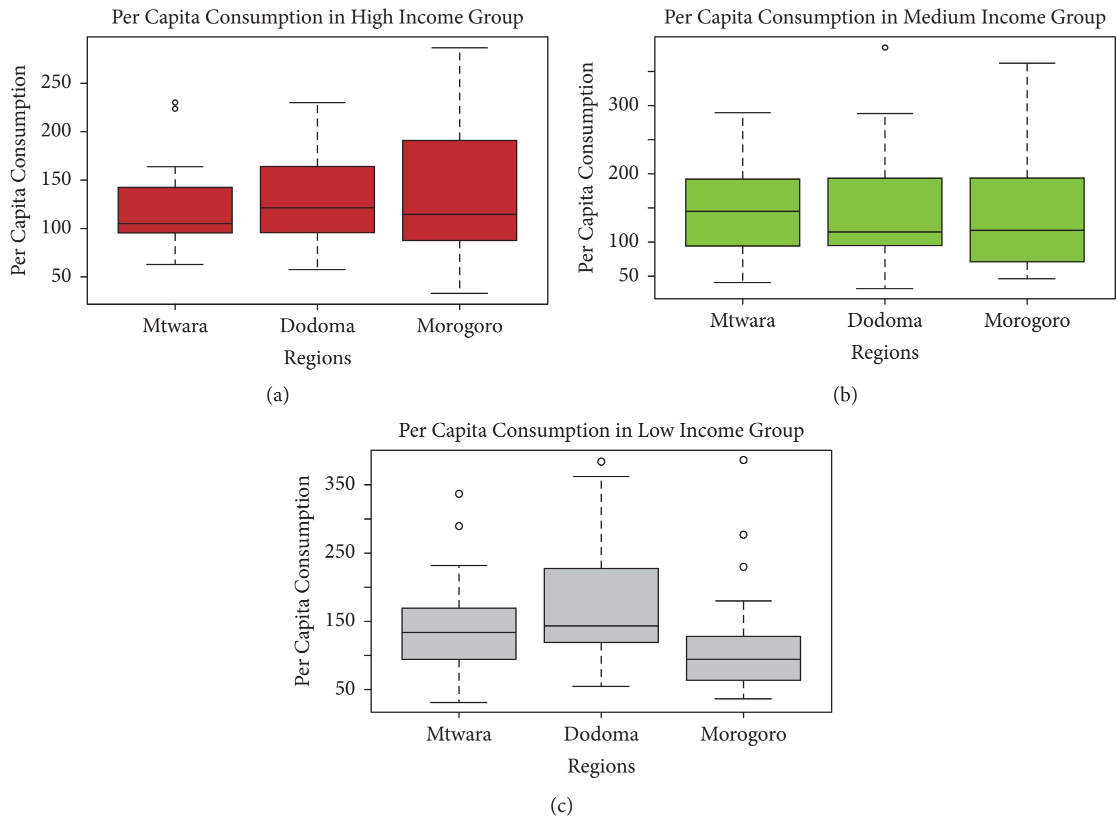


Figure 7: Per capita charcoal consumption (y-axis in kg per year) in (a) high-income, (b) medium-income, and (c) low-income groups in the three regions (x-axis).

and for price of charcoal in different regions and income groups. However, the per capita consumption of charcoal was not found significantly different between income groups and regions, except between Morogoro and Dodoma regions (Figure 6). Correlation coefficients between each of the independent regression variables were below 0.19, indicating low multicollinearity.

3.2. Regression Analysis Results. The fitted residual plots and the Q-Q plots (Figure 10) behaved normally, and none of the estimated econometric equations violated the statistical assumptions of independence, normality, and constant variance. The regression models were tested for heteroscedasticity using the Breusch–Pagan tests, both the lmtest and NCV test [62], and the results show low heteroscedasticity.

For the full sample, all three independent variables are significant, with elasticities being −0.13 for price and 0.034 for per capita income (Table 2). The negative coefficient of −0.62 for the household size implies a rather high economies of scale in the household cooking.

In the three income subsamples, per capita income is significant only for the high-income group, with an elasticity of 0.17. Price is significant only in the low-income group, with elasticity of −0.44. Household size is significant in all three subsamples, with elasticities of −0.59, −0.81 and −0.44 in, respectively, the low, medium, and high-income groups. The adjusted R^2 varies from 0.22 in the high-income group to 0.41 in the low-income group.

We also tried other statistical models, like total household consumption as dependent variable and charcoal price, total household income and household size as independent variables, or to exclude household size, or use no transformation of the input data. These specifications all gave lower R^2 and lower F-values or positive coefficient for the variable charcoal price. Including region as explanatory (dummy) variable, the price coefficient turned insignificant, probably due to the large differences in price levels between the three regions (Figure 4). We therefore rejected these models.

4. Discussion

The higher prices of charcoal experienced in Morogoro and Dodoma than in Mtwara may be attributed to both demand and supply factors. The presence of the universities and other institutions in Morogoro and Dodoma contributes to increased population and purchasing power implying high charcoal demand. On the supply side, the Dodoma region experiences aridness most of the time as compared to Morogoro and Mtwara (Figure 1), and the increased demand has caused exhaustion of the woodlands and forests for charcoal production in Dodoma, hence lowering the supply of charcoal from local areas. In Mtwara, the relatively low charcoal price can be explained by the large supply from

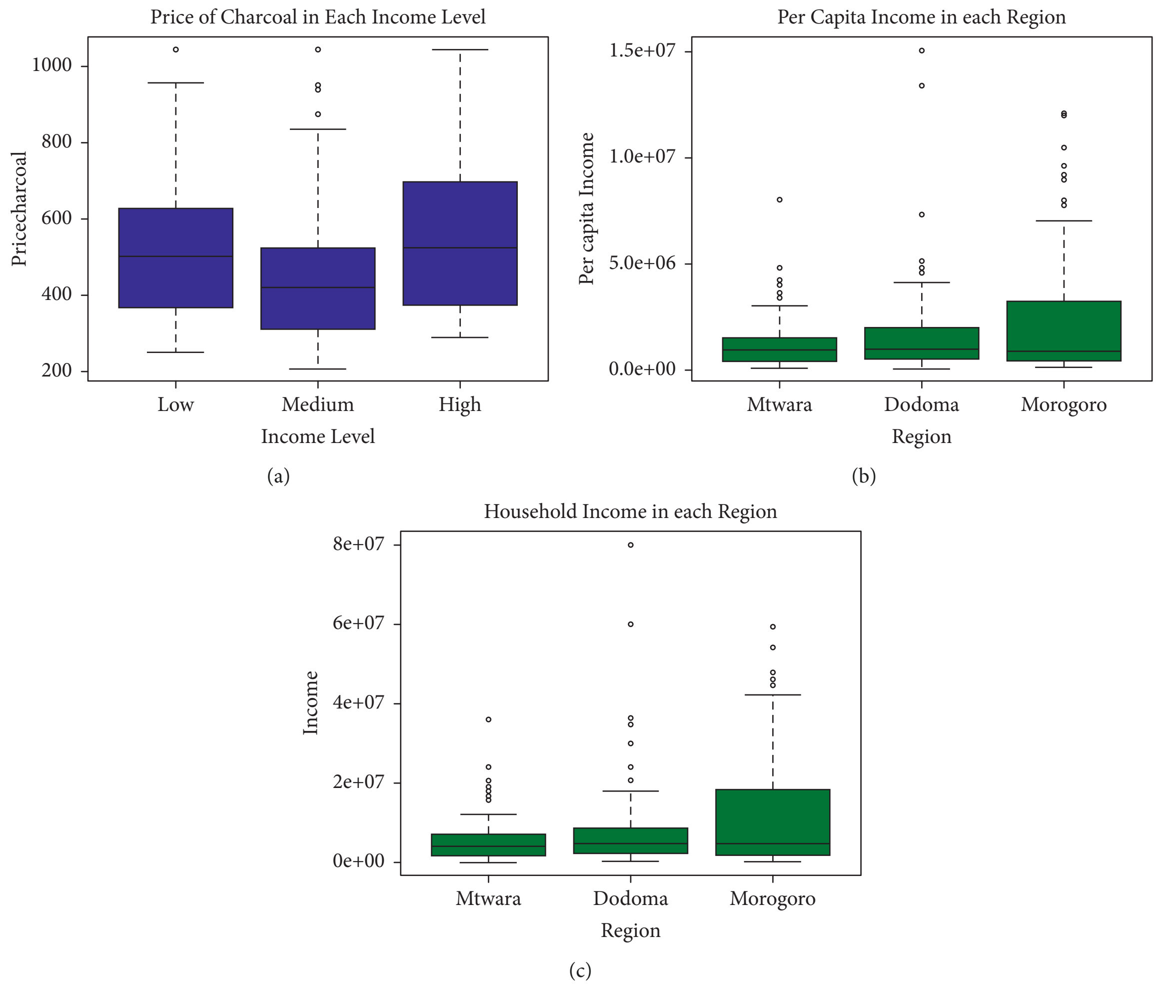


Figure 8: (a) Price of charcoal (TZS per kg) in the three income groups, (b) per capita income (TZS per year) in each of the three regions, and (c) household income (TSZ per year) in each of the three regions.

Miombo woodlands in the region and low labor costs for charcoal production due to lack of work opportunities. Also, higher average distances from production centers to the main market simply lower charcoal prices in Mtwara compared to Dodoma and Morogoro. Previous studies have shown that Mtwara, Lindi, and the neighboring regions are the main suppliers of charcoal to Dar es Salaam and Zanzibar [11, 43]. Other studies have reported Zanzibar and Dar es Salaam to have the highest prices of charcoal, partly caused by transport distances and costs [11, 25, 26]. In addition, Malimbwi et al. [43] found that of the 10,500 bags of charcoal transported daily to Zanzibar, about 7,500 bags (i.e., 72%) were transported illegally, hence not charged with any taxations or levies and thus lowering the supply costs. The illegal charcoal production and trading system distort the market price of charcoal and at the same time makes the government losing a substantial amount of revenues. According to Baumert et al. [23], small-scale producers tend to have trouble in receiving commercialization rights. This hinders most of the members in the communities to integrate in the formal charcoal value chain, thus pressing them to produce illegally and selling in local markets at lower price and profits [63, 64]. Despite owning and having the rights to control the woodlands, most of these communities lack the capacity to govern their resources sustainably because of the weak institutions existing in their villages, hence experiencing continued illegal charcoal production [23].

The main aim of this study was to provide empirical estimates of charcoal demand elasticities. An interesting result is that the charcoal price demand elasticity estimated for the low-income group is significantly higher (in absolute term) than for the whole sample, but not statistically significant in the middle and high-income households. One likely explanation for this is that medium and high-income households are relatively less influenced by increased charcoal prices as their charcoal costs constitute a much smaller share of their total household expenditures than the corresponding share for low-income families. A vital aspect here is how much of the total income is used for charcoal. Sabuhungu et al. [65] estimated that about 11% of the total household income was spend on charcoal in Bujumbura, Burundi. In our study, using the average estimates in Table 1 of income, charcoal consumption, and charcoal price, this percentage is 2.4%, 4.8%, and 20.8% for, respectively, the

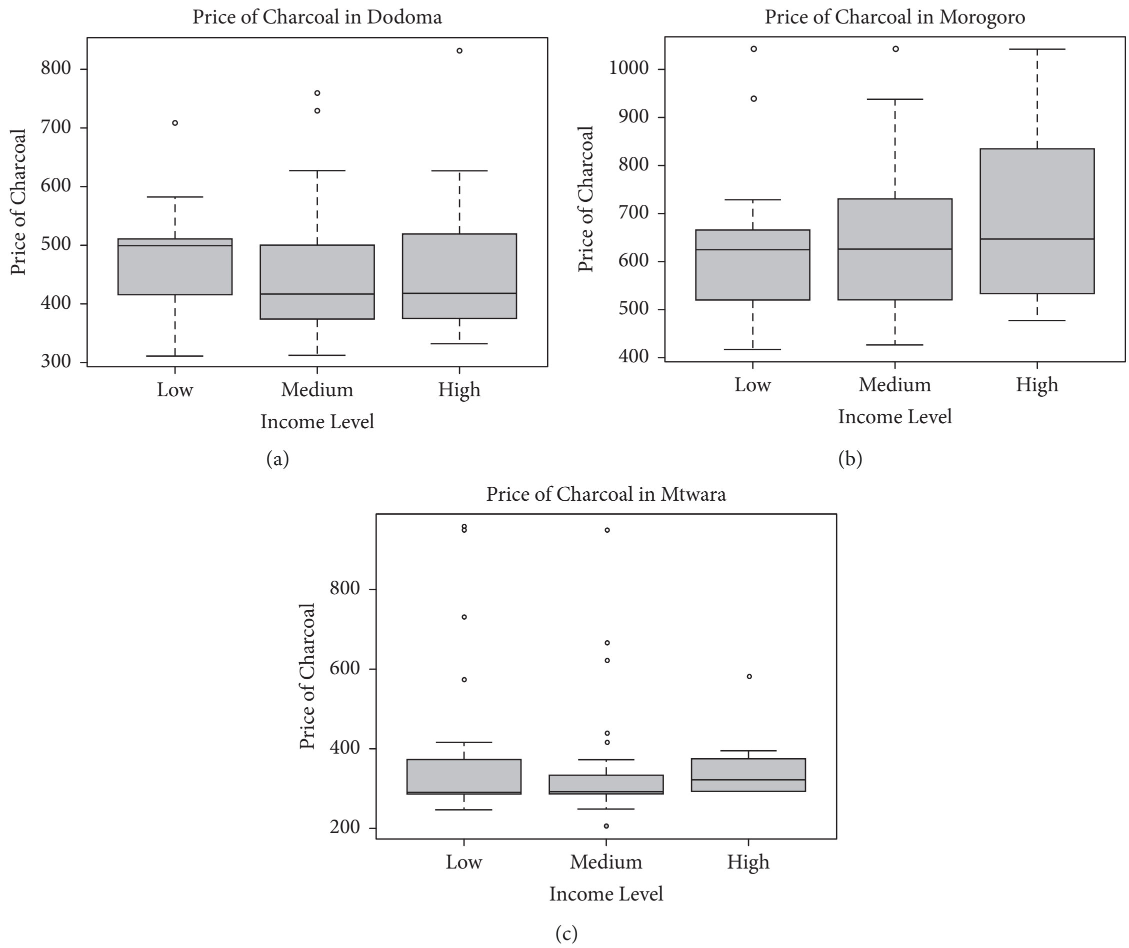


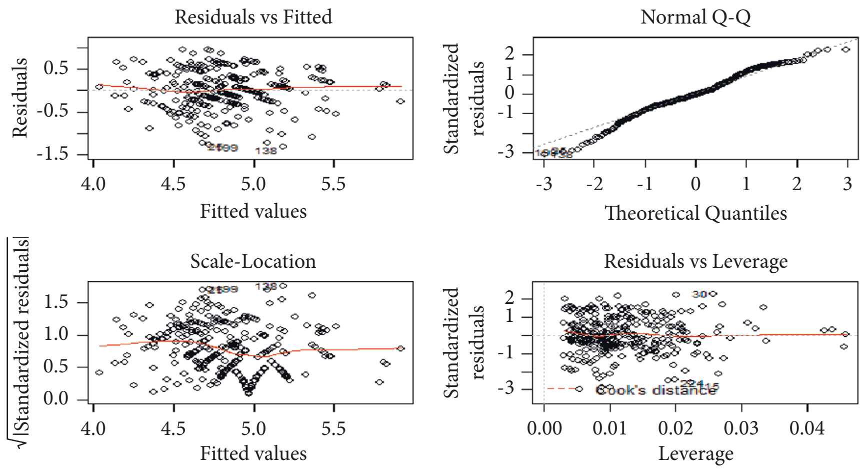
Figure 9: Price of charcoal (TZS per kg) for each income group in each region.

high, medium, and low-income groups. Another possible reason for the rather high price elasticity in low-income households found in our study is that the poor urban families compared to the richer ones may live in housing facilities which have more possibilities for using cheaper cooking energy sources like firewood or forest residues. Previous studies (e.g., [28, 40, 41, 45, 57]) confirm that high initial costs limit the low-income households to invest in electric, gas, or improved charcoal cooking stoves.

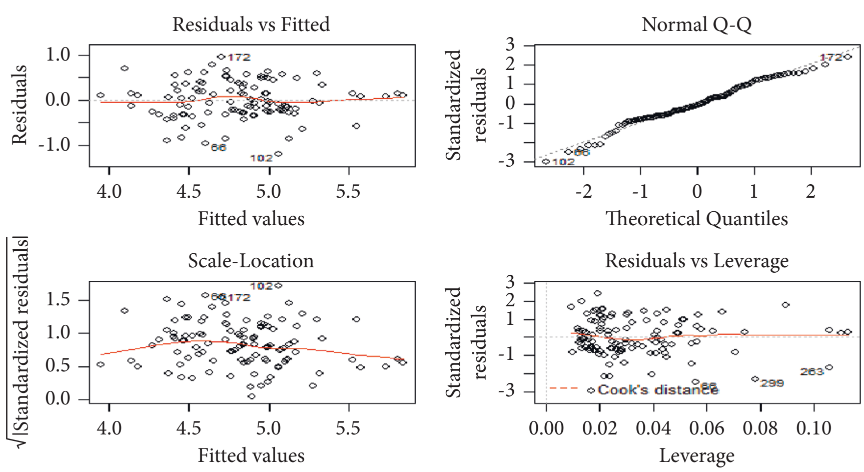
For households in the medium and high-income samples, increased charcoal prices within the range observed in this study might still result in charcoal being both cheaper and more reliable than shifting to electricity or kerosene cooking. Food tradition and taste considerations may also play a part in those groups.

The positive income elasticities found in the regression analyses of the total sample and the high-income sample (respectively, 0.03 and 0.17, Table 2) are interesting. One should of course be careful in drawing strong conclusions from these results: because the whole sample is small, the three income-group samples are even smaller, and because the income variations within these groups are considerably lower than for the whole sample (Figure 5 and Table 1). Nevertheless, it is noteworthy that the only statistically significant income elasticities we found were positive and highest in the high-income group, as it may indicate that the transition of going from charcoal to more modern cooking facilities such as kerosene, gas, and electricity might take longer time than one may expect.

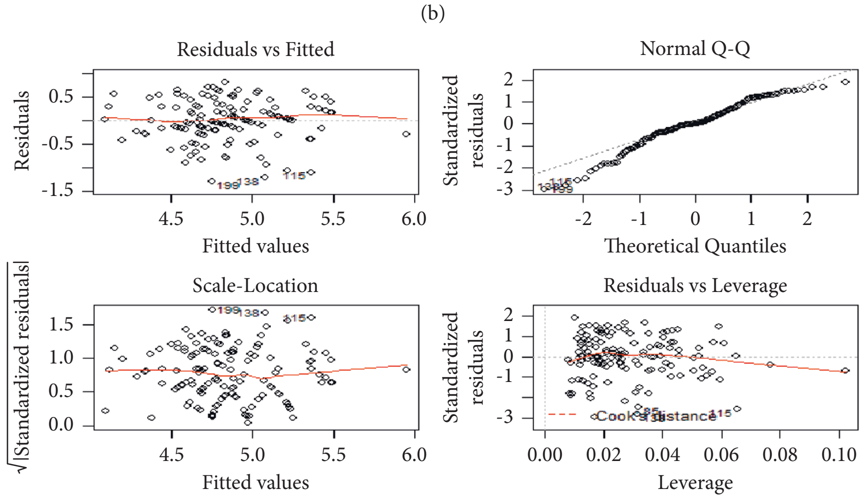
As mentioned in the introduction, the study by D'Agostino et al. [43] is the only econometric study of charcoal demand in Tanzania we have come across, and it is interesting to compare their result with ours, although such a comparison should be done with caution. First, they use household expenditures (TZS) on charcoal as dependent variable, whereas we use quantity (kg) of charcoal consumption per household member. Second, they have total household expenditures minus expenditures on utilities as income independent variable, whereas we use total household income (provided from question 16 in the questionnaire Supplementary material). Third, they did not include charcoal price as explanatory variable, whereas we include this variable as provided by question 20 in the questionnaire (see Supplementary materials). Fourth, they had a sample of more than 3000 respondents covering all urban areas of Tanzania, whereas we had 360 respondents in three urban areas. Fifth, their data were collected in 2008 and 2010, whereas ours were collected in 2015. Sixth, in order to verify result robustness, they include several potential confounders as explanatory variables (like level of education, rural location, radio listening, electric light,



(a)

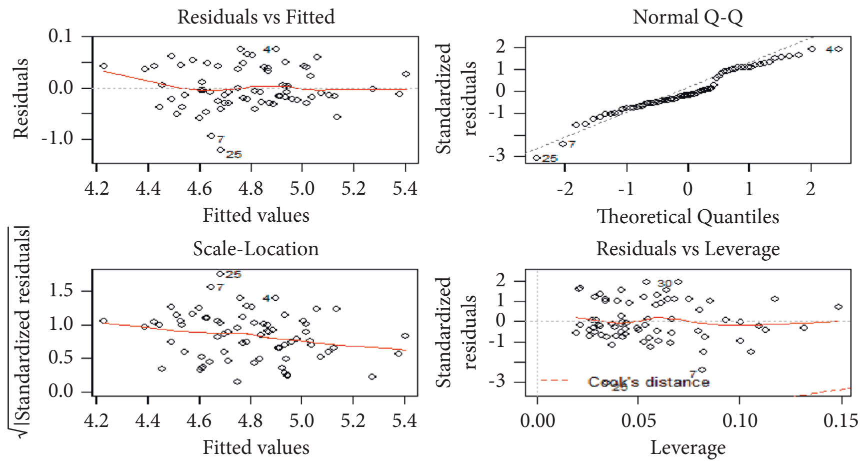


(b)



(c)

Figure 10: Continued.



(d)

Figure 10: Residual plots for the regression equations given in Table 2. (a) Full sample equation. (b) Low-income equation. (c) Middle-income equation. (d) High-income equation.

mobile phone, and male household head), whereas we did not include any such variable because we emphasized to concentrate on getting estimates which could be relatively easily applied to make socioeconomic consistent projections of the future urban charcoal demand development in Tanzania.

D'Agostino et al. [43] covered both rural and urban households and showed statistical results for several subsamples, and for comparing with our study, it is logical to use the subsample "urban households only." For that subsample, they find a statistically significant expenditure elasticity of 0.808, which is much higher than the statistically significant income elasticities in our study of 0.034 for our full sample and 0.167 for the high-income group (Table 2). Potentially, each of the six explanations stated above could be the reasons for the large income-elasticity differences between the two studies, and omitting charcoal price as explanatory variable might be one of the most important reasons.

In the same subsample, D'Agostino et al. [43] reported a statistically significant household size elasticity of 0.212 having household charcoal expenditures (less utility expenditures) as dependent variable, whereas we got a household per capita charcoal consumption elasticity of −0.621 (Table 2, full sample) with respect to household size. Again, each of the six explanations stated above could be reasons for the differences. But also, the results in D'Agostino et al.' study [43] show economies of scale regarding the impacts of household size on the household per capita charcoal consumption.

In Section 2.1, we used the energy ladder theory to hypothesize that per capita charcoal consumption would decrease with increased per capita income. Our statistical results regarding income are not showing this, but it would be misleading to claim that they can be used to reject this theory as we had in our survey very few respondents who used electricity, gas, or kerosene for cooking. A new study with a larger sample size to test the energy ladder hypothesis is, therefore, of high interest. Such a study could preferably include larger cities like Dar es Salaam, Mwanza, Arusha, Mbeya, Dodoma, Tanga, and the entire Zanzibar.

Our study includes several elements which may cause uncertain results and, therefore, should be kept in mind when interpreting or using our results. Two important elements are the methods used for choosing respondents and the relatively small sample size. Also, the interview situations where data were collected varied, as in some households, other persons than the head of the household were interviewed. The income was estimated by using only the respondents' answers on expenditures, and savings were not considered. The charcoal prices were estimated based on various types of bag sizes. Furthermore, the definitions of the cutoffs between the three income groups might impact the results.

A vital question here is to check how representative our data inputs are by comparing with corresponding data from other studies or official statistics. Regarding representativeness of our choice of income classes, the only study we have come across for comparison is World Bank [59], in which the Tanzanian population is divided into the four income classes: extreme poor, poor, middle class, and the richest. The percentage of total population in each of those classes was estimated indirectly to be 10% for the extreme poor, 28% for the poor, 40% for the middle class, and 22% for the richest class. In our study, we have only three income classes and the following distribution in the whole sample (Section 2.3): 36% in the low-income, 43% in the middle-income, and 21% in the high-income groups. If we add the two poorest classes in World Bank [59] into one poor class, we see that the income distribution in our study is not very far from the income distribution shown in the World Bank study.

Also, our mean values for the two variables annual per capita charcoal consumption and number of persons per household are within the range of estimates reported in previous studies, e.g., Nyamoga and Solberg [16]. Misspecification of the statistical regression models is another potential reason for uncertainty, but the Breusch–Pagan test (lmtest and NCV test) did not reveal any misspecifications.

Considering the abovementioned uncertainty elements, the study should be viewed as exploratory and to be confirmed by larger surveys. But because few studies of this kind have been conducted for Tanzania, our results on the impacts of price, income, and household size ought to be of interest. Improved studies of charcoal consumption in Tanzanian households are important and should, compared to our study, preferably be based on larger samples, include more regions, and have more respondents who have moved from charcoal use to more modern cooking energy carriers. Detailed data on the consumption and costs of each of these carriers are important to include. To get sufficiently many representative respondents, one should try to coordinate such research with the existing governmental household surveys done regularly in Tanzania.

5. Conclusions and Recommendations

A total of 360 households situated in the Tanzanian cities Dodoma, Morogoro, and Mtwara were surveyed and statistical analysis on how income, charcoal prices, and household size influenced household per capita charcoal consumption were conducted. For the total sample, statistically significant elasticities were found to be 0.03, −0.13, and −0.62 for per capita income, charcoal price, and household size, respectively. In the sample of low-income households, charcoal price and household size were found to be statistically significant. In the sample of middle-income households, only household size was found to be significant, while in the sample of high-income households, the two explanatory variables per capita income and household size were found statistically significant. The estimated charcoal price elasticity of −0.44 in the low-income group indicates that the poor families are living on very strict household budgets and are highly sensitive to changes in charcoal prices.

The study results are based on small samples and should, therefore, be interpreted and used with caution. More studies of charcoal consumption in Tanzanian urban households are needed and compared to our study preferably based on larger samples, including more regions and higher number of respondents who have moved from charcoal use to modern cooking energy carriers and incorporating consumption and costs of these carriers. To get enough number of respondents, we suggest coordinating such studies with existing governmental household surveys done regularly in Tanzania.

The current high urbanization in Tanzania of 5-6% per annum together with the high population and economic growths lead to a growing demand of charcoal. This may cause severe environmental and social challenges like increased deforestation, reduced ecological resilience, severe health diseases in charcoal-using urban households, and increased GHG emissions. This will be the case if no improved alternative cooking technologies or energy carriers are made available at affordable costs, especially for the households in large and densely populated cities like Dar es Salaam, Mwanza, Mbeya, Tanga, Dodoma, Morogoro, Iringa, and Arusha. The ongoing exploration of gas in Tanzania and investments in Mwalimu Julius Kambarage Nyerere Hydroelectric Project (Stiegler Gorge Dam) may contribute to changes in charcoal consumption patterns in these households in the future. But these changes will depend upon many factors related to costs, income, consumer acceptance, technological changes, policies, and reliability of the new technologies. More research on main factors deciding changes from traditional to more modern cooking energy systems in Tanzania are needed for developing appropriate policies related to energy, land use, and climate mitigation.

Data Availability

The data used to support this study are available upon request from the corresponding author.

Additional Points

In the three urban areas of Tanzania surveyed in this study, charcoal was the main energy source for cooking. In the whole sample, per capita charcoal consumption was significantly affected by charcoal price, household per capita income, and household size. Price of charcoal showed a significant effect on the per capita charcoal consumption in the low-income sample and was insignificant in the middle and high-income samples. Household size affected significantly the per capita charcoal consumption in all three income samples. Per capita income influenced the per capita charcoal consumption in the full sample and the high-income sample and was insignificant in the low and middle-income samples.

Disclosure

The manuscript is part of the PhD study conducted at the Norwegian University of Life Sciences (NMBU) in As, Norway. The article does not by any means reflect views of Sokoine University of Agriculture nor the Norwegian University of Life Sciences.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

Greyson Zabron Nyamoga first drafted the questionnaire, collected the field data, structured the data for statistical analysis, performed the first statistical analysis, wrote first draft of the article, and participated in discussion of results, all article redrafts, and the final manuscript. Hanne Katherine Sjølie and Greg Latta participated in questionnaire design, assisted in structuring the data, the statistical analyses, and discussion of results, and participated in all article drafts and the final manuscript. Yonika Mathew Ngaga and Rodgers Malimbwi participated in questionnaire design, facilitated research permit and data collection, and participated in the discussion of results, all article drafts, and the final manuscript. Birger Solberg had the original idea, participated in questionnaire design, participated in the statistical analyses, all article drafts, and the final manuscript, and provided project funding and administration.

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Supplementary Materials

Household questionnaire for assessing charcoal consumption in Dodoma, Morogoro, and Mtwara urban centers. (*Supplementary Materials*)

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