Urban demand for cooking fuels in two major African cities and implications for policy

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Abstract

Nearly 2.4 billion people lack access to clean cooking fuels and technologies worldwide, representing a critical failure to achieve SDG7's cooking energy access goal. Dependence on polluting cooking fuels is particularly high in Sub-Saharan Africa, where it generates considerable environmental, health, and time-related costs. In the region, progress has been greatest in urban areas, but understanding of the dynamics of urban cooking energy transitions remains limited. On the one hand, higher average incomes and greater availability of alternative fuels, relative to rural areas, helps to explain urban populations' generally higher access rates. Nonetheless, different cities display divergent paths, and the impacts of policy instruments in fostering household energy transition remain unclear. This paper considers the demand for several fuels among low-income households in two such contrasting cities – Nairobi (where the transition is well advanced) and Dar es Salaam (where progress has been slower). Household preference data from our double-bounded, dichotomous choice contingent valuation experiment helps us understand how urban households respond to changes in the price of their preferred cooking fuels. We find that fuel price responses vary across the income distribution and across the two cities. Specifically, the willingness to pay for the most commonly used cooking fuel in Nairobi – liquefied petroleum gas – is nearly twice that in Dar es Salaam, where more households prefer charcoal. In Dar es Salaam, low-income charcoal users appear especially entrenched in their choice of cooking fuel. The extent to which different policy tools (such as bans, taxes, or clean fuel subsidies) can be effective depends on these price sensitivities, enforcement, and also on the readiness of the supply side to meet increased demand. Importantly, policy-makers need to understand nuances in the local demand context very well when choosing appropriate instruments to support energy transition among their most vulnerable citizens.

Author Summary

Though populations in urban areas are more rapidly progressing towards SDG7's universal clean cooking access goals, there is limited understanding of urban cooking energy transitions in low- and middle- income countries. The higher average incomes and greater availability of alternative fuels in these locations certainly facilitate adoption of clean alternatives, relative to rural areas, but different cities display widely divergent paths. Understanding of what drives these differences remains rudimentary, and the impacts of policy instruments in fostering urban energy transition remain particularly unclear. This paper considers the demand for several cooking fuels among low-income households in two such contrasting cities – Nairobi (where the clean cooking energy transition is well advanced) and Dar es Salaam (where progress has been slower). We show that the willingness to pay for the most commonly used clean cooking fuel – liquefied petroleum gas – among the poor in Nairobi is nearly twice that in Dar es Salaam, where households prefer charcoal. Importantly, these cities have implemented very different policies to support household cooking energy transition. Our findings have important implications for policies that effectively promote clean cooking fuels.

Introduction

Globally, nearly 2.4 billion people lack access to clean cooking fuels and technologies. High reliance on polluting fuels such as biomass and kerosene persists especially in Sub-Saharan Africa (SSA), generating time and drudgery costs, high exposures to health-damaging emissions, and substantial environmental damages. Among the 20 countries with the smallest population share with clean cooking access, 19 are least-developed countries in SSA (1). Moreover, between 2010 and 2020, the region experienced the lowest annualized increase in access (+0.48 percentage points per year) (1). Progress towards clean cooking goals lags other energy-related objectives such as ensuring access to electricity.

Prior literature has largely focused on rural settings in low- and middle-income countries (LMICs), where clean energy access is generally lowest. However, clean cooking fuel use remains far from universal in many urban LMIC settings, and use of polluting fuels persists alongside high rates of electricity access and ample availability of a variety of alternative cooking fuels. Typical explanations revolve around the widespread belief that clean fuels like liquefied petroleum gas (LPG) and electricity are too expensive to use for cooking purposes (2), or issues related to the unreliability of electricity supply in many LMIC cities. Poor distribution networks and small-scale production also mean that more affordable efficient biomass stoves can be difficult to find in many urban centers. As such, household use of polluting fuels continues to be a major contributor to the cocktail of sources that are increasingly making ambient air in urban areas unbreathable (3).

This paper focuses on urban cooking fuel demand in two of East Africa's largest and fastest growing cities – Nairobi, Kenya and Dar es Salaam, Tanzania. Our double-bounded, dichotomous choice contingent valuation (CV) experiment help us to understand how urban households would respond to changes in the price of their preferred (main) cooking fuels (4). It acknowledges that households typically stack fuels, and that households may react to higher prices by either maintaining their current cooking energy portfolio, cooking less with their preferred fuel, or switching entirely away from it. In the latter two cases, the surveys also provide information on households' preferred back-up fuel, which helps to reveal the transitions that might occur if policy actions were to change relative fuel costs.

In addition to the basic analysis, we explore the correlates of households' willingness to maintain their current fuel use under increased prices, focusing especially on the heterogeneity in responses across cities and across the income distribution. The analysis adds nuance and policy relevance to the conventional finding that low income and affordability are key factors that slow the transition away from polluting cooking fuels (5-10). Judicious application of price instruments can facilitate substitution into socially beneficial solutions, but those responding to policy instruments such as taxes and subsidies are not always the most intensive users of polluting fuels (11, 12). Better understanding variation in both price and income responses of demand for cooking energy across locations is essential to informing more effective policy design and targeting.

Context of cooking energy use in Nairobi and Dar es Salaam

There are key differences between Nairobi and Dar es Salaam that inform interpretation of the comparative analysis of cooking fuel use in these two large and important East African capitals. In 2019, average gross annual income per capita in Nairobi County was 5,497 USD, compared to 1,941 USD in the Dar es Salaam Region (assuming 1 USD = 2,333.3 TZS, and 1 USD = 108.5 KS) (13, 14). Despite having similar urban use of clean fuels in 2000, adoption in urban Kenya has far outpaced that in urban Tanzania over the past twenty years (SI Appendix, Figure S1) with apparent rapid changes in the primary cooking fuel identified by households in both cities between 2015 and 2020. Over the same period, the LPG market has been expanding especially rapidly in both cities, with the proportion of households using LPG more than doubling in Dar es Salaam even as charcoal dependence remains high (SI Appendix, Figure S2). In both locations and in other settings, households perceive that electricity is expensive to use for cooking purposes (15).

Policies that affect cooking fuel prices likely played some role in influencing these trends. The pro-clean cooking policy stance of the Kenyan government, and the dynamism of the private sector response to rising demand for clean fuels, for example, are well known (16). Throughout the 2000's, Kenya charged no excise duties on kerosene, facilitating adoption of that fuel at the expense of solid fuels (17). In 2016, Kenya zero-rated the value-added tax (VAT) on LPG, and introduced subsidized access to electricity for low-income households (18). The Government-led Mwananchi gas project then launched in 2017 with the ambitious target of increasing nation-wide LPG penetration from 10-70% in three years, by subsidizing purchases of LPG canisters and stoves by low-income households (19). Finally, though it was criticized as regressive and ineffective, a ban on the production and transportation of charcoal into Nairobi was introduced in 2018, which did increase the effective price of charcoal (20-22).

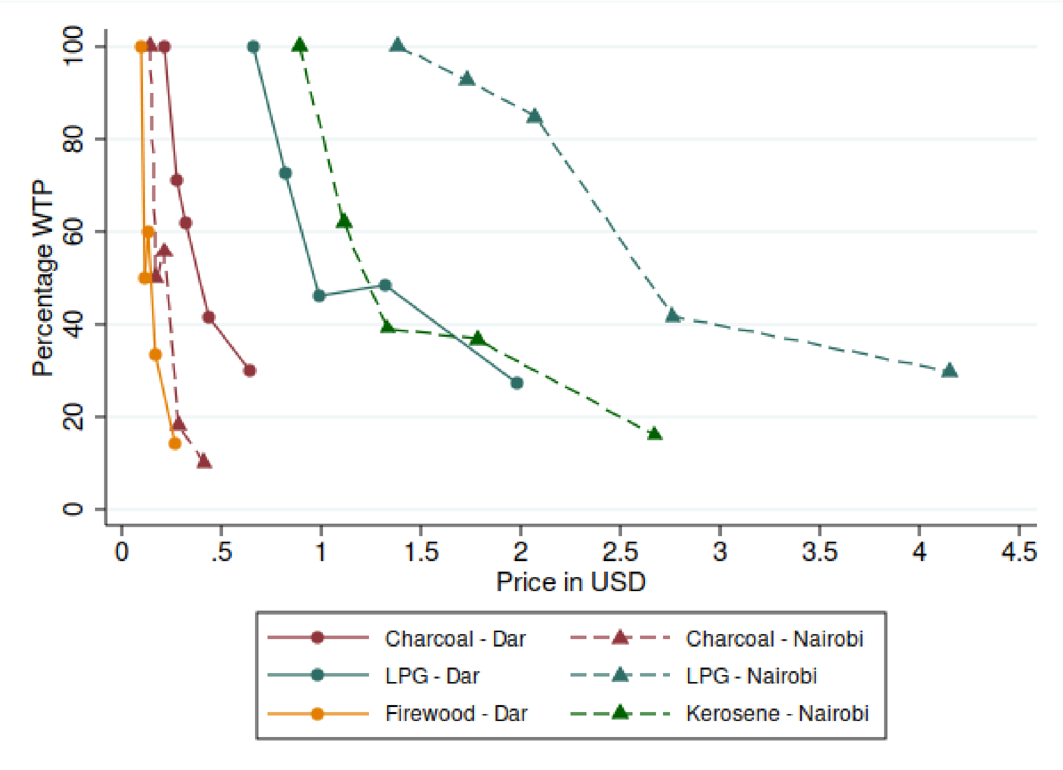
In contrast, while the Tanzanian government has long embraced similar goals for households transitioning to modern fuels (in its national energy policy of 1992, amended in 2003 and 2015) (23), it has taken fewer specific policy actions to support those goals, and most urban households continue to use charcoal as their main cooking fuel. In 2008, the government did exempt LPG stoves and fuel from VAT and excise duties in order to encourage uptake (24). In both Nairobi and Dar es Salaam, the VAT is not collected on charcoal transactions given the informality of this industry, though various other royalties and license fees are collected from producers and transporters in Tanzania (25).

Energy use characteristics of sampled households

In 2019, we interviewed 354 households in four informal settlements in Nairobi (we focused only on lower income areas in Nairobi since these are the areas where the population continues to rely on polluting fuels), and in 2020 we interviewed a representative sample of 1,100 households (largely residing in informal settlements) across Dar es Salaam (SI Appendix, Figure S3). A detailed summary of the characteristics of sampled households in both locations is presented in Table S1. Here, we specifically describe the energy profile of the sampled households. In the Nairobi sample, LPG is the most common cooking fuel (54%), followed by kerosene (29%) and charcoal (11%) (Panel B, Table S1). In Dar es Salaam, charcoal is the most common cooking fuel (61%), followed by LPG (32%) and kerosene (4%). In Nairobi, fuel procurement times for all major cooking fuels are similar, ranging from 10-14 minutes per purchase. Average reported daily fuel collection times in Dar es Salaam are much higher than in Nairobi, with firewood collection time being the highest (44 minutes per trip) and kerosene collection time being the lowest (24 minutes). All Nairobi households in the sample have electricity, and electricity access is slightly lower in the Dar es Salaam (85%) sample. Households in the Nairobi sample are of slightly higher socio-economic status than those in the Dar es Salaam sample. Per capita monthly expenses are 94 USD in Nairobi, compared to 78 USD in the Dar es Salaam sample, and roughly 51% of the Nairobi sample had completed secondary schooling, compared to 33% in Dar es Salaam.

Primary cooking fuel choices in response to price increases

For each of the three main cooking fuels in Nairobi (charcoal, kerosene and LPG) and Dar es Salaam (firewood, charcoal and LPG), we assessed demand over randomly-assigned price increases that ranged from 25% to 200% (SI Appendix, Table S2 presents the full range of prices offered for the three fuels in both cities). The derived demand curves from responses to initial bids show a mostly linear relationship between WTP for cooking fuel and price (Figure 1).



Note: This figure shows the percentage of households in the Dar es Salaam and Nairobi samples reporting that they would continue using their primary cooking fuel when faced with a given initial price increase. Price increases are randomly assigned across survey respondents and baseline prices are converted into USD for comparison in this figure. The initial bids in the price increases and willingness to maintain use responses are presented here.

Figure 1. Demand graph for cooking fuels in Nairobi and Dar es Salaam (initial bids only)

Among respondents in Nairobi that use charcoal as their primary cooking fuel, nearly half the respondents were willing to maintain their primary fuel use under the lowest price increase of 25%, but only 10% were willing to pay 200% more for the fuel. The WTP probabilities among primary kerosene-using respondents were similar: ranging from 62% to 16% for these initial lowest and highest bids, respectively. For primary LPG fuel respondents, the range of WTP probabilities was somewhat higher, dropping from 93% to 30%. Regression analyses further show that the price elasticities of maintaining use of each of these primary fuels are somewhat similar, ranging from -0.5 to -0.7 (Table 1, columns 1, 4, and 7). Yet, controlling for fuel stacking (i.e., use of multiple cooking fuels), which represents an important strategy for coping with high fuel costs or unreliable fuel alternatives, adds important nuance to these findings. Specifically, we find that accounting for stacking leads to higher estimates of the price elasticity for charcoal and LPG (columns 2 and 8), while kerosene users appear less price sensitive (column 5). Primary LPG-using households are 13 percentage points more likely to switch away from that fuel when they already use other cooking fuels (column 8). Moreover, the higher the proportion of LPG consumed in total cooking fuel use, the more likely they maintain this option (column 9). In SI Appendix, Section S3, we further explore the determinants of cooking fuel stacking.

Table 1. Probability of maintaining primary cooking fuel use in Nairobi and Dar es Salaam: average marginal effects

	Nairobi									Dar es Salaam					
	Charcoal			Kerosene			LPG			Charcoal			LPG		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Log of Initial bid: Price of charcoal per kg (in USD)	-0.540***	-0.726***	-0.842***							-1.117***	-1.134***	-1.134***			
	(0.190)	(0.142)	(0.152)							(0.115)	(0.110)	(0.110)			
Log of Initial bid: Price of kerosene per liter (in USD)				-0.496***	-0.341***	-0.320***									
				(0.114)	(0.106)	(0.105)									
Log of Initial bid: Price of LPG per kg (in USD)							-0.662***	-0.738***	-0.729***				-0.347***	-0.347***	-0.363***
							(0.050)	(0.053)	(0.057)				(0.057)	(0.059)	(0.059)
Binary fuel stacking		0.020			0.065			-0.130**			-0.070*			0.110*	
		(0.140)			(0.098)			(0.064)			(0.037)			(0.059)	
Continuous charcoal stacking variable			-0.661									0.091*			
			(0.432)									(0.046)			
Continuous kerosene stacking variable						-0.244*									
						(0.145)									
Continuous LPG stacking variable									0.537***						0.159*
									(0.137)						(0.083)
Observations	40	38	39	104	102	102	192	192	192	583	583	583	321	321	321
R-squared	0.124	0.485	0.518	0.098	0.327	0.343	0.219	0.412	0.447	0.084	0.182	0.182	0.065	0.143	0.143

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1 Household-level controls included are log of monthly per capita total household expenditures (in USD), household size, age, education and gender of household head, dependency ratio, whether household has saved money anywhere in the past year, whether household is connected to electricity, time taken to acquire firewood, charcoal, kerosene and LPG. As the sample for the number of primary firewood users in Dar es Salaam is small (22 households), we do not show results for that sub-sample.

For primary charcoal users in Dar es Salaam, 70% were willing to pay the lowest increase, and 30% the highest price (Figure 1). For primary firewood users, half of the respondents facing the lowest bid level were willing to pay, and only 14% were willing to pay the highest price. Finally, for LPG 72% of primary LPG users were willing to continue using LPG at the lowest price increase, which dropped to 27% willing to continue at the highest price. Unlike in Nairobi, the regression analyses indicate very different price elasticities for maintaining use of charcoal (-1.1) vs. LPG (-0.3) in Dar es Salaam (Table 1, columns 10 and 13), and controlling for fuel stacking does not substantively alter these estimates (columns 11, 12, 14 and 15). However, primary charcoal and LPG users are more likely to maintain their primary use when they rely more heavily on these as their primary fuels, as measured by proportion of total cooking fuel use (columns 12 and 15).

In models that pool across all fuels in each location, based on conversions of quantities in kg or L to energy equivalents (Columns 1-6, Table S4), we find similar negative fuel price elasticities in the two cities (ranging from -0.5 to -0.6). The relationship between the stacking variables and the WTP probability is markedly different in the two cities, however. Stacking is associated with a greater likelihood of switching away from one's primary fuel in Nairobi. In Dar es Salaam, stacking has the opposite relationship with switching away from one's primary fuel. This may be due to the differing stage of the energy transition in these cities and how it relates to fuel preferences. That is, given the relative early stage of LPG adoption in Dar es Salaam compared to Nairobi, LPG users (who tend to be stackers) there may perceive charcoal as their primary fuel despite reporting, aspirationally perhaps, that LPG is their primary fuel.

Percentage decreases in cooking

Rather than responding on the extensive margin of primary fuel use (that is, switching away from it entirely), households may choose only to reduce their use of a more expensive primary cooking fuel when its price increases. In the restricted sample of households that accepted the first proposed price increase and maintained primary use of their preferred fuel, we analyze the extent of the cooking reduction they predicted they would make. In Nairobi (Table S5), we find that a 1 USD increase in LPG price per L would reduce cooking with LPG by 9-12 percentage points. In Dar es Salaam (Table S6), we find that a 1 USD increase in charcoal per kg and LPG price per L faced by primary users of those fuels would reduce cooking with those fuels by 25-30 percentage points, and 8 percentage points, respectively.

Willingness to pay for the various primary cooking fuels

We provide three different measures of WTP for each of the primary fuels considered: non-parametric a) Turnbull lower-bound estimates and b) Kristrom mid-point estimates, as well as c) estimates obtained from application of maximum likelihood regression estimation to the double-bounded dichotomous choice responses to the CV questions (see methods for details on the differences in these methods).

In Nairobi, the measures range from 0.14-0.2 USD/kg charcoal, 1.1-1.4 USD/liter kerosene, and 2.3-2.9 USD/kg LPG (Table 2). These measures are generally not sensitive to controlling for stacking behavior in the regression models, though the estimate declines slightly for LPG in Nairobi, from 2.7 to 2.3 USD/kg. In Dar es Salaam, the measures range from 0.05-0.13 USD/kg firewood, 0.3-0.4 USD/kg charcoal, and 1.0-1.2 USD/kg LPG. Controlling for stacking measures slightly increases WTP for firewood and LPG. In the pooled analysis, despite the substantial difference in the fuel mix relative to that in the Nairobi sample, WTP for 1 MJ of cooking fuel in Dar es Salaam is similar to that in Nairobi, at 0.1 USD.

Table 2. Willingness to pay estimates (in USD) for cooking fuels in Nairobi and Dar es Salaam

	Nairobi				Dar es Salaam			
	Charcoal (per kg)	Kerosene (per L)	LPG (per kg)	Pooled (per MJ useful energy)	Firewood	Charcoal	LPG	Pooled (per MJ useful energy)
Market price	0.14	0.89	1.38		0.09	0.21	0.66	
Turnbull lower bound	0.14	1.08	2.60		0.09	0.32	1.01	
Kristrom mid-point estimates	0.20	1.41	2.90		0.13	0.40	1.21	
Double bound								
With household covariates (no stacking variables)	0.20	1.10	2.67	0.07	0.05	0.43	1.20	0.06
Binary stacking (with household covariates)	0.20	1.10	2.67	0.07	0.05	0.42	1.22	0.06
Continuous stacking (with household covariates)	0.20	1.18	2.28	0.07	0.13	0.41	1.10	0.06
Observations	40	102	192	334	22	583	321	926

These estimates provide valuable insight on the nature of demand for cooking fuels in these two cities. First, in both cities, the WTP for users' primary fuels is somewhat higher than currently observed prices. For LPG, WTP is much higher (by roughly over 65%) than current prices, reflecting a strong preference among users of this clean fuel for the benefits that it provides. This may indicate that the LPG subsidies that have recently gained traction in both Kenya and Tanzania may not be necessary over the long-term, since households that have made the switch to this fuel appear to appreciate the benefits it provides. Instead, policy may need to focus on better targeting of incentives and other approaches to foster uptake and increase access among households who persist in their use of polluting alternatives.

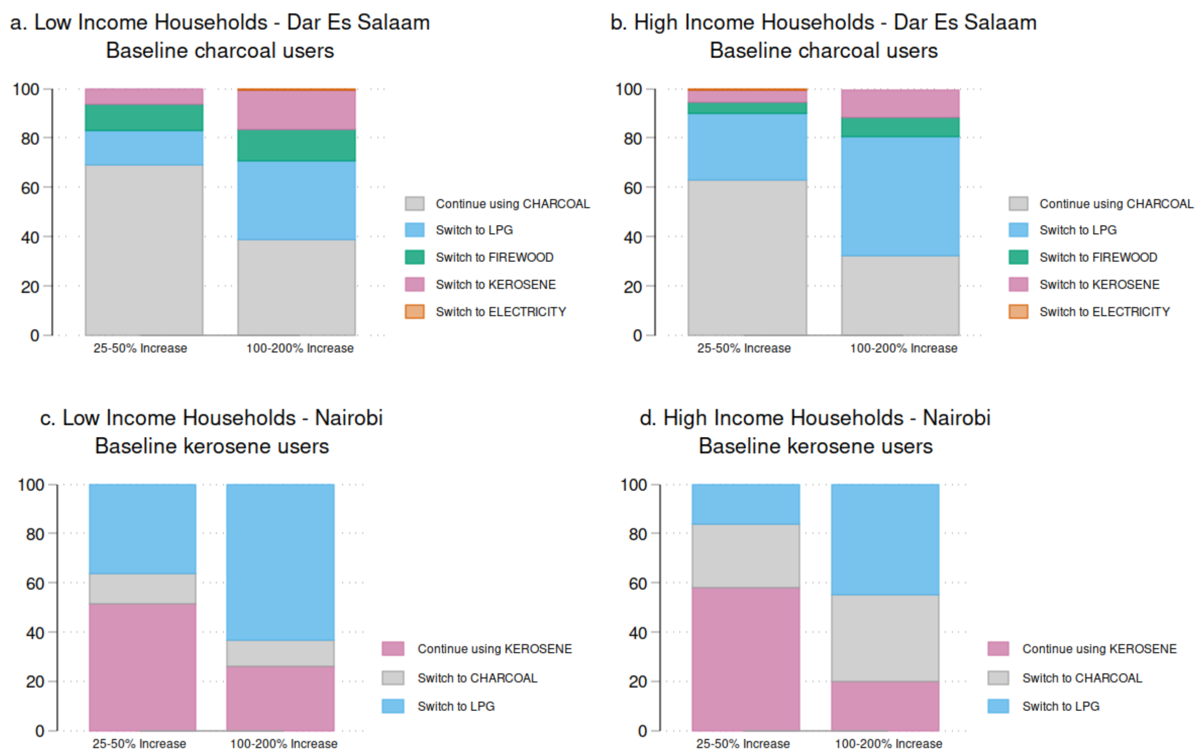
Second, WTP for LPG in Nairobi is roughly double that in Dar es Salaam, despite the low-income Nairobi sample only being slightly richer on average than the representative sample that was drawn in Dar es Salaam. Third, WTP for charcoal among primary charcoal users is substantially lower and different in Nairobi (where it is less than 1.5 times the prevailing market price) and Dar es Salaam (where it is twice the prevailing market price). Thus, households clearly have higher demand for charcoal in Dar es Salaam, which may be related to the less vigorous clean cooking policy agenda there relative to that in Nairobi. From a clean cooking transition perspective, it is important to know how much relative charcoal prices would need to change to induce more substantial switching towards clean fuels.

Distributional aspects of price change policies

It is critical to also understand the distributional impacts that fuel pricing policies might have across the income distribution. Low-income households are likely to respond differently to price increases than high-income households, especially when the switching costs are high. There is also a risk that price increases on some fuels could be regressive.

To explore such aspects, we restrict the Dar es Salaam sample to households who cook mainly with charcoal, given that over 60% households (n=672) use charcoal as their primary cooking fuel. In Nairobi, we restrict the sample to households who cook mainly with kerosene, who constitute 30% of the sample (n=104). These two subsamples represent households that policy makers might target for transitioning to cleaner fuels. We then divide the income distribution into relatively low- and high-income households, based on whether households fall below or above the median of per capita monthly expenditures. Finally, we group the low price (25-50%) and high price increases (100-200%) together.

In Dar es Salaam, high-income charcoal users are more likely than low-income charcoal users to switch up the energy ladder to LPG for any given price increase, especially when the price increase is large (Figure 2). Lower-income households are less likely to switch away from charcoal, but those switching more often move to kerosene and firewood. Thus, large charcoal price increases in Dar es Salaam at this time could be regressive, in the sense that low-income households either maintain the use of charcoal, or switch down the energy ladder. In Nairobi, in contrast, where policies are more supportive of clean options, low-income households appear more likely to switch to LPG than high-income households. High-income kerosene-using households are instead more likely to switch to charcoal, suggesting that these households' current preference for polluting fuel may reflect a resistance to using LPG that should be further explored.



Note: This figure restricts the samples to households who mainly cook with charcoal in Dar es Salaam, and households who mainly cook with kerosene in Nairobi, as these are the most commonly used primary cooking fuels in our study sample. These respondents are divided into relatively low-income and relatively high-income households, based on whether they fall below or above the median of per capita monthly expenditure in the sample. The hypothetical price increases are then categorized into low increases (25-50%) and high price increases (100-200%). The figures present stated responses to the question of whether households continue to use their primary fuel, or switch to another fuel. The figures are based on responses of 672 households in the Dar es Salaam sample of charcoal users and 104 households cooking mainly with kerosene in Nairobi.

Figure 2. Stated responses to hypothetical price increases for low- and high-income households in Dar es Salaam and Nairobi

Similar results are obtained from regression analyses (Table S4). In the Dar es Salaam sample, higher expenditure households are more likely to switch fuels, while the income elasticity of fuel switching is much lower in the Nairobi sample. The Nairobi results may be driven by vertical differentiation in the quality of kerosene stoves (between wick and kerosene stoves); in Dar es Salaam, charcoal stoves are comparatively homogenous. Thus, low-income kerosene users in Nairobi may switch up the energy ladder because the low utility of using a low-quality kerosene stove constitutes an additional cost for the poor. Alternatively, these results may be driven by differences in the market for alternative fuels like LPG and charcoal in these two contexts, as influenced by historical and existing policy actions.

Conclusion

Over the last decade, there have been rapid changes in cooking fuel use in Dar es Salaam and Nairobi, with LPG emerging as a key competitor to charcoal and kerosene. However, much of this transition has been driven by high-income households who can afford the higher upfront and running costs of LPG. Given the challenge of financing clean fuel subsidies, a critical question that policy makers face is whether and to what extent taxes, fees, charges, and other policies should be used to reduce demand for polluting fuels and encourage fuel switching. The effectiveness and viability of each of these depends on the elasticities of demand for different fuels, which we estimated in this paper, as well as targeting and policy enforcement aspects.

Our findings show that fuel switching patterns in response to price changes vary across the income distribution and depending on the specific context, i.e., across these two East African cities. In both locations, the price elasticity of demand for cooking energy overall is similar, and LPG demand appears to be somewhat less price elastic than charcoal demand. WTP for LPG among respondents cooking primarily with that fuel is also significantly higher than prevailing market prices. In relative terms, however, the ratio of the market price to WTP is low for LPG compared to charcoal and kerosene in Nairobi, while it is only low for LPG compared to firewood (and not compared to charcoal) in Dar es Salaam. In the latter city, low-income charcoal users thus appear more entrenched in their choice of cooking fuel and less likely to switch to cleaner LPG. Important for interpreting these findings is the fact that the WTP estimates apply specifically to the subsamples using particular primary fuels, rather than the overall sample in each city.

The extent to which different policy tools can be effective also depends crucially on the readiness of the supply side to meet increased demand. Non-price instruments such as bans on charcoal that effectively increase the price of charcoal in low enforcement contexts, or taxes, may be successful in urban areas where a market for alternative fuels exists, but can be regressive when households have limited access to affordable clean fuel alternatives, and may also induce back-sliding to even dirtier fuels. LPG subsidies, while critical for fostering uptake, can also be regressive unless they are well targeted to reach the poor. As such, other complementary mechanisms are essential, such as supporting access to clean fuels by reducing upfront stove and canister investments, aiding the private sector in developing efficient supply networks for fuel refills, and shifting preferences away from polluting fuels with information and behavior change efforts.

Materials and Methods

Sampling strategy

We draw on data collected in mid-2019 in Nairobi, Kenya and early-2020 in Dar es Salaam; all data was gathered before the COVID-19 pandemic began in these countries. In Nairobi, the sample comprises 354 households living in four informal settlements, with sampling in each area following a probability proportional to size (PPS) sampling methodology (Figure S3, Panel A). In each informal settlement, households were randomly selected using a field-based counting method to fulfil the study sample requirement. In Dar es Salaam, the fieldwork was conducted in January and February 2020, and a total of 1,100 households were interviewed (Figure S3, Panel B). A similar multi-stage stratified random sampling design was applied for selection of final wards, streets and households, also using a PPS sampling methodology. The key difference in the two surveys is that in Dar es Salaam, the sampling strategy aimed for a representative sample of fuel use in the city. This is reflected in comparisons between the Dar es Salaam data and other household surveys such as the Household Budget Survey and National Panel survey for the Dar es Salaam Region. On the other hand, the Nairobi sample was explicitly designed to cover lower-income households in informal settlements. These somewhat different approaches were used owing to the much lower use of solid fuels in Nairobi as a whole, and to meet our goal of obtaining a distribution of users of different fuels in each setting.

Informed consent

The Campus Institutional Review Board (IRB) at Duke University reviewed and approved the research protocol for the Nairobi survey (Campus IRB Protocol Number: 2019-0330). Research permits were obtained from the University of Dar es Salaam (UDSM) and study district officials for the Dar es Salaam survey (UDSM Reference Number: AB3/12(B)). In both Nairobi and Dar es Salaam, we obtained oral informed consent from the household head and the primary cook in our sampled households, prior to administering the questionnaire. Oral consent was deemed acceptable because the research took place in settings where requesting people to sign a document can cause distress and mistrust. Field officers read out the consent script to the respondents, and their response to the consent question was recorded in the survey form.

Survey

The survey instruments in Nairobi and Dar es Salaam were similar, save for minor adjustments to ensure suitability to the local context. Surveys were completed using tablet-based, in-person enumeration. Surveyors collected comprehensive data on household demographics, cooking practices and fuel preferences, household consumption and wealth and access to credit. To assess households' WTP for cooking fuels (namely, firewood, charcoal, kerosene and LPG), the surveys included a double-bounded, dichotomous choice design. In each location, the enumerator training and pilot testing of the survey, including the contingent valuation (CV) experiment, informed the final questionnaire. Testing of the CV experiment was especially important given the dearth of prior work in resource-constrained settings that aimed to value cooking fuels. In addition to helping frame the CV scenario, pilot testing helped determine the percentage price increases that would be most relevant to selected wards in Nairobi and Dar es Salaam.

In the CV experiment, enumerators first described how different cooking fuels affect households in a multitude of ways. They then asked respondents if they would consider switching their primary cooking fuel should there be an increase in its price. In both settings, respondents received randomized initial bids for cooking fuel price increases (in percentage terms) from a set of four different prices increases (25%, 50%, 100% and 200%). Table S2 shows the randomized price increases offered to households in both locations. If respondents responded positively to the initial bid, they received a follow up question with a payment option that was double the initial bid; if respondents replied in the negative to the initial bid, they received a follow up question of a payment option that was half the initial bid. In addition, respondents who declined to switch their main cooking fuels were asked whether, and to what extent, they would reduce their cooking in response to the price increase. This design allows us to assess both intensive and extensive margin responses to hypothetical fuel price changes.

Relationship between cooking fuel preferences and price

We examine households' propensity to maintain their primary fuel use in the face of the randomly-assigned price increases. In the basic analysis, we examine the role of price alone (Model 1); more sophisticated regression analysis then controls for fuel stacking behavior and a range of household characteristics (Models 2 and 3). Fuel stacking behavior is operationalized as both binary and continuous (proportion energy use) variables. (In SI Appendix, Section S3, we describe the construction of these variables and also examine the determinants of cooking fuel stacking among surveyed households in Nairobi and Dar es Salaam). In determining the relationship between cooking fuel preference and stacking, WTP is a binary variable that indicates whether the respondent agreed to the first price increase randomly offered. Using a probit specification, we estimate a household's demand for cooking fuel, wherein the functional form assumes that:

$$P\left(E_i = 1 \,\middle|\, P, S, Z\right) = \Phi\left(\beta_1 S + \beta_2 Z + \gamma P\right) \qquad (1)$$

where Φ is the cumulative distribution function of the standard normal distribution.

In Equation 1, the outcome variable is the binary answer of whether (1) or not (0) the household is willing to pay the first randomly allocated price increase, P is the price variable of the randomized increase (categorical), S is the fuel stacking variable (run separately for binary and the continuous variables), and Z is the vector of all other variables included in the model.

The Z variables included in the regressions are: household size, dependency ratio (defined as the ratio of the younger (ages 14 and under) and older (ages 65 and above) population in the household to the working age population (between 15-64 years) in the household), the age of the household head (in years), the education level of the household head (categorical), an indicator for whether the household head is female, the log of monthly per capita total expenditures (in USD), whether the household has saved money anywhere in the past year, whether the household has an electricity connection, and weekly time taken (in minutes) to acquire various cooking fuels (firewood, charcoal, kerosene, LPG).

We also analyze whether households that said they would continue with the same primary fuel use, would change their amount of cooking given the price increase. For this analysis, we run a conditional regression on those that responded positively to the initial bid (in other words, they would continue using their primary fuel even if its unit price increased), wherein the outcome variable is the percentage of normal cooking that would be reduced, and the explanatory variables are the same right-hand side variables as in Equation 1.

Estimating WTP for cooking energy

We adopt a double-bounded, dichotomous choice CV experiment to elicit respondents' willingness to maintain both primary reliance on their main cooking fuel (namely, charcoal, kerosene and LPG in Nairobi, and charcoal, LPG and firewood in Dar es Salaam) (4, 26). We examine the sensitivity of that main fuel use to price increases that were randomly assigned to survey respondents. We estimate average WTP in the sample of primary users of each fuel, both in terms of units purchased, and their useful energy content.

Taking into account the double-bounded design of the CV experiment, we use a maximum likelihood estimator that includes both the initial and second bids to estimate the WTP for each cooking fuel –

charcoal, kerosene and LPG in Nairobi, and firewood, charcoal and LPG in Dar es Salaam. The user-generated STATA command 'doubleb' is used for this calculation (27). The independent variables controlled for are the same as those used in Equation 1. For comparison, we also derive non-parametric WTP estimates, namely the conservative Turnbull lower-bound estimates of WTP and the Kristrom mid-point estimates (28, 29). These alternative estimates only leverage the data on response to the first experimentally assigned price increase, which maximizes the incentive compatibility of the CV design, and do not control for household-specific factors that might influence demand (30).

We also pool responses across the three cooking fuel categories in each city to examine the links between household characteristics and cooking fuel valuation, in addition to eliciting WTP for cooking fuels. We use a similar probit regression approach as in Equation 1 to estimate this association, where the left-hand side variable is the probability that a household responds positively to the CV questionnaire. We normalize across fuels in the pooled models to account for the different useful energy content of each. Specifically, prices were pooled and normalized by dividing by calorific value for each fuel (MJ/kg) and again by fuel efficiency (%); the final unit is in KES/MJ in Nairobi and TZS/MJ in Dar es Salaam, which have further been converted into USD/MJ.

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References

1. IEA, IRENA, UNSD, World Bank, WHO. Tracking SDG7: The Energy Progress Report. Washington DC: World Bank; 2022.

2. Coelho ST, Sanches-Pereira A, Tudeschini LG, Goldemberg J. The energy transition history of fuelwood replacement for liquefied petroleum gas in Brazilian households from 1920 to 2016. Energy Policy. 2018;123:41-52.

3. Katoto PD, Byamungu L, Brand AS, Mokaya J, Strijdom H, Goswami N, et al. Ambient air pollution and health in Sub-Saharan Africa: Current evidence, perspectives and a call to action. Environmental research. 2019;173:174-88.

4. Hanemann M, Loomis J, Kanninen B. Statistical efficiency of double-bounded dichotomous choice contingent valuation. American journal of agricultural economics. 1991;73(4):1255-63.

5. Beyene AD, Koch SF. Clean fuel-saving technology adoption in urban Ethiopia. Energy economics. 2013;36:605-13.

6. Choumert-Nkolo J, Motel PC, Le Roux L. Stacking up the ladder: A panel data analysis of Tanzanian household energy choices. World Development. 2019;115:222-35.

7. Gebreegziabher Z, Mekonnen A, Kassie M, Köhlin G. Urban energy transition and technology adoption: The case of Tigrai, northern Ethiopia. Energy Economics. 2012;34(2):410-8.

8. Puzzolo E, Pope D, Stanistreet D, Rehfuess EA, Bruce NG. Clean fuels for resource-poor settings: A systematic review of barriers and enablers to adoption and sustained use. Environmental research. 2016;146:218-34.

9. Alem Y, Beyene AD, Köhlin G, Mekonnen A. Modeling household cooking fuel choice: A panel multinomial logit approach. Energy Economics. 2016;59:129-37.

10. Barnes DF, Krutilla K, Hyde WF. The urban household energy transition: social and environmental impacts in the developing world: Routledge; 2010.

11. Gupta G, Köhlin G. Preferences for domestic fuel: analysis with socio-economic factors and rankings in Kolkata, India. Ecological Economics. 2006;57(1):107-21.

12. Arthur M, Bond CA, Willson B. Estimation of elasticities for domestic energy demand in Mozambique. Energy Economics. 2012;34(2):398-409.

13. Kenya National Bureau of Statistics. Gross County Product (GCP) 2021 Report. Available at: https://www.knbs.or.ke/download/gross-county-product-gcp-2021/. Nairobi: Kenya National Bureau of Statistics; 2021.

14. Tanzania National Bureau of Statistics. National Accounts Statistics of Tanzania Mainland 2013 – 2019. Available at: https://www.nbs.go.tz/index.php/en/census-surveys/national-accounts-statistics/na-publications/577-national-accounts-statistics-of-tanzania-mainland-2013-2019. Dar es Salaam: Tanzania National Bureau of Statistics; 2019.

15. Program ESMA. Cooking with Electricity: A Cost Perspective: World Bank; 2020.

16. Van den Berg IC. Kenya's Strategy to Make Liquefied Petroleum Gas the Nation's Primary Cooking Fuel. Washington, DC: World Bank; 2018.

17. Mutua JM. Essays on Distributional Consequencies of Fuel Taxation in Kenya: University of Nairobi; 2012.

18. Jeuland M, Das I, Plutshack V, EED Advisory. Value-Added Tax on Cleaner Cooking Solutions in Kenya. [Accessed on June 3, 2022] Available at: https://cleancooking.org/binary-data/RESOURCE/file/000/000/631-1.pdf. Washington, DC: Clean Cooking Alliance; 2021.

19. National Oil Corporation of Kenya. Gas Yetu-The Mwananchi Gas Project. 2022. [Accessed on June 3, 2022]. Available at: https://nationaloil.co.ke/gas-yetu-the-mwananchi-gas/. 2022.

20. Government of Kenya. Moratorium and Charcoal Ban Gazette Notice of 2018. Available at: http://www.environment.go.ke/wp-content/uploads/2018/11/4048264.pdf. 2018.

21. Wekesa C, Mutta D, Larwanou M, Kowero G, Roos A. Effects of charcoal ban on value chains and livelihoods in Kenyan coast–Stakeholders' perceptions. Environmental Development. 2023;45:100809.

22. Bailis R, Ghosh E, O'Connor M, Kwamboka E, Ran Y, Lambe F. Enhancing clean cooking options in peri-urban Kenya: a pilot study of advanced gasifier stove adoption. Environmental Research Letters. 2020;15(8):084017.

23. Government of United Republic of Tanzania. National Energy Policy 2015 [Accessed on June 3, 2022]. Available at: https://www.nishati.go.tz/uploads/documents/en-1622283004-National%20Energy%20Policy%20(NEP),%202015.pdf. 2015.

24. Gill-Wiehl A, Sievers S, Kammen DM. The value of community technology workers for LPG use: A pilot in Shirati, Tanzania. Energy, Sustainability and Society. 2022;12(1):1-16.

25. Doggart N, Ruhinduka R, Meshack CK, Ishengoma RC, Morgan-Brown T, Abdallah JM, et al. The influence of energy policy on charcoal consumption in urban households in Tanzania. Energy for Sustainable Development. 2020;57:200-13.

26. Arrow K, Solow R, Portney PR, Leamer EE, Radner R, Schuman H. Report of the NOAA panel on contingent valuation. Federal register. 1993;58(10):4601-14.

27. Lopez-Feldman A. doubleb: Stata module to estimate contingent valuation using Double-Bounded Dichotomous Choice Model. 2010.

28. Vaughan WJ, Rodriguez DJ. Obtaining welfare bounds in discrete-response valuation studies: comment. Land Economics. 2001;77(3):457-65.

29. Haab TC, McConnell KE. Valuing environmental and natural resources: the econometrics of non-market valuation: Edward Elgar Publishing; 2002.

30. Johnston RJ, Boyle KJ, Adamowicz W, Bennett J, Brouwer R, Cameron TA, et al. Contemporary guidance for stated preference studies. Journal of the Association of Environmental and Resource Economists. 2017;4(2):319-405.

Figure Captions

Figure 1. Demand graph for cooking fuels in Nairobi and Dar es Salaam (initial bids only)

Figure 2. Stated responses to hypothetical price increases for low- and high-income households in Dar es Salaam and Nairobi