Costs of cooking with different fuels: a case study from mini-grids in Tanzania

Working paper for comment

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Executive Summary

There is a common misconception that electricity in many countries is too expensive for cooking, both at national grid tariffs and, in particular, at mini-grid tariffs that are generally significantly higher than national tariffs. Cost effectiveness of cooking with electricity has been discussed in some detail in ESMAP (2020), but the relative costs of various fuels is quite specific to the context. In this paper we take one of the most challenging contexts for electric cooking, i.e. mini-grids in Tanzania. We find using evidence from household data that even in this case and with a high tariff of $1/kWh, using an energy efficient electrical appliance is the cheapest option for some foods.

The paper explores the cost of cooking with different fuels found in communities served by mini-grids in Tanzania in 2021. The paper builds on work previously undertaken on an electric pressure cooker (EPC) pilot programme convened by the Access to Energy Institute (A2EI). The paper addresses three questions:

- What are the relative costs of cooking with different fuels?
- What mini-grid tariff would enable electric cooking to be cost competitive with traditional fuels?
- How do relative fuel costs (electricity and charcoal) affect adoption of electric cooking?

The analysis is based on fuel and energy data from a Cooking Diaries study, which is combined with fuel cost and price data from two separate surveys conducted at the beginning of the study, and five months into the study.

The cost of cooking is largely dependent on the price paid for fuels. The paper shows that households buying charcoal in small amounts can pay up to twice the price paid by those buying in bulk. The cost of cooking has, therefore, been based not only on the individual cooking practices of each household (the amount of energy used will vary according to individual cooking styles), but also on the specific prices paid by each household. The original mini-grid tariff was 1.00 USD/kWh, but during the project, a change in regulation required tariffs to be in line with national grid prices, which were 0.04 USD/kWh, so both tariffs have been used in the analysis.

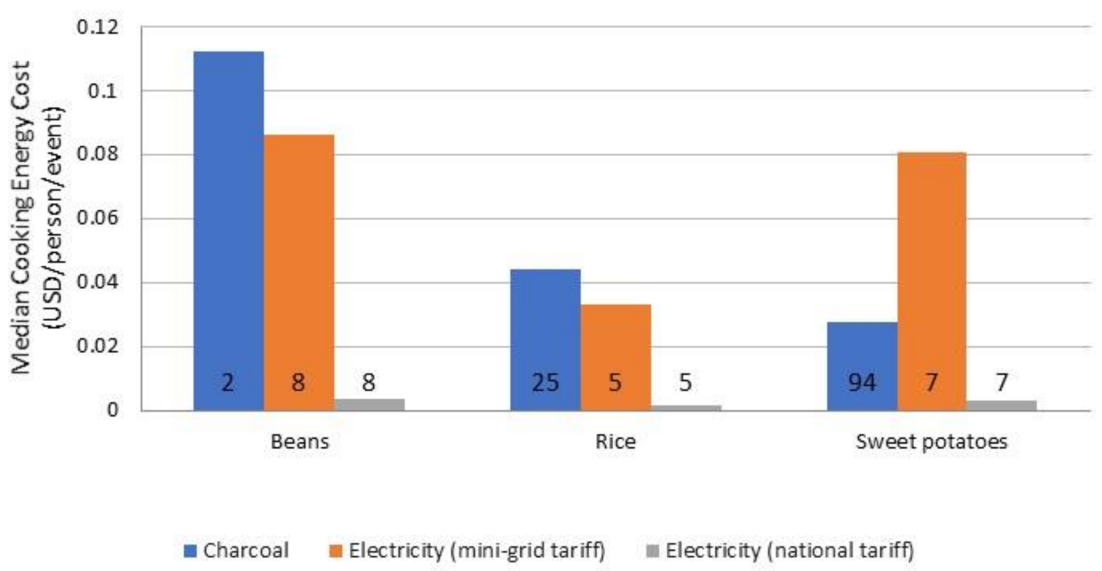

Figure 1 Median cost of cooking specific dishes using charcoal and electricity (at the two rates). Number of records given at the bottom of the bar.

At the national tariff, the cost of cooking with an EPC is cheaper than using any of the traditional fuels commonly used in these communities. Even at the higher, mini-grid tariff, it was cheaper to cook some foods using electricity rather than charcoal (see Figure 1). This is a result of the high efficiency of the EPC, which means that for certain foods like beans and rice, charcoal uses 40 times the amount the 'electrical' energy used. This energy ratio is smaller for other foods so overall, **cooking with charcoal requires approximately 20 times the electrical energy used**.

The price of electricity that would achieve parity with the cost of cooking with charcoal is different for each household. The electricity parity price depends on the charcoal measure that the household purchases. This means that the parity price for poorer households that typically buy in smaller amounts will be higher. Customers may also be willing to pay a premium for other benefits of electric cooking such as convenience, cleanliness etc.

The cost ratio is the cost of cooking with electricity at the mini-grid tariff divided by the cost of cooking using charcoal (C_{elec}/C_{char}). A high cost ratio suggests cooking using electricity is more expensive than charcoal. There is a weak link between the cost ratio and the adoption of EPC use (represented by the percentage of cooking events in which an EPC was used), such that adoption is weaker among households where the cost ratio is higher, i.e. ($C_{elec}/C_{char}>1$). A few households that used the EPC mostly to cook beans and rice showed a cost ratio less than one. This illustrates how some households had quickly assessed cooking costs and adjusted their cooking practices to make best use of the EPC.

The key conclusions from the paper are, for this location with its specific context and costs:

- At the national tariff, cooking with an EPC would be cheaper than using traditional fuels;
- At the mini-grid tariff, it can still be cost effective to cook certain foods with an EPC;
- In the future if the concern is to set a viable tariff as a balance point between fairness and cost effectiveness to the consumer, and cost recovery to the mini-grid operator, then at a tariff of $0.6/kWh cooking with electricity would still be cost effective for half of households (assuming charcoal prices remained the same[1]).
- Households have varying capacities to assess the cost effectiveness of cooking with different devices as evidenced by a weak link between the cost ratio of electricity to charcoal and the adoption of EPC use.

[1] Which is unlikely as deforestation is pushing prices up.

Contents

Acknowledgements

Many thanks to Anna Clements and Simon Batchelor for reviewing the original manuscript.

1 Introduction

There is a common misconception that electricity is too expensive for cooking, and it is certainly thought to be more expensive than biomass fuels (Bawakyillenuo et al., 2021; Leary et al., 2021). There is, therefore, a need for clear data and evidence regarding the cost comparison of cooking with alternative fuels in real life settings. In particular, the cost of electric cooking as it compares with other fuels in specific contexts is a key factor for unlocking a transition to electric cooking in low-income countries.

These perceptions of high costs are, understandably, exacerbated in mini-grid contexts where tariffs are significantly more expensive than national grid tariffs. This paper presents an analysis of the cost of cooking with different fuels found in communities served by mini-grids in Tanzania.

The work builds on the analysis of data collected in two communities in Tanzania (Bezi and Mavota) under an electric pressure cooker pilot programme convened by the Access to Energy Institute (A2EI, 2020). The analysis in this paper is based on data generated by the Modern Energy Cooking Services (MECS) program (Gamos and Strathclyde University). The data consist of records from two phases. In phase 1, data were collected on unchanged cooking habits and in phase 2, the households were given an EPC and trained how to use it. Data was successfully generated from a total of 28 households (15 in Bezi and 14 in Mavota).

The first objective of this paper is to compare the cost of cooking with different fuels at market prices. This provides users and policy makers with an understanding of the nuances of relative cooking costs. The second objective is to investigate what mini-grid tariff would enable electric cooking to be cost competitive with traditional fuels, based on the costs that mini-grid customers were paying for biomass fuels. This may be informative for policy makers and mini-grid companies alike to know where to set electricity tariffs. The third and final objective is to explore the extent to which relative fuel costs (electricity compared with charcoal) impact on adoption of electric cooking.

2 Methodology

This paper is an extension of previous work on the adoption of EPCs and the impact on cooking practices and energy consumptions. The key reference used is an analysis of dishes cooked and specific energy consumptions, gathered over both Phase 1 and Phase 2 of a cooking diaries study (Jones et al., 2021). An overview of the A2EI pilot study and a description of the methodology for the cooking diaries study is described in further detail in (Kweka et al., 2021).

The energy used in an event must be divided by the number of people served to be able to compare energy use between households of varying size. The values for energy consumption are, therefore, generally expressed in MJ/person/event. An event was a record produced by a participant when energy was used for heating; either for a meal or another purpose such as heating water for bathing. The participant was asked to weigh their fuel and/or read their electricity meter before and after the event. Each event could have multiple purposes (such as cooking both breakfast and lunch) but the majority were single purpose events only. A single purpose (such as cooking dinner) could contain multiple dishes (and water heating). A dish (such as rice) is a component of a meal and was recorded by the participant. Where multiple fuels were used in a heating event, it is not always clear how much fuel (and energy) was used to cook individual dishes. Therefore, most of the figures are based on heating events that used only a single fuel. Analysis that looks at unspecified dishes pertains to all single fuel heating events across both phases, irrespective of dish cooked. A more detailed approach considers the energy used to cook specified dishes.

The cooking diaries study gathered detailed data on fuel consumptions, but the day-to-day data did not include any information on costs. However, participants were given two opportunities to report fuel cost data:

- Registration survey. At the beginning of the study, a brief household survey was conducted to gather background information on demographics, cooking appliances, as well as fuel procurement and costs.
- Indicative diaries study. The Strathclyde University team had previously developed a rapid survey tool under a separate project (Coley et al., 2020). The tool was developed to gather information on demographics, cooking practices, use of cooking devices, food storage, dishes cooked, as well as fuel procurement and costs. The tool was used for a survey in the A2EI pilot sites, which was conducted 5 months into the study (i.e., 3 months into Phase 2).

Given that both surveys relied on participant recall for costs, quantities and frequency of fuels purchased, a good deal of inconsistency between the two data sources was to be expected. This analysis draws on both datasets with the aim of estimating fuel prices that can be used for the subsequent cost comparison analysis.

To estimate the market prices of charcoal, firewood and kerosene, the participant data on the quantity of fuel bought and cost of that quantity was used. For each quantity of fuel stated, a weight was estimated (in kg). Calorific values for each fuel (MJ/kg) (Jones et al., 2021) were then used to convert estimated weight to estimated energy. Dividing the cost of the quantity bought by this estimated energy gives the price (in USD/MJ).

The price of electricity is based on two tariff rates; a min-grid tariff (1 USD/kWh, 0.2778 USD/MJ) and a 'national' tariff (0.04 USD/kWh, 0.0111 USD/MJ). The mini-grid tariff reflects the tariff agreed between the mini-grid developer and customers that was prevailing at the start of the trial. However, during the trial, the Tanzanian energy regulator introduced a policy to reduce mini-grid prices to the same rate as the national grid price; the mini-grid changed its pricing policies to reflect the national tariff price.

To obtain cost of cooking figures (in USD), the energy consumptions (in MJ) given in (Jones et al., 2021) are multiplied by the price of the respective fuel (in USD/MJ). Prices are converted to USD at the conversion rate of 2,300 TZS/USD prevailing in April 2020.[2]

3 Fuel Prices

3.1 Firewood Price

The Registration survey generated data from 7 participants, whereas the Indicative diaries study generated data from 12 participants. Four participants were common to both datasets. Most participants reported wood consumption in terms of bundles. A precise definition of this unit was beyond the scope of the study. Some participants qualified the bundle as varying from 6 to 10 pieces of wood. Others reported purchasing 2 to 6 "pieces" of wood. What is the volume of a piece of wood in this context?

For example, a box of firewood marketed in Tanzania on the internet weights 35 lb (16 kg)[3]. This is estimated to contain approximately 1.0 cu.ft wood (0.028 m^3) in 6 pieces approximately 0.5 m in length. This equates to a wood density of 570 kg/m^3, which is not unreasonable. For example, tree species with a density of 500 kg/m^3 or higher are considered to be well suited as fuel (Petro et al., 2015). On this basis, one piece of wood can be estimated to weigh 2.7 kg.

[2] From Google, accessed on 2 September 2021.

[3] https://tanzania.desertcart.com/products/353947326; Accessed on 2 September 2021.

Based on the estimated weight of a piece of wood (2.7 kg), the prices in Table 1 have been derived. Note that the number of pieces included in a 'bundle' has been estimated at four, as this gives a price per kg that is consistent with the other data points – see Figure 1.

Three respondents to the Indicative diaries survey reported wood purchased in 'logs', consistently priced at 1,000 TZS, but it has not been possible to estimate the mass of wood in a log.

Table 1 Wood costs and calculated prices (both datasets)

Measure	N	Pieces	Weight (est'd) (kg)	Cost (mean) (TZS)	Price (TZS/kg)
log	2	n/a	n/a	1000	n/a
2 pieces	1	2	5.4	1000	185
4 pieces	1	4	10.8	2000	185
6 pieces	2	6	16.2	2000	123
8 pieces	1	8	21.6	2000	93
10 pieces	1	10	27.0	5000	185
bundle	9	4 (est'd)	10.8	1278	118

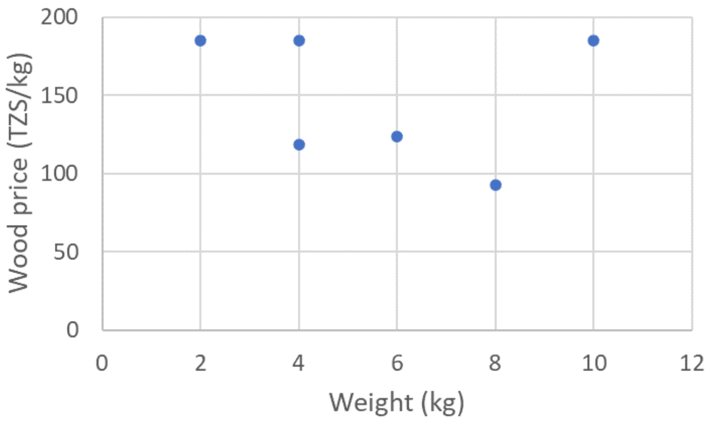

Figure 2 Wood prices at estimated weights of market measures

For the following analysis, a single estimated wood price of 150 TZS/kg was used.

3.2 Charcoal Prices

The Registration survey generated data from 33 participants, whereas the Indicative diaries study generated data from 41 participants. (N.B. not all respondents in the Registration survey went on to generate valid data for the Cooking Diaries study). Amounts reported in both surveys are based on a range of local units, or amounts in which charcoal is purchased; the most common are:

- gunia (sack)
- kincha (poorly filled sack)
- debe (tin)
- beseni (bowl)
- kopo 2 (large bundle)
- kopo 1 (small bundle)

Each of these measures appears to be flexible; for example, a tin (debe) can be large (e.g., cooking oil tin) or small, and this can be seen in the data where costs range from 7,000 to 1,000 TZS. For most measures, there is some consistency in costs, although there are outliers. Given that outliers clearly refer to a different measure of charcoal (e.g., an unusually low cost for a sack (gunia) may represent an unusually small sack), Table 2 presents cost figures for the majority of records. Note that mode figures closely match median values, indicating that median costs are also the most commonly reported costs, which gives confidence that the median values are likely to represent prices commonly found in markets.

Table 2 Charcoal costs for different measures (both datasets)

Measure	N	Median	Mode
gunia (sack)	15	45,000	45,000
kincha	9	5,000	4,000
debe	10	4,500	4,000
beseni	7	1,500	1,000
kopo 1	10	1,000	1,000
kopo 2	4	2,000	2,000

The estimates of weights for each measure presented in Table 3 have been based on weights found in the literature. Weights have been selected and estimated in order to provide a progressive discount in price with increased larger measures, as illustrated in Figure 3.

Table 3 Charcoal prices derived from estimated weights

	Cost (median) (TZS)	Est'd weight (kg)	Justification of estimate	Price (TZS/kg)
gunia	45,000	90	Some respondents indicates 60 kg sack, but large sack can be 90 kg (UNEP & African Union, 2019)	500
kincha	5,000	8	Authors' estimate	625
debe	4,500	7	(Preston, 2012) 5-gallon cooking oil tin.[4] (Perrett, 2020)	643
beseni	1,500	2	Authors' estimate	750
kopo 2	2,000	2.8	Kopo kubwa (van Beukering et al., 2007)	714
kopo 1	1,000	0.95	Kopo dogo (van Beukering et al., 2007)	1,053

[4] http://theses.gla.ac.uk/30783/1/1992LynchPhD%20.pdf

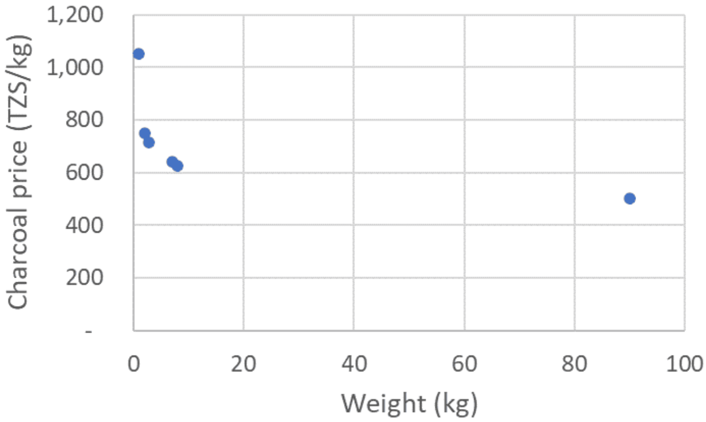

Figure 3 Charcoal prices at estimated weights of market measures

For the following analysis, the charcoal price used is based on the measure of charcoal most commonly used by each household and the prices in Table 3.

3.3 Kerosene Price

The Registration dataset contains no information on kerosene consumption.

There are four records in the Indicative diaries dataset, indicating a price of 2,500 TZS/litre, although there is evidence of a small discount when buying larger volumes (see Table 4).

Table 4 Reported kerosene prices

Measure	N	Mean (TZS)	Price (TZS/litre)
500 ml bottle	2	1250	2,500
1 litre bottle	2	2450	2,450

For the following analysis, a single estimated kerosene price of 2,500 TZS/litre was used.

3.4 Electricity Prices

At the start of the trial, the mini-grid operator, PowerGen, set the tariff at 1.00 USD/kWh (0.2778 USD/MJ). During the trial new regulation was introduced that stipulated mini-grid prices should not exceed that of national grid prices, which were 0.04 USD/kWh (0.0111 USD/MJ). PowerGen subsequently developed innovative charging structures to comply with the new regulation, and for the purposes of this comparison, the national tariff has been introduced at 0.04 USD/kWh.

3.5 Overview of Fuel Prices

Fuel prices have been combined with the calorific values to calculate the price of energy for each fuel (Table 5). Note that these figures do not reflect the costs of cooking with different fuels because the efficiency of cooking devices varies greatly. Note that the energy prices follow the traditional energy ladder structure (Masera et al., 2000), with lower prices for poorer quality fuels such as wood, and higher prices for premium fuels, notably electricity.

Table 5 Overview of Fuel prices.

Fuel Type	Calorific value (MJ/kg)[5]	Estimated price (TZS/unit)	Median price (USD/MJ)
Firewood	15.9	150 TZS/kg	0.0041
Charcoal	29.9	600 TZS/kg*	0.0087
Kerosene	34.9 (MJ/ltr)	2,500 TZS/ltr	0.0311
Electricity (mini-grid tariff)		2,300 TZS/kWh	0.2778
Electricity (national tariff)		90 TZS/kWh	0.0111

* Table 3 presents different prices depending on the measure of charcoal bought; 600 TZS/kg has been selected as an estimate of the average price paid across all households.

4 Results

4.1 Cost of Cooking using Different Fuels

The cost of cooking a meal (comprising any dish and any number of dishes) was calculated by taking the median energy consumption when cooking with each fuel (Jones et al., 2021) and multiplying by the median price for that fuel (Table 5).

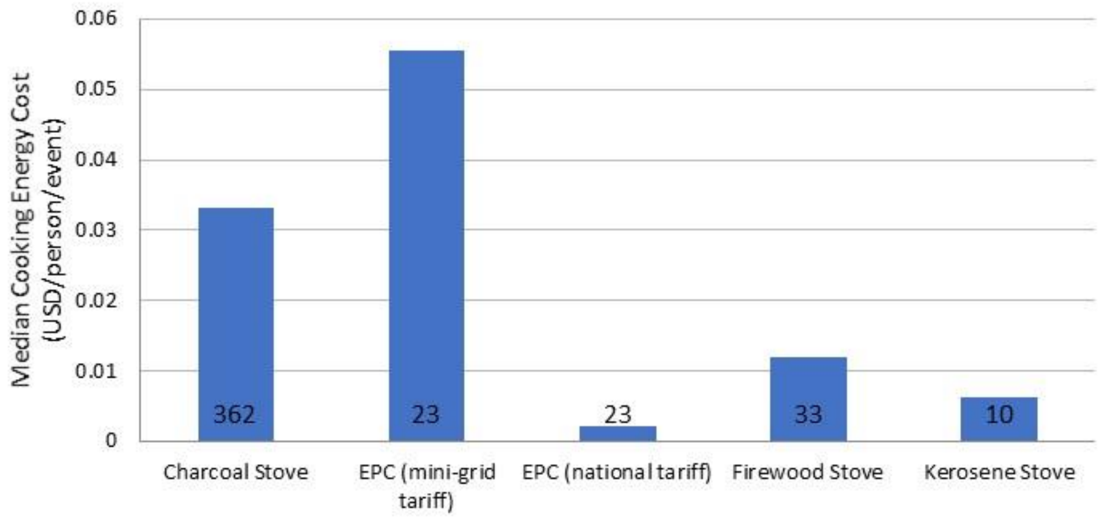

Figure 4 Median cost of cooking unspecified dishes using a single fuel (number of records are noted at the bottom of the bar).

Using electricity to cook with EPCs was more expensive than charcoal when users were charged at the mini-grid tariff. However, at the low tariff, cooking with EPCs becomes far cheaper than charcoal, and cheaper also than cooking with firewood and kerosene.

However, it should be noted that the menu cooked using EPCs is not the same as the menu cooked on charcoal stoves. In phase 2 the EPC was used more for certain dishes (such as beans, rice, and sweet potatoes) and charcoal (or other biomass fuels) was preferred for other dishes. This means the comparison of the cost of cooking is not truly descriptive of a scenario where charcoal is wholly replaced by electricity as the fuel for cooking. Charcoal was used in far more records than any other fuel, which reflects the popularity of charcoal as a cooking fuel. This is in part because the data used here are for single fuel events only. That is cooking events where, for example, only an EPC was used to cook, i.e. no fuel stacking occurred. Uncertainty in firewood cost

[5] (Jones et al., 2021)

figures arises due to basing the price estimate on a small number of records, combined with a number of assumptions on bundle size and weight. In contrast, price estimates for charcoal are based on a large number of records, and the price of electricity is a known value for all users of the grid. Therefore, only these two fuels are carried forward for further analysis.

Using the data from Jones et al. (2021) on the energy required to cook specific dishes using different fuels, the cost of cooking beans, rice and sweet potatoes was calculated for charcoal and electricity using the median prices from Table 5 (see Figure 5). This represents the cost of cooking a single dish with a single fuel only.

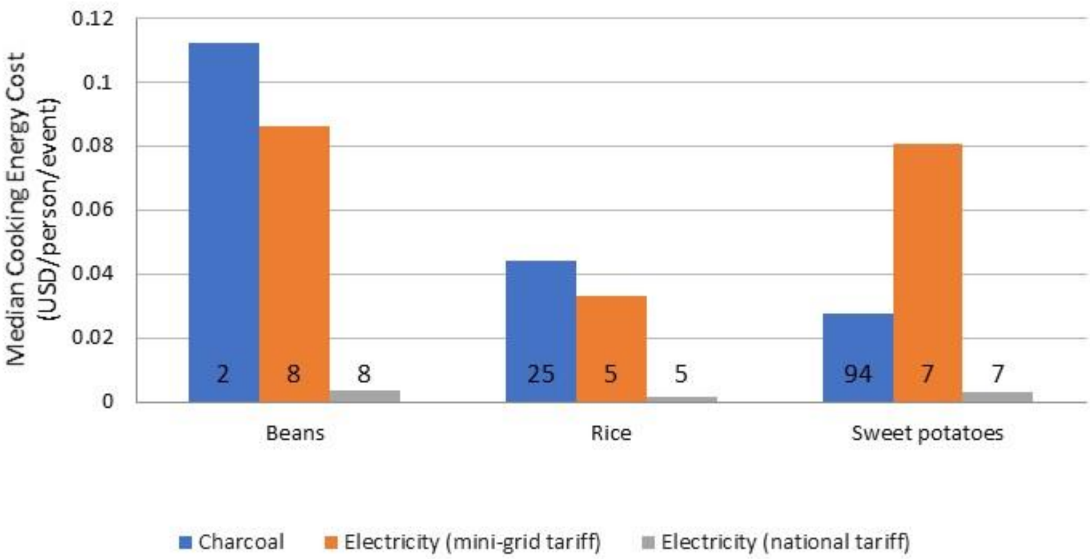

Figure 5 Median cost of cooking specific dishes using charcoal and electricity (at the two rates). Number of records given at the bottom of the bar.

Cooking beans and rice is cheaper using electricity rather than charcoal, even at the mini-grid tariff. When using a charcoal stove, beans are usually cooked along with another dish, such as ugali, in which case it is not possible to distinguish how much of the energy used is used to cook just the beans. This means that there is only a small number of records in which charcoal was used to cook beans alone, so there will be a degree of uncertainty associated with this figure. Median energy consumption figures used in Figure 5 **for cooking beans and rice (individually) indicate that charcoal requires around 40 times more energy than cooking with electricity in an EPC** (Jones et al., 2021). This energy ratio, thanks to the EPC's high efficiency, is high enough to result in cost savings for the user even when electricity is priced at the mini-grid tariff. Whereas, **to cook sweet potatoes, cooking with charcoal requires only 10 times the energy to cook with an EPC** (Jones et al., 2021) and this ratio is not high enough to counter the price difference between the fuels, so the cost is greater to cook electrically on the mini-grid tariff. **Note that if electricity is priced at the national tariff, all dishes would be substantially cheaper to cook using electricity.** This demonstrates that the relative cost of cooking with different fuels is dependent on the dish that is being cooked.

The amounts of energy required to heat water for hot beverages using different fuels (from Jones et al. (2021)) were also applied to the median fuel prices to obtain costs of water heating using different fuels (see Figure 6).

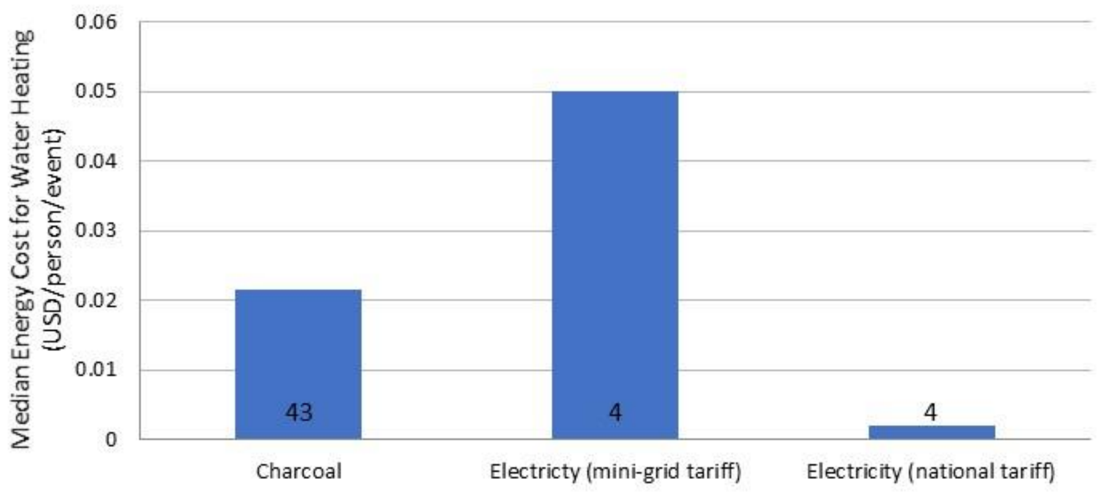

Figure 6 Median cost of water heating for charcoal and electricity (at both tariffs). Number of records are given at the bottom of the bar.

This demonstrates a similar trend. Heating water with electricity charged at the mini-grid tariff is more expensive than using charcoal. However, if charged at the national tariff, the cost would be significantly less than charcoal.

4.2 Parity prices

The price charged for electricity determines whether cooking with electricity is cheaper than biomass fuels. The parity price is the tariff at which the cost of cooking with electricity is equal to the cost of cooking with charcoal, and the following relationship holds true:

$$P_{elec}.E_{elec} = P_{char}.E_{char}$$

$$P_{elec} = P_{char} \times \frac{E_{char}}{E_{elec}}$$

Where:

- P_{elec}, P_{char}: The price of electricity and charcoal respectively (USD/MJ)
- E_{elec}, E_{char}: The median energy used per capita (MJ/person)

The price of electricity to achieve parity with charcoal is different for each household. It is influenced by a number of factors:

- Households pay different prices for the same fuel; a household that buys charcoal in a large amount will enjoy a lower cost per MJ of energy than one that buys small tins of charcoal.
- Cooking styles differ from household to household; one household may prefer to cook a dish for longer than another and thus require more energy to do so.
- Size of the household; economies of scale can make cooking some dishes for a large household less energy intensive than for a small household.

The electricity tariff that would achieve price parity with charcoal has been calculated for each household. For each household in the study:

- the price of charcoal was calculated based on the methodology described above;

- the median per capita charcoal energy used was obtained from events recorded in phase 1 in which only charcoal was used;
- the median per capita electrical energy used was obtained from all electric cooking events recorded in phase 2 in which only electricity was used (Two households were omitted because their electricity consumption rates were exceptionally low (less than 0.03 kWh/person)).

The electricity tariff that would achieve price parity with charcoal was then plotted against the price of charcoal, for each household - see Figure 7.

The median of these price parity results suggests that an electricity tariff of 0.64 USD/kWh (0.18 USD/MJ) would enable one half of users to cook with electricity at the same cost as they would incur with charcoal (notwithstanding differences in the foods cooked using electricity and charcoal in the pilot). For 9 of the 12 households represented in Figure 7 (75%), the calculated parity price is less than the mini-grid tariff (1 USD/kWh). Note that the figure indicates that cooking with electricity at the national tariff (0.011 USD/MJ) would be cheaper for almost all households.

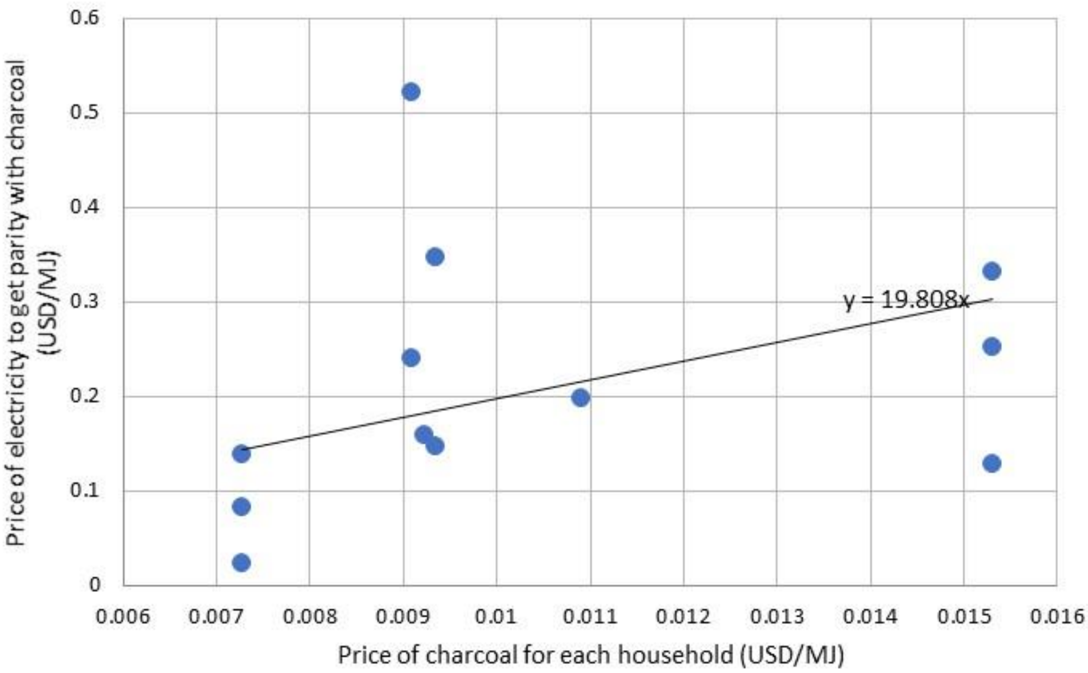

Figure 7 Price parity graph, a measure of what price of electricity would enable each household to cook with electricity at the same cost as charcoal (single fuels only).

Even though these parity prices are based on very small numbers of records in which electricity alone was used, the graph shows that, **as a rough rule of thumb, one can charge around 20 times the price of charcoal for electricity (on a per MJ basis) for the cost of cooking to be roughly the same.** This reflects the overall, or 'useful', efficiency of the cooking devices where an EPC uses roughly one 20th of the energy of charcoal to cook food (Jones et al., 2021). Note the households fall at discrete locations along the x axis, which is due to the method of determining charcoal prices based on the quantity bought. Households that pay the highest price for charcoal purchase the smallest quantities (tins) and the lower prices come from purchasing charcoal in larger quantities (bags). The households are distributed along the y axis due to different cooking styles leading to variations in the energy used.

The electricity parity price depends on the charcoal measure that the household purchases. This is summarised by looking at the median values of parity price for three measures used to purchase charcoal (see Table 3 for estimates of measures):

- Gunia median: 0.30 USD/kWh (0.08 USD/MJ)
- Combined kincha, debe, benseni and kopo 2 median: 0.79 USD/kWh (0.22 USD/MJ)
- Kopo 1 median: 0.91 USD/kWh (0.25 USD/MJ)

For those households who can afford a large sack (gunia) of charcoal, due to the lower cost per MJ, electricity would need to be charged at a lower rate to achieve parity. On the other hand, if a household only buys charcoal one tin at a time, electricity can still be cost competitive at higher tariff levels.

Price competitiveness is not the only factor involved in consumer decisions to transition from cooking with charcoal to electricity. Participants in electric cooking studies in Kenya and Cambodia have articulated a range of benefits of cooking with electricity including convenience, cooking faster, keeping the kitchen and clothes clean, easier to cook, health benefits and aspiring to a modern lifestyle (Leary et al., 2021; Leary & Fodio Todd, 2019). These reasons may justify a premium above the price of parity with charcoal.

4.3 Impact of Energy Cost on Adoption

To measure the effect of energy cost on the adoption of electric cooking, a cost ratio was produced for each participating household. This is the cost of cooking with electricity divided by the cost of cooking using charcoal. A high cost ratio suggests cooking using electricity is more expensive than charcoal and vice versa. The cost ratio takes into account the energy used by each household (and thus their cooking style) and the respective prices each household was paying (i.e., the quantity of charcoal each household buys). To calculate the charcoal cost, the median per capita energy consumption (among all heating events which used a single fuel only) for each household was used from Jones et al. (2021). Records from phase 1 were used as this gives an indication of the energy required to cook a full menu with charcoal. This was multiplied by each household's respective charcoal price to give cost, i.e. C_{char}

There is no suggestion that electricity was used by any household to cook the entire menu in Phase 2. Records in which a dish was cooked with electricity only would not be directly compatible with the Phase 1 charcoal records, because only a restricted number of dishes were cooked using electricity. Records in which a dish was cooked with electricity, including when used in conjunction with another fuel, would also not be compatible with Phase 1 charcoal records, because the electricity consumption does not reflect the entire energy needed to cook the dish. In the absence of data that is strictly compatible, Figure 8 has been prepared using electricity costs at mini-grid tariff of $1/kWh based on all records in Phase 2 in which electricity was used, including fuel stacking events. The median per capita electrical energy consumption (for all events) was multiplied by the high tariff to give a cost of cooking with electricity, i.e. C_{elec}. The cost ratio was then compared with the percentage of all cooking events in Phase 2 only that were performed electrically (including fuel stacking).

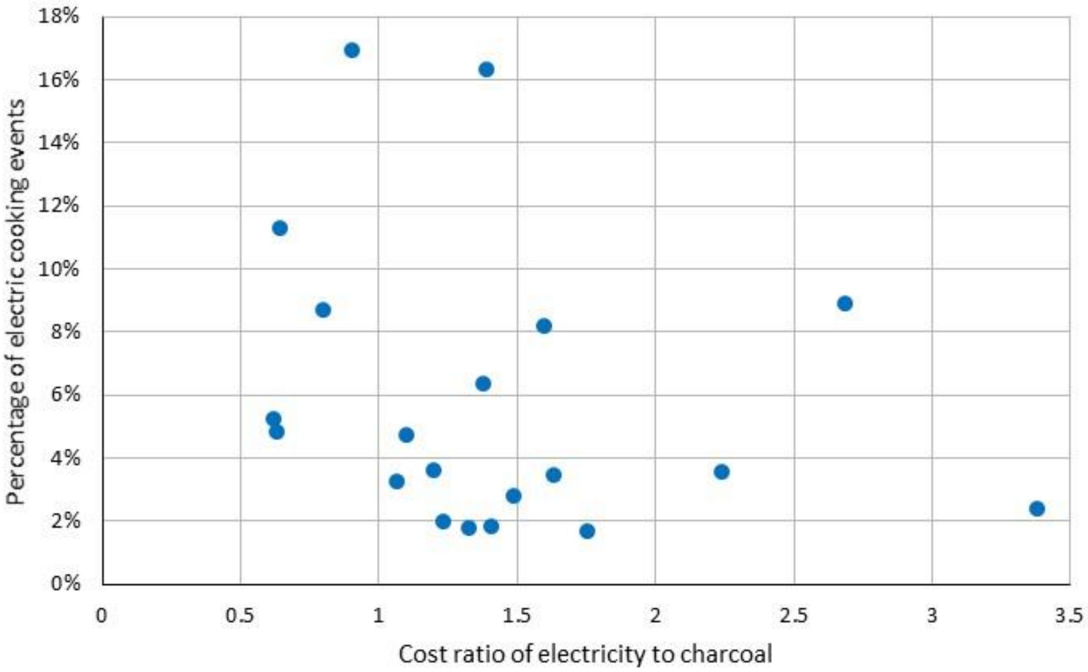

Figure 8 The percentage of electric cooking events (Phase 2) against the cost ratio of electricity to charcoal for each household (mini-grid tariff).

The hypothesis is that if the cost of cooking with electricity is greater than the cost of cooking with charcoal, $C_{elec}/C_{char}>1$, then households will be less inclined to use the electric cooking device provided in Phase 2 of the study. Indeed, Figure 8 does show an overall trend of higher EPC use at lower cost ratios. Of particular interest are the five 5 households on this graph with a cost ratio less than 1; this implies that cooking with the EPC was cheaper than cooking with charcoal, even at the mini-grid tariff. Inspection of the electric cooking records revealed that these households cooked mostly beans or rice with the EPC. Referring back to Figure 5 shows that even at the mini-grid tariff, cooking beans or rice in an EPC is cheaper than using charcoal. This illustrates how some households had quickly assessed cooking costs and adjusted their cooking practices to make best use of the EPC.

5 Key conclusions

At the national tariff, cooking with an EPC would be cheaper than using traditional fuels. The EPC is a highly efficient device, featuring insulation, automated control and cooking under pressure, so it uses a fraction of the energy of a charcoal stove. Overall, cooking with charcoal requires approximately 20 times the electrical energy used by an EPC, and this this ratio rise to 40 for certain foods like beans and rice. At the national tariff, the energy price (expressed in USD/MJ) is not much higher than the price paid for charcoal in these communities, so the cost of cooking with electricity is a fraction of the cost of cooking with charcoal. At this tariff, even less efficient electrical cooking devices would also be cost competitive.

Even at mini-grid tariffs it can still be cost effective to cook certain foods with an EPC. The question of whether electricity from a mini-grid is cheaper to cook with than charcoal (or any other fuel) does not have a binary answer. Surveys consistently confirm that people have a strong belief that electricity is too expensive to cook with but, as electric appliances are stacked with other fuels, cost decisions need to be more nuanced. The relative cost of cooking depends on a number of factors. The quantity, or measure, in which charcoal is bought, and the prevailing electricity tariff affect relative cooking costs. Different households buy charcoal in different measures; in this study some households pay more than twice what others pay for charcoal, which makes a huge difference to the relative cost of cooking. As cooking style varies, so the energy used by each household varies and this impacts the cost of cooking. The cost also varies with what is being cooked, as different dishes require different amounts of energy, and some dishes can be cooked more efficiently using different appliances; for example, beans are well suited to cooking in an EPC, meaning that cooking with electricity can cost less than using charcoal, even at the mini-grid tariff.

The national tariff set by the regulator was to ensure parity for households on the mini-grid with those on the national grid. The cost of cooking with electricity at this tariff was much lower than all other measured fuels. In the future, if the concern is to set a viable tariff as a balance point between fairness and cost effectiveness to the consumer, and cost recovery to the mini-grid operator, then cost effective cooking with electricity could have been achieved at a higher tariff. A median parity price with charcoal was calculated, that is the price at which cooking with electricity becomes cost competitive with charcoal for half of households; this was estimated to be 0.64 USD/kWh. Aside from the cost of cooking, consumers may be willing to pay an additional premium for the many user benefits associated with electric cooking. This kind of analysis can be used as evidence in negotiations with the regulatory authorities.

Households have varying capacities to assess the cost effectiveness of cooking with different devices. There is a weak link between the cost ratio of electricity to charcoal cooking costs and the adoption of EPC use (represented by the percentage of cooking events in which an EPC was used), such that adoption is weaker among households where the cost ratio is higher ($C_{elec}/C_{char}>1$). Conversely, the study highlighted a number of households in which the costs of cooking with electricity and charcoal were similar ($C_{elec}/C_{char}<=1$), which cooked more frequently with the EPC. These households had quickly assessed relative cooking costs and adjusted their cooking practices accordingly.

Both sources of data on fuel prices were based on recall at the time of the survey; there was no ongoing collection of fuel price data. Furthermore, the menu cooked using the EPC is not representative of the full menu cooked with charcoal, so there are some incompatibilities in the data. **Further research** should gather more data on fuel prices and seasonal variations, and the energy used when cooking a full menu using electricity, both of which will improve the accuracy of estimates used in this analysis.

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