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Experiences of Electric Pressure Cookers in East Africa?

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Abstract

This paper seeks to highlight the emerging opportunity for manufacturers to enter the largely untapped market for efficient electric cooking appliances such as the Electric Pressure Cooker (EPC) in East and Southern Africa. The paper is an output of the UK Aid[1] programme Modern Energy Cooking Services, a 5 year programme of work (2018 – 2023) led by Loughborough University. In East Africa, electricity networks are growing stronger and broader, opening up electric cooking to an almost entirely untapped market particularly in urban areas that are still dominated by charcoal. In each country, approximately 10 million people pay for polluting cooking fuels, yet they have a grid connection that is not used for cooking. Historically this has been due to the pricing and unreliability of the grids. As Grids get stronger and appliances more efficient the affordability and convenience of electric cooking is becoming more realistic. In Southern Africa, electric cooking has been and is more popular, however inefficient appliances are placing a heavy strain on national utilities, many of whom are now looking to manage demand more sustainably. Again, the advent of energy efficient appliances changes the dynamic for the household.

Cooking is deeply cultural and any new energy efficient cooking devices must be compatible with local foods and cooking practices. This paper presents insights from cooking diaries, focus groups and 'kitchen laboratory' experiments carried out in Kenya, Tanzania and Zambia. The results show that EPCs are not only acceptable, but highly desirable. Over 90% of the menu can be cooked in an EPC and certain foods require just one fifth of the energy of a hotplate. In real homes, participants with EPCs, rice cookers and hotplates chose the efficient appliances for approximately half their menu and for these dishes, they used roughly half the energy of the hotplate. Without training and with limited experience of the new devices, the trial participants in Kenya who cooked solely on electricity had a median daily consumption of 1.4kWh/household/day, and the cooking of 50% of the menu on an EPC utilised 0.47kWh/household/day of that total. Given that EPCs could have cooked 90% of the desired menu, with appropriate training and broader experience, the median could have been reduced to less than 1kwh/day/household. This research feeds into a new UK Aid programme, *Modern Energy Cooking Services* and concludes with recommended design modifications that could enable users to do more cooking with EPCs and open up sizeable new market segments including strengthening weak-grid and off-grid.

[1] This material has been funded by UK aid from the UK government; however the views expressed do not necessarily reflect the UK government's official policies.

Introduction

This paper seeks to highlight the emerging opportunity for manufacturers to enter the largely untapped market for efficient electric cooking appliances such as the Electric Pressure Cooker (EPC) in East and Southern Africa. The paper is an output of the UK Aid[2] programme Modern Energy Cooking Services, a 5 year programme of work (2018 – 2023) led by Loughborough University.

IMARC [1] estimate the annual EPC (or multicooker) sales to be worth $578 million (USD), however Africa accounts for just 5% of this. Globally, 3 billion people still cook with biomass, yet 2 billion of these now have access to electricity [2]. Cooking with biomass is estimated to cause in excess of 4 million deaths every year, due to respiratory illnesses from breathing in smoke [3]. As a result, the international community is putting significant effort into finding solutions. However, Batchelor et al [4] note that whilst past attempts have focussed on improving the efficiency of biomass cooking, there is an emerging opportunity to leverage progress in electrification to drive forward access to clean cooking solutions. The United Nations set the optimistic goal of achieving universal access to both electricity and clean cooking by 2030 with SDG 7 (Sustainable Development Goal 7) [2]. Whilst the former may be within sight, at current rates of progress with predominantly biomass-based solutions, the world will fall far short of the latter for cooking [2], [4]. This paper highlights a key opportunity to address this globally important challenge.

Regionally, East Africa presents a strategic opportunity, as it contains many of the world's largest charcoal markets, whilst at the same time, electricity grids are becoming stronger and reaching more people than ever before. This paper focusses in on four politically stable East African countries, Tanzania, Kenya, Uganda and Ethiopia, where the uptake of energy-efficient products has already revolutionised other sectors such as lighting [5]. To date, electric cooking has seen limited uptake in East Africa, due to the intertwined challenges on both the supply (reliability, access, poor quality wiring) and demand (perception of cost, taste, behavioural change). However, the supply side barriers are decreasing rapidly and as will be shown in this paper, energy efficient appliances offer a new opportunity to overcome many of the demand side challenges.

Southern Africa presents a different, but equally important opportunity, as electric cooking is already the aspirational solution for many, however the legacy of old and inefficient equipment makes cooking with electricity unnecessarily expensive. Many Southern African grids are dominated by hydropower (excluding South Africa, which is predominantly coal based), leading to frequent seasonal power shortfalls and load shedding. This paper gives the example of Zambia, where over 10% of the population already cook on electricity. However, recent load shedding caused a significant number of these users to revert back to charcoal, rapidly accelerating deforestation. As a result, the national utility, ZESCO, is looking for ways to reduce demand for electricity, so finding a more efficient alternative to inefficient hotplates is vitally important.

The paper presents insights from empirical data collected in Kenya, Tanzania and Zambia[3] where the cooking practices and associated energy consumption of households were recorded. Households then switched to electric cooking with a range of conventional (hotplate) and energy efficient appliances, including EPCs. The data presented includes perception of cost, taste and experiences of behavioural change.

Electricity in East and Southern Africa

Generating capacity

On the supply side, driven by long term economic growth ambitions, East African grids have been growing stronger and broader, presenting an opportunity to expand electrical demand into new sectors such as cooking. Whilst utilities in the region have historically shied away from stimulating demand due to shortfalls in supply, Batchelor et al [4] note that several countries in the region now have surplus

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[3] At the time of writing, the collection of comparable data is underway in Uganda and Ethiopia.

electricity. Kenya's national utility, KPLC (Kenya Power and Lighting Company) has already begun to promote electric cooking through a television series, Pika na Power (Cook with Electricity) [6]. Recent installations in Uganda have increased generating capacity to 950 MW, creating a generating surplus, for the moment. Power Africa has identified a further 1,900 MW of projects for completion by 2030. The World Bank estimate that generating capacity in Kenya double from 2,300 MW in 2015 to 5000 MW in 2020 [7]. Generating capacity in Tanzania was roughly 1,500 MW in 2017 [8], and with a further 1600 MW planned, this capacity is projected to double imminently [9]. More recently, the Stiegler's Gorge hydropower project has been given the go-ahead, which will bring an additional 2,100 MW online [9], so the government's aim to reach 5,000 MW by 2020 [10] appears feasible. The government's Better Results Now initiative (2013) contains a longer term ambition to reach 10,000 MW by 2025 [11].

Reliability and security of supply

Error! Reference source not found. shows that with the notable exception of Tanzania, the majority of electricity in the region is generated from renewable sources and that reliability in urban areas is now relatively high. Batchelor et al [4] note that there are still many outstanding transmission, infrastructure and management issues within the private and public sector including utilities. However, **Error! Reference source not found.** suggests that in major cities, reliability is already sufficient to consider cooking – the SAIDI and SAIFI from each country's economic centre indicate that in all four countries, power outages average less than 5 hours per month.

Table 1: Electricity supply factors in selected East and Southern African nations [12]–[18]**.**

	Electricity access – total, urban	**Blackout frequency & duration (SAIFI[4], SAIDI[5])**	**Electricity tariff (USD/kWh)**	**Lifeline tariff & allowance (USD/kWh, kWh/month)**	**Generation mix (% renewable)**
Ethiopia	44% (urban 97%)	n/a	0.09 $/kWh	0.01 $/kWh 50 kWh/month (0.03, 100 0.06, 200 0.07, 300 0.08, 400)	100%
Kenya	64% (urban 81%)	13/yr, 60hrs/yr	0.23 $/kWh	0.17$/kWh, 100 kWh/month	87%
Tanzania	33% (urban 65%)	47/yr, 21hrs/yr	0.15 $/kWh	0.04 $/kWh 75 kWh/month	34%
Uganda	22% (urban 57%)	42/yr, 59hrs/yr	0.20 $/kWh	0.06 $/kWh 15 kWh/month	93%
Zambia	40% (urban 75%)	5/yr, 50hrs/yr	0.09 $/kWh	0.02 $/kWh 200 kWh/month	97%

Urbanisation and biomass cooking

Africa is rapidly urbanising and many areas that were previously rural are becoming peri-urban, meaning that many people who used to collect firewood are now forced to purchase charcoal. As nearby forests are exhausted, charcoal has to be brought from further and further away, pushing up the price in urban centres [19]. Another Nigeria will be added to the continent's total urban population by 2025 and urban centres are set to double in size over the next 25 years, reaching one billion people by 2040 [20]. Ironically, despite having a surplus, while 22% of Ugandans and 64% of Kenyans are covered by electricity, electric cooking doesn't even register on national surveys (0%). Even in urban areas, where access rates are 57% and 81% respectively, electricity is only used as a primary cooking fuel by 1% in

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[4] SAIFI (System average interruption frequency index) is the average number of service interruptions experienced by a customer in a year.
[5] SAIDI (System average interruption duration index) is the average total duration of outages over the course of a year for each customer served, measured in hours.

both nations [21]. Figure 1 shows that cooking in urban areas of East and Southern Africa is still dominated by charcoal, with all its associated problems of respiratory illness, deforestation, general air quality, climate change contribution, and ever rising monetary cost. Only in Zambia (27%) and Ethiopia (18%) do significant fractions of the population cook with electricity, most likely due to the low unit cost, which at consumption levels below 200 kWh/month (which as will be shown later in this paper, is more than enough to cook with), averages approximately 0.02 USD/kWh in both nations. There is therefore a considerable latent opportunity for a relatively easy switch to clean cooking that has to date been held back by reliability and security concerns.

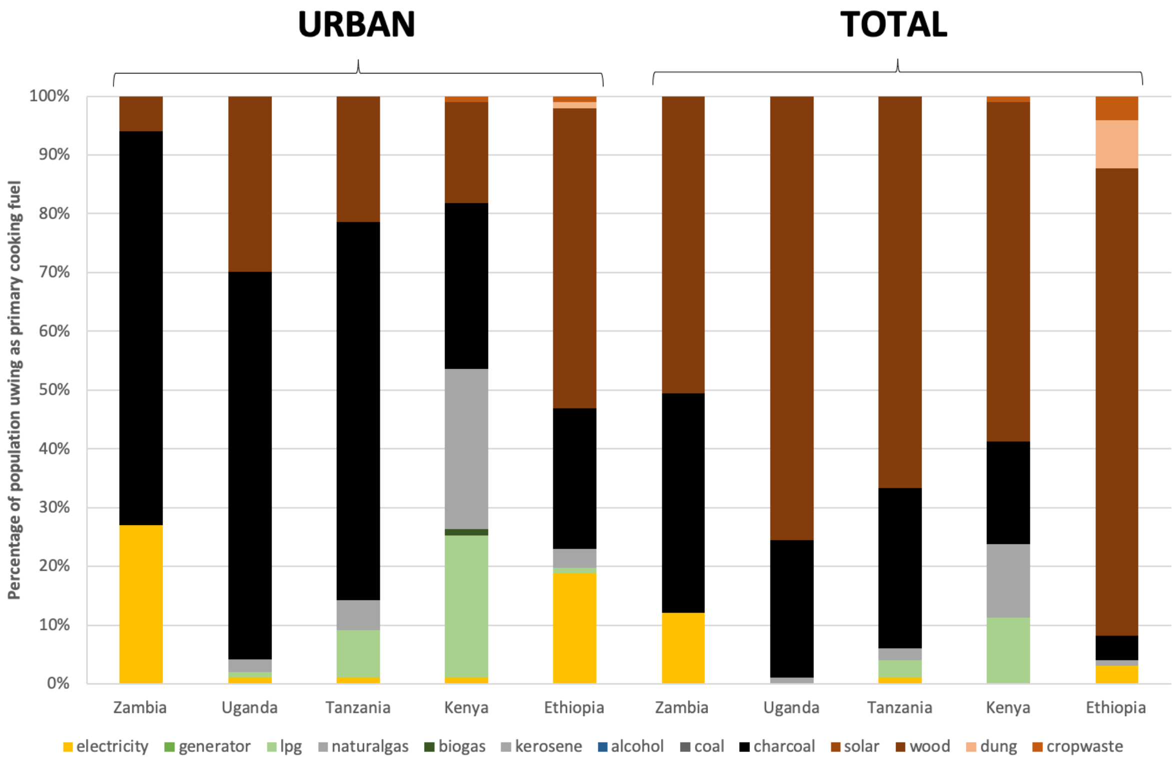

Figure 1: Breakdown of fuel users for selected East & Southern African nations. Adapted from eCook Global Market Assessment [22] **with data from WHO Household Energy Database** [21]**.**

Collectively, Kenya, Uganda, Tanzania, Zambia and Ethiopia are home to 38 million people who have a grid connection, yet choose to cook with commercialised polluting fuels (charcoal and kerosene). **Figure 2Error! Reference source not found.** shows that Kenya, Uganda and Tanzania each have approximately 10 million people who are paying to cook with charcoal and kerosene, whilst approximately the same number have a grid connection, but do not use it for cooking. In Zambia, electrification rates are modest (40%), but uptake of electric cooking amongst those that are connected is relatively high (12% of total population). As a result, roughly half the number of people cooking with commercialised polluting fuels (6 million) have a grid connected, but do not yet use it for cooking (3 million). Ethiopia is a much bigger country than Zambia and electrification rates are similar (44%), however, Figure 1 shows that the majority of the population (even in urban areas) cook with firewood, which is often collected for free. As a result, relatively few people (5 million) cook with commercialised polluting fuels compared to those who are grid connected but not cooking with electricity (25 million).

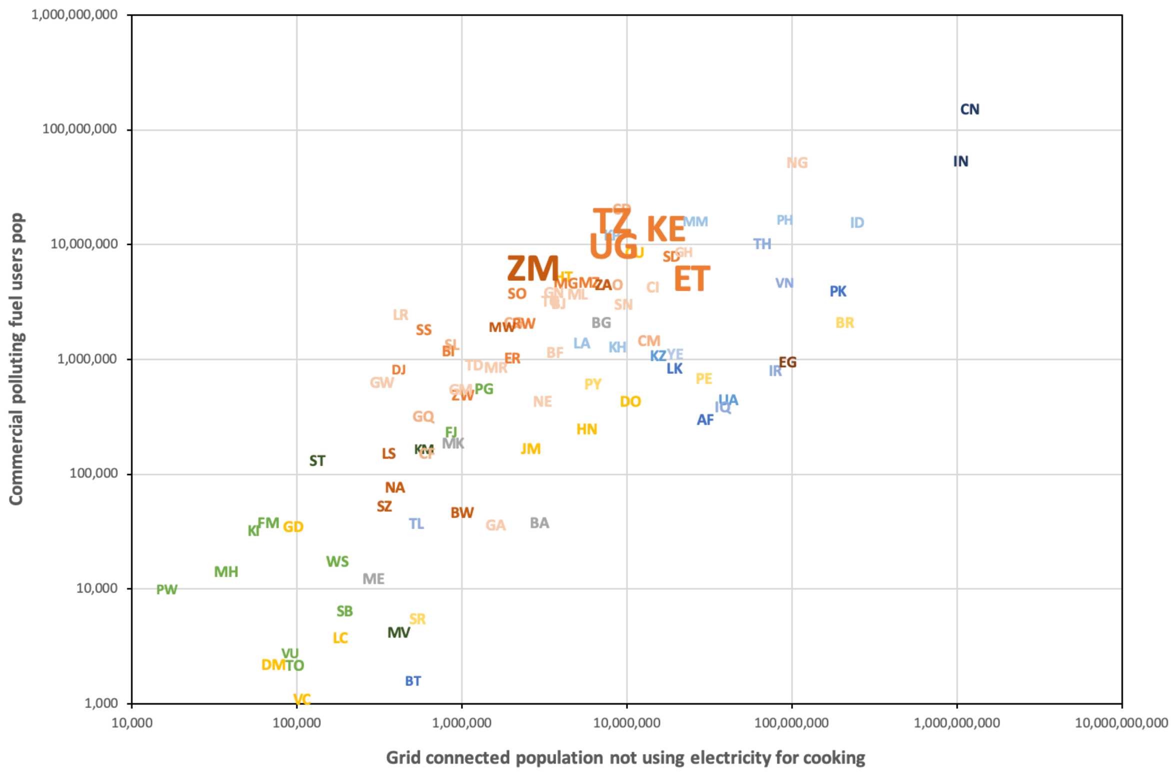

Figure 2*:* Size of key market segments by country: commercialized polluting fuel (kerosene, charcoal, coal) users and grid connected population that are not using electricity as their primary cooking fuel. Adapted from eCook Global Market Assessment [22] **with data from World Development Indicators** [12] **and WHO Household Energy Database** [21]**.**

Countries coloured by region: AIMS, Central Africa, Central America & Caribbean, Central Asia & North Korea, East Africa, Europe, India & China, Middle East, North Africa, Pacific Islands & PNG, South America & Mexico, South Asia (excl. India), Southeast Asia, Southern Africa and West Africa.

ET = Ethiopia, ZM = Zambia, TZ = Tanzania, KE = Kenya, UG = Uganda. All two-letter country codes listed in *Appendix B – Regional colour coding and two-letter country codes*.

Affordability of electric cooking

Whilst charcoal prices have risen significantly in most East and Southern African nations, electricity tariffs have remained relatively affordable. **Error! Reference source not found.** shows that despite hiking prices by 75% in 2017, electricity prices in Zambia are still below 0.10USD/kWh. In fact, the national utility, ZESCO, offer a generous lifeline tariff of just 1.5 cents (USD) per unit for the first 200kWh per month, which is actually more than enough for most households to cook with. Researchers undertaking a global review of price data found that even when utilising an inefficient hotplate, there are a number of African countries (including Ethiopia, Tanzania and Zambia) where it is already affordable for grid-connected households cooking with charcoal to switch to cooking with electricity [22]. Of course, when energy-efficient appliances are considered, many more countries rise above the price parity line between electricity and charcoal. **Figure 3** shows that there is a clear correlation between the cost of electricity and uptake of electric cooking. Several East and Southern African nations with low to moderate tariffs already have reasonably high levels of uptake of electric cooking (amongst those that have access). Zambia, Ethiopia, Zimbabwe and South Africa all have over 1 million people using electricity as their primary cooking fuel. Of particular note is South Africa, which appears second only to

China[6], offering a market of over 40 million people already cooking with electricity and a moderate tariff of 0.12 USD/kWh.

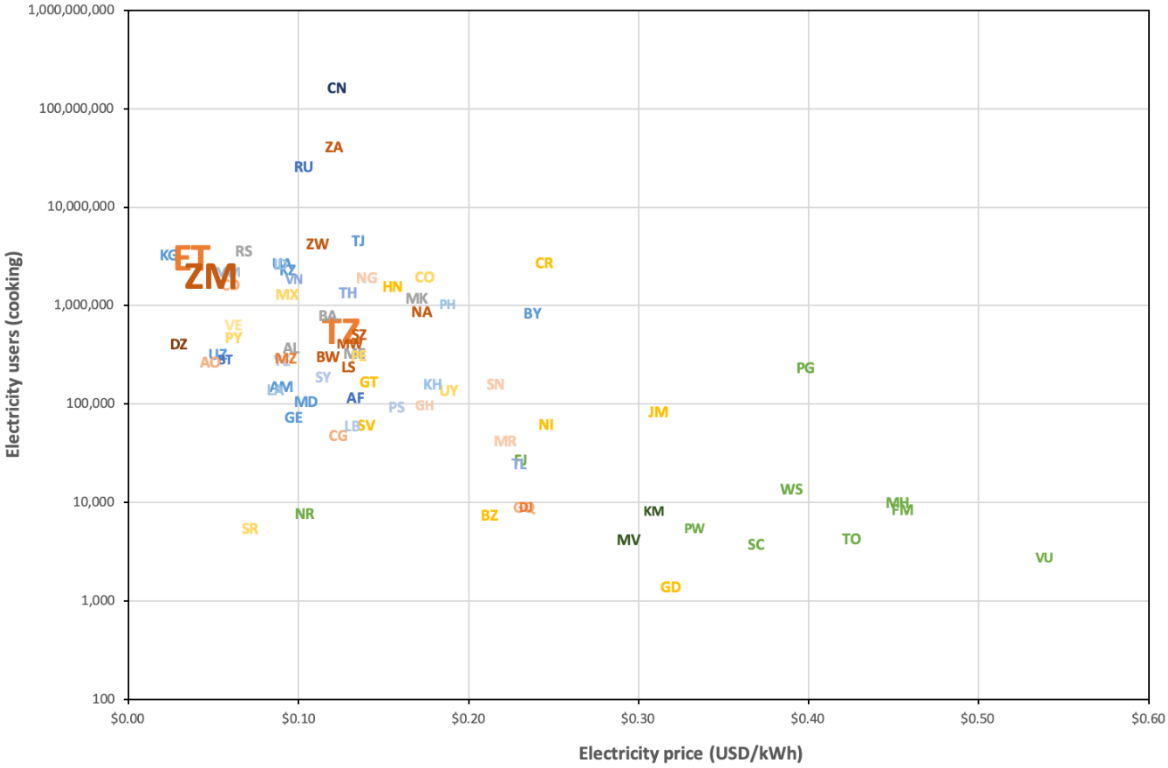

Figure 3: Size of existing electric cooking markets by country. Adapted from eCook Global Market Assessment [22] **with data from World Development Indicators** [12] **and WHO Household Energy Database** [21]**.**

Countries coloured by region: AIMS, Central Africa, Central America & Caribbean, Central Asia & North Korea, East Africa, Europe, India & China, Middle East, North Africa, Pacific Islands & PNG, South America & Mexico, South Asia (excl. India), Southeast Asia, Southern Africa and West Africa.

ET = Ethiopia, ZM = Zambia, TZ = Tanzania. Kenya & Uganda not shown, as household surveys show 0% electric cooking [21]**. All two-letter country codes listed in *Appendix B – Regional colour coding and two-letter country codes*.**

The impact of energy-efficient products/services in East/Southern Africa

The paper argues that the EPC has the potential to revolutionise cooking markets across the region in the same way that the Light Emitting Diode (LED) has transformed lighting markets. The LED has enabled access to lighting across the region in ways that simply were not possible before. The LED reduces energy demand for lighting by an order of magnitude compared to incandescent light bulbs, whilst simultaneously increasing reliability and product size. Notably, East Africa in particular has embraced this new technology through the development of solar home systems designed to replace inefficient, expensive and polluting technologies such as kerosene lanterns, candles and torches with disposable batteries. Pay as you go (PAYGO) business models have enabled the high upfront costs of such systems to be broken down into manageable repayments in tune with how kerosene, candles and dry cell batteries are purchased. GOGLA [23] state that East Africa represents about 80% of total sales volumes of solar lighting products in Sub-Saharan Africa, with 1.49 million products sold, generating US$ 44.07 million revenue in the second half of 2016 alone.

While this example clearly demonstrates that significant improvements in quality of life for poor households can result from by strategic use of an energy efficient appliance, it is important to note the

[6] High Income Countries (HICs) were excluded from the analysis.

differences between lighting and cooking. Cooking is deeply cultural, and it is not enough to ensure a supply chain of an energy efficient appliance; people will need to know that it can cook their food and that the food will be just as tasty. In the data below, we approach the potential of EPCs as an energy efficient device for East and Southern Africa by showing how it fits existing cooking practices. However, before getting to the specifics of cooking processes and acceptability of EPCs in East and Southern African culture, we consider why the EPC is so efficient in its energy use.

Why the EPC?

In developed economies, EPCs are attractive not so much for their energy saving capability, but for their convenience and speed [1]. The first Electric Pressure Cooker (EPC) patent was filed by a Chinese scientist in 1991 [24], but the appliance has recently gained popularity in other parts of the world, with North America now dominating the market [1]. In fact, newer models can even be controlled remotely via a smartphone app, allowing food to be loaded in the morning and the cooking process triggered when the user leaves work in the evening. The accelerated speed of cooking can also support the busy lifestyle of many modern households [1].

However, the features of automatic control, insulation and pressurisation also enable the EPC to save a lot of energy, and therefore money. What is more, the insulation allows it to continue cooking during short blackouts and also keeps food warm after cooking has finished. These may not be important parts of the value proposition in North America and Europe, but as we will show in this paper with data from East and Southern Africa**,** they become all the more important when relating this to impoverished societies with more unreliable electricity supplies.

The EPC (or multicooker) simply combines an electric hotplate, a pressure cooker, an insulated box and a fully automated control system (**Error! Reference source not found.**). Batchelor et al [25] explain that unlike other cooking fuels that rely on combustion, electricity does not need air flow to create heat. It therefore opens up the possibility of the food being cooked in a highly insulated environment. This principle is used in many popular electric cooking appliance, such as rice cookers, slow cookers and thermo pots. Having raised the temperature of the device to the cooking temperature, the insulation drastically reduces heat loss, meaning that little to no extra energy is required to continue to cook the food (see **Error! Reference source not found.**). Indeed this is the basis of the 'fireless' cooker, sometimes called Wonderbag or Lindamoto. A pot of beans, for instance, is cooked for some minutes to remove toxins, and then taken off (any) stove and placed in the fireless cooker. With the highly insulated bag keeping the temperature high, the beans continue to cook – thus saving fuel.

In addition to minimising heat losses through insulation, the EPC adds the option to pressurise. This raises the boiling point of water and enables the food to be cooked faster. **Error! Reference source not found.** shows that after the initial pressurisation, the hotplate in an EPC only comes on periodically to maintain the temperature in the sealed environment inside and resulting in considerable energy savings. As Prof. R. Khan states: "*it is temperature that cooks food, not energy per se*" [25].

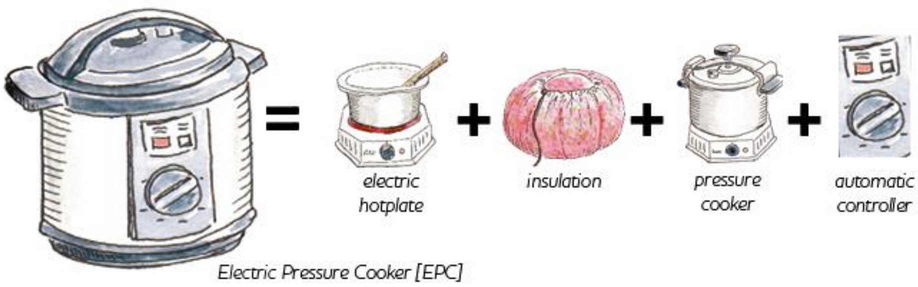

Figure 4: The fundamental components of an EPC.

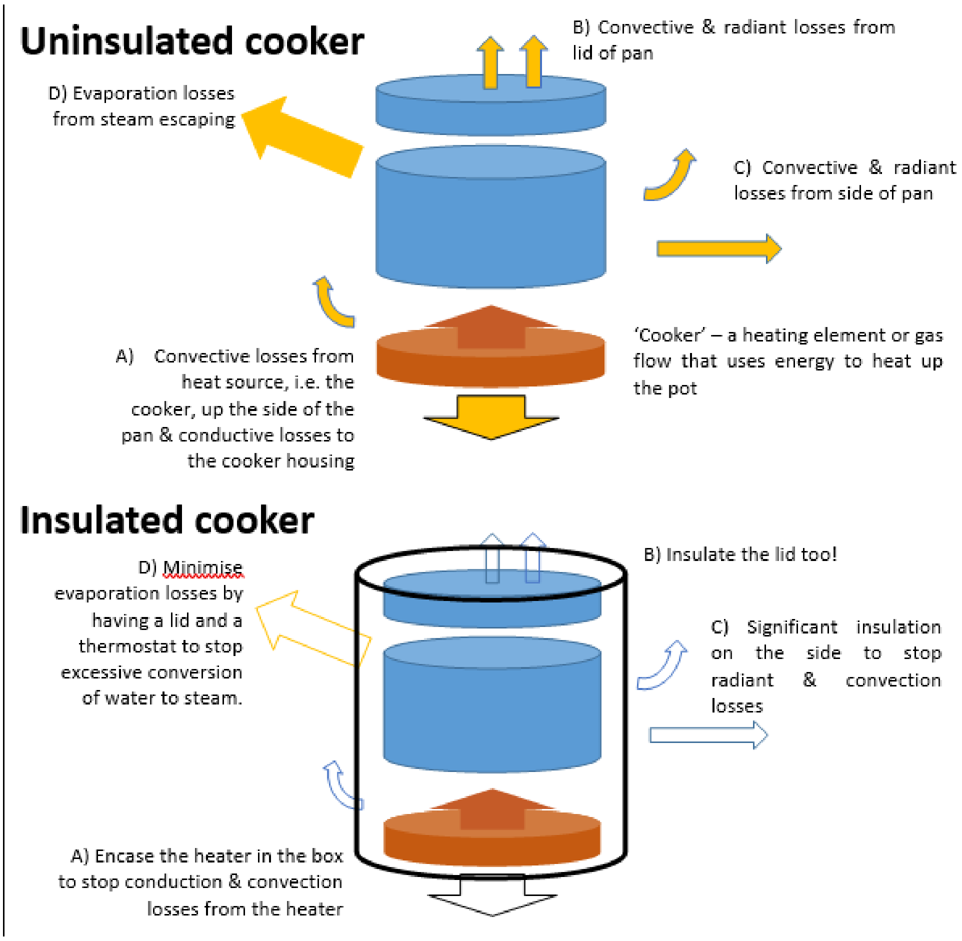

Figure 5: Heat loss mechanisms mitigated by insulating the cooking pot and heating device. Adapted from Batchelor et al. [25]**.**

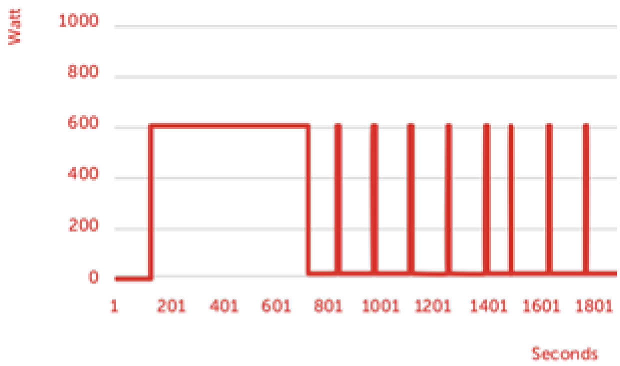

Figure 6: Typical load profile for a 700W rated EPC on a half hour cooking cycle [26]**.**

In contrast, whilst rice cookers are also insulated and automated, they are not sealed and their control system is much simpler, merely dumping full power into the pot until all the water has been vaporised. However, they are much more useful than their name suggests, as one participant noted: "I have learnt that rice cookers are badly named – they can cook so much more than rice!" It should also be noted that because of the insulation, 'full power' on a rice cooker is generally much lower than on a hotplate, which has important implications for systems where peak power is a constraint, such as battery-supported cookers or mini-grids.

As stated above, the EPC goes further by pressurising the system; during this stage the boiling point of water is raised up from 100°C to around 120°C. The increased temperature enables the food to cook faster, resulting in shorter cooking times and therefore reduced energy consumption. 'Manual' stove-top pressure cookers (heated by charcoal and gas) are common in East Africa, although their safety is of concern to many users. EPCs integrate an array of safety and control features, offering multiple redundancies if any one were to fail (see **Error! Reference source not found.**7). It controls the energy input into the device, such that the cook can walk away and leave the device cooking autonomously.

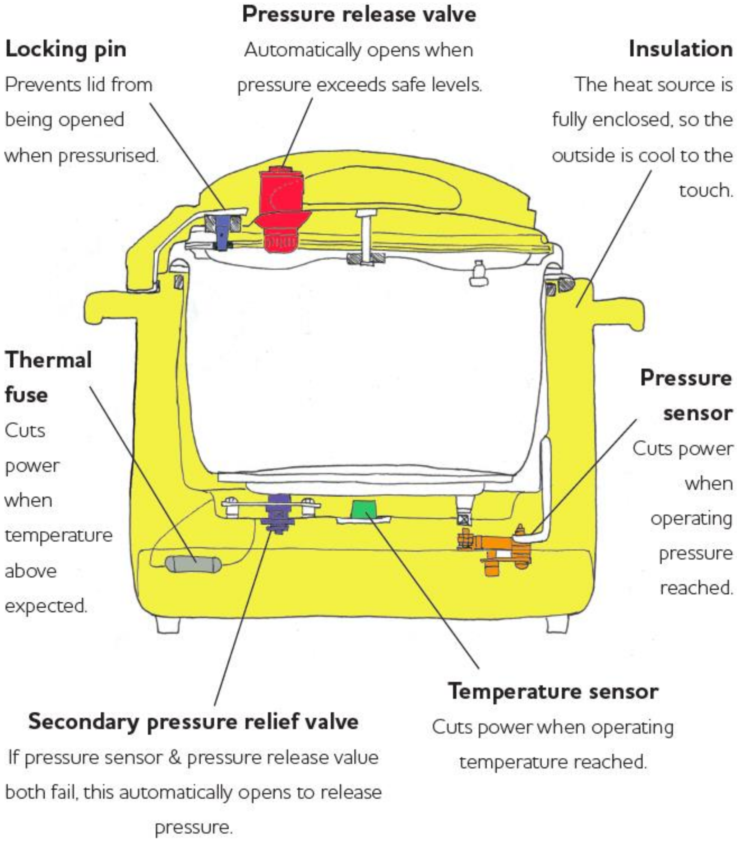

Figure 7: Automatic control and safety features of a typical EPC [27]**.**

While the sealed environment has a positive effect on energy consumption, the sealed, blind, nature of pressure cooking can make inexperienced cooks nervous. They believe that more stirring is required, or they need to see the food to make sure it is cooking, or has not overcooked. Such responses hold back many cooks from utilising the EPC. In fact, much less stirring is needed, as no water escapes from the sealed environment during pressure cooking and the temperature is automatically limited to 120°C, so it is almost impossible to burn the food. In the data below we identify whether these beliefs are an insurmountable barrier to using EPCs in East and Southern Africa or whether the other benefits might outweigh this particular challenge.

Methodology

This paper seeks to demonstrate the compatibility of East and Southern African cooking practices with EPCs by answering the following research questions:

- How much energy is really needed to cook popular East/Southern African dishes with an EPC?
- How does the EPC fit into the kitchen routines of East/Southern African cooks?
- What is the user experience for everyday cooks in East/Southern Africa with EPCs?

A range of multidisciplinary techniques including cooking diaries, focus groups and kitchen laboratories were employed to understand how households in East and Southern Africa currently cook and how they aspire to cook. To date, these techniques have been applied in Kenya, Tanzania and Zambia. At the time of writing, similar studies are underway in Ethiopia and Uganda. This paper focusses on the data from Kenya, which is the most detailed dataset currently available.

Cooking diaries

Despite decades of work on improving the efficiencies of biomass stoves, there seems to be little available data on ‘how’ people cook. Modern fuels such as gas & electricity are more controllable & can be turned on/off in an instant. There are also a huge range of electric cooking appliances, each designed for specific processes (e.g. kettles for heating water). Therefore, it is important to know how often people are frying, boiling, reheating or something else entirely.

To date international improved cookstove tests have focused on the Water Boiling Test and the Kitchen Performance Test [28], [29]. Neither of these tests were designed to give insight into ‘how’ a cook cooks, and whether, when they transition to a different fuel or appliance, their cooking practices change. Cooking is a deeply cultural experience, as the foods people cook and the practices they use to prepare them vary widely. To date studies of ‘how’ people cook have largely been based on observational qualitative data.

The cooking diaries study was designed to offer a deeper exploration into the unique cooking practices of individual households, paired with quantitative measurements of energy consumption. In each country, 20 households were selected to participate in the study, based upon the fuels they cooked with and their willingness/ability to record high quality data for the duration of the study. This mixed methods approach gathers data from various sources:

- *Cooking diary forms:* foods cooked, cooking processes/times, appliances used.
- *Energy measurements:* manual measurements of fuel use and electricity consumption taken by participants.
- *Registration surveys:* simple demographic data on participants.
- *Exit surveys:* qualitative user experience feedback from participants.

Figure 8: An enumerator training a participant to record data during the cooking diaries in Nairobi, Kenya. The electric cooking appliances are plugged into an energy meter in the top right of the photo.

Data was recorded in two stages:

- *Baseline (2 weeks)*: cooking as normal, simply recording data.

- *Transition (4 weeks)*: cooking with electric appliances only.

Energy measurements were taken before and after each heating event to give '*meal-level resolution'* data (**Error! Reference source not found.**). Solid, liquid and gaseous fuels were measured using a hanging balance and calculating the difference in weight between before and after cooking measurements. Electricity consumption was measured using a plug-in electricity meter (Figure 8). Paper records kept by participants were transcribed into digital form by the enumerators. Subsequent analysis of the complete database was performed in both SPSS and Excel.

In the second part of the experiment, the households were asked to transition to using solely electricity for cooking. In Kenya[7], each household was given a hotplate, a rice cooker and an EPC, and received basic training on how to use each appliance. The 3 appliances were plugged into an extension cable, which fed into a plug-in energy meter (Figure 8). Participants were also able to continue using any electrical appliances that they already owned, as long as they were plugged into the meter, so that energy consumption data could be captured. Data was recorded for a further 4 weeks, allowing participants time to adapt their cooking practices around the new appliances.

The study finished with an exit survey, asking participants about their experience with cooking with different electric appliances. Participants were also invited to share their energy-efficient cooking practices by participating in the Githeri eCooking Challenge. A prize was offered to the participant who could cook half kg of githeri using the least energy possible, whilst the enumerators observed and recorded their cooking practices to understand exactly where energy was being saved/wasted.

The cooking diaries protocols offer a more complete guide to this methodology for those looking to replicate the cooking diaries study: https://elstove.com/forward-looking-guidance/

'Kitchen laboratory'

A mixture of 'ethno-engineering' techniques were employed to explore the compatibility of East and Southern African cooking practices with a range of electric cooking appliances in a 'kitchen laboratory' setting (Figure 9). 'Ethno-engineering' blends anthropological and engineering approaches to create more holistic and culturally-informed development solutions. Initially, this focussed on simply observing the cooking practices of everyday cooks. Evidence was recorded as recipes, tips and reflective notes in a field diary and supplemented by photography. The plug-in energy meters from the cooking diaries study enabled a more quantitative dimension. In Kenya, this methodology evolved to be much more prescriptive, delving deeper into the findings from the cooking diaries study by exploring where energy is saved/wasted within a specific dish. This resulted in the production of an eCookBook [27], designed to inform everyday cooks of how to save time and money in the kitchen with smarter cooking practices, in particular adopting EPCs.

[7] In Zambia, participants used hotplates and EPCs and in Tanzania, participants were given free choice from a range of 7 different electric cooking appliances.

Figure 9: Experiments in the Nairobi 'kitchen laboratory' during the production of the first eCookBook.

Focus groups

Focus groups were carried out in each country to gain further insight into current and aspirational cooking practices in a range of different contexts. A series of questions were designed to guide the discussion, however open dialogue was encouraged when unforeseen issues were brought up by the participants. An EPC was demonstrated during each session, inviting comments from the audience on how compatible the device was with the current and aspirational cooking practices (see Figure 10).

Figure 10: Participants interacting with a range of energy-efficient electric cooking appliances during a focus group in Kibindu, Tanzania.

Results

How energy efficient are EPCs at cooking East/Southern African foods under controlled conditions?

Controlled tests in the 'kitchen laboratory' for the eCookBook in Kenya revealed that EPCs can save up to 85% of the cost of cooking 'heavy foods' on charcoal [27]. 'Heavy foods' typically involve boiling for an hour or more on conventional stoves. They include beans, tripe, githeri (beans and maize stew) and stews with tougher cuts of meat.

A fireless cooker utilises the principles of insulation (but not pressurisation) as a means to save fuel on any conventional cooking device during the simmering section of a recipe. For beans, the pot is heated until they are partially cooked (there is a need to cook until the toxins are removed) and then the pot is transferred into the fireless cooker and sealed in an insulated environment. Because the temperature is maintained with minimal heat losses, the food continues to cook with no further input of energy. Figure 11 shows that judicious use of the fireless cooker can save between 10 to 15 KSh (0.10-0.15 USD) on fuel for charcoal, kerosene, LPG or an electric hotplate.

As it is an insulated appliance, a fireless cooker is effectively inbuilt into every EPC, allowing it to prevent heat from escaping from the pot throughout the entire recipe (not just the simmering stage). As a result, Figure 11 shows that whilst cooking on LPG or an electric hotplate works out roughly the same cost as charcoal, the pressurisation and automatic control features of the EPC make it an order of magnitude cheaper. Kerosene is slightly cheaper than charcoal, LPG or an electric hotplate, however still several times more than the EPC.

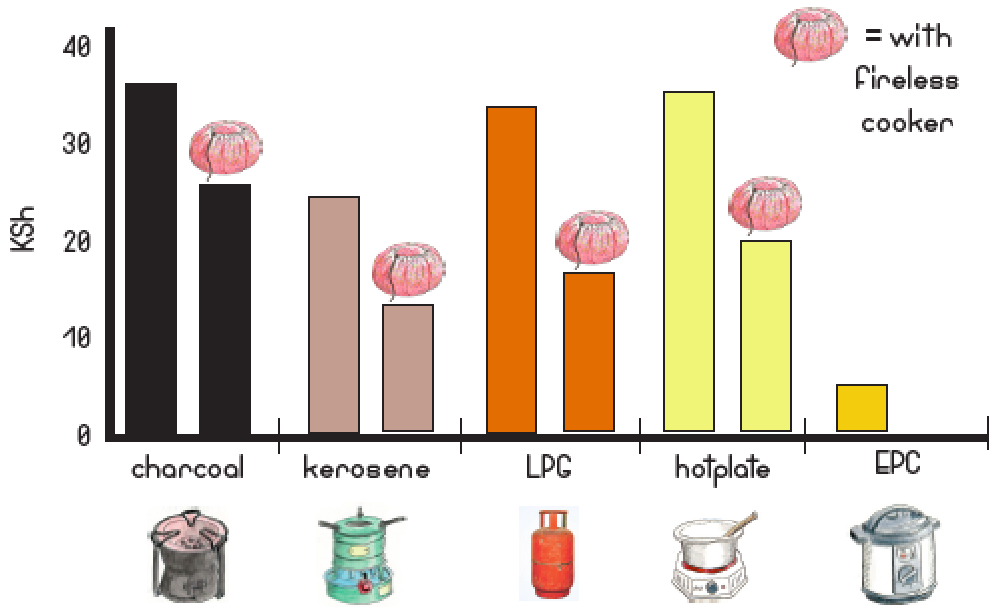

Figure 11: Cost comparison for ½kg dried yellow beans on the most popular fuels in urban Kenya (Nairobi costs, July 2018) [27].

How energy efficient are EPCs when used by everyday East/Southern African cooks under semi-controlled conditions?

The results of the Githeri eCooking Challenge show that almost all households were capable of cooking very efficiently (80-90% savings) when they want to (Figure 12). On a hotplate, cooking ½ kg githeri usually exceeds 2kWh and can even reach 4kWh if no efficiency measures are in place (using the slowest cooking beans, leaving the lid off, etc.). Figure 12 shows that almost all households (16/19) were able to complete the challenge with under 0.4kWh – an 80% saving over hotplates.

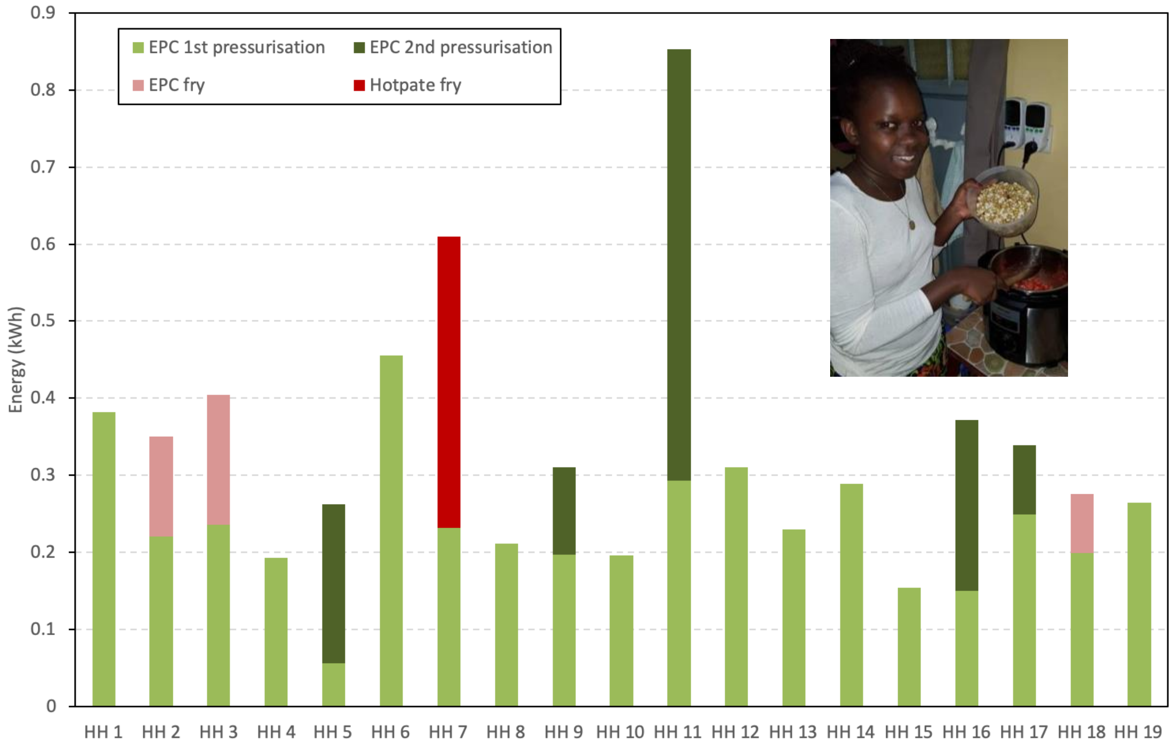

Figure 12: Energy consumption during the Githeri eCooking Challenge by participant, appliance and process.

How useful are EPCs and how energy efficient are they when used by everyday cooks in real kitchens?

In the Kenya cooking diaries, households were able to cook all their food on electricity as they had all three key devices available: a hotplate, rice cooker and EPC. In these circumstances, the menu did not vary significantly from the baseline data obtained during the preceding weeks with their existing stoves and fuels. The analysis below shows that it is possible to cook over 90% of this typical Kenyan menu in an EPC. However, after limited training, with the free choice of 3 appliances, participants chose to cook approximately half their menu in efficient appliances (EPC or rice cooker), and that for these dishes, they used about half the energy of a hotplate.

Beyond 'heavy foods'

Energy savings on 'heavy foods' are clearly substantial in controlled and semi-controlled conditions; however, it is important to understand how they fit into the kitchen routines of everyday cooks. The evidence from the cooking diaries shows that 'heavy foods' comprise approximately one third of all dishes on a typical urban East African household's menu (see Table 2). In fact, many other dishes can also be cooked on an EPC: some are intuitive (e.g. rice), whilst others require some behaviour change (e.g. using a heatproof glove to hold the pot still whilst stirring ugali), however there are several that are extremely challenging on most models of EPC available on the market today (e.g. chapati).

A typical East/Southern African menu can be understood as composing of a set of categories of dishes, each with varying degrees of compatibility with EPCs. An overview of typical preparation techniques for popular Kenyan foods is given in *Appendix A - Typical Kenyan* foods*.* Table 2**Error! Reference source not found.** proposes the following categories:

- 'Heavy' foods – usually require boiling the main ingredient (e.g. beans) for over an hour on a conventional stove and may also contain a frying stage with extra ingredients to add flavour (e.g. a tomato and onion sauce).

- Staples – normally boiled for approximately half an hour. Some require stirring (e.g. ugali, porridge), but others are simply left to boil (e.g. rice).

- Quick fryers – usually fried for 5-15 minutes, a shallow pan and high heat is often preferred, but not essential. Access to the pan is usually required to stir the food and prevent burning.

- Deep fryers – food is completely submerged in oil at 175-190°C.

- Flat breads – medium heat, evenly distributed across a shallow pan is required to cook the whole of the flat bread at the same rate. Access to the pan is required to turn the bread frequently.

Table 2: Categorisation of typical Kenyan foods by their compatibility with EPCs.

Food category	Frequency on urban Kenyan menu	Typical dishes	Compatibility with EPCs	Energy savings with EPCs	Enablers
'Heavy foods'	32%	Beans, matumbo (tripe), meat stews	Users instinctively use EPCs	High (50-90%)	Cooking times & water quantities for popular local foods
Staples	39%	Ugali (maize meal), rice	Users use EPCs if encouraged	Moderate (20-50%)	Demonstrations, extra EPC
Quick fry	20%	Sukuma wiki (kales), eggs	Users use EPCs if encouraged	Low (5-20%)	Demonstrations, manual heat control, extra EPC, shallow pan
Deep fry	2%	Mandazi (donut), fried chicken, chips	Users cannot currently use EPCs	Low (5-20%)	Manual heat control or deep fry settings (175-190°C)
Flat breads	4%	Chapati (flat bread)	Users cannot currently use EPCs	Low (5-20%)	Manual heat control & shallow pan
Other	3%	Unknown			

Analysis of the Kenya cooking diaries data allows us to deduce that EPCs use roughly half the energy of electric hotplates across the full range of dishes that they are able to cook. On average, rice cookers used 39% (median of 0.09 kWh/person/event, n=46) and EPCs used 76% (0.18 MJ/person/event, n=49) of the energy of a hotplate (0.23 MJ/person/event, n=119). However, Figure 13 reveals that EPCs were chosen to cook 'heavier' (and therefore more energy intensive) dishes, when in fact they can also be used for the lighter staples (e.g. rice), which had been cooked in the rice cooker. As all participants in the Kenya cooking diaries had an electric hotplate, a rice cooker and an EPC, it can be assumed that all the dishes that were cooked in a rice cooker could also have been cooked in the EPC with the same energy consumption. Averaging the per capita, per heating event energy consumption figures for rice cookers and EPCs comes to just under half (45%) that of the electric hotplate.

Further analysis of the Kenya cooking diaries dataset suggests that with minimal training, households would choose to use an EPC to cook half their menu if it were the only electric appliance available. Figure 13 shows that a total of 645 dishes were cooked on EPCs and rice cookers. Ignoring all other appliances (which totalled only 150 dishes and were mainly microwaves) and comparing directly to the 739 dishes cooked on a hotplate, roughly half (47%), of a total of 1,387 dishes were cooked by choice on an EPC or rice cooker. We can therefore conclude that without additional training or design modifications, households with an EPC as their efficient appliance are likely to choose to cook roughly half their menu with it.

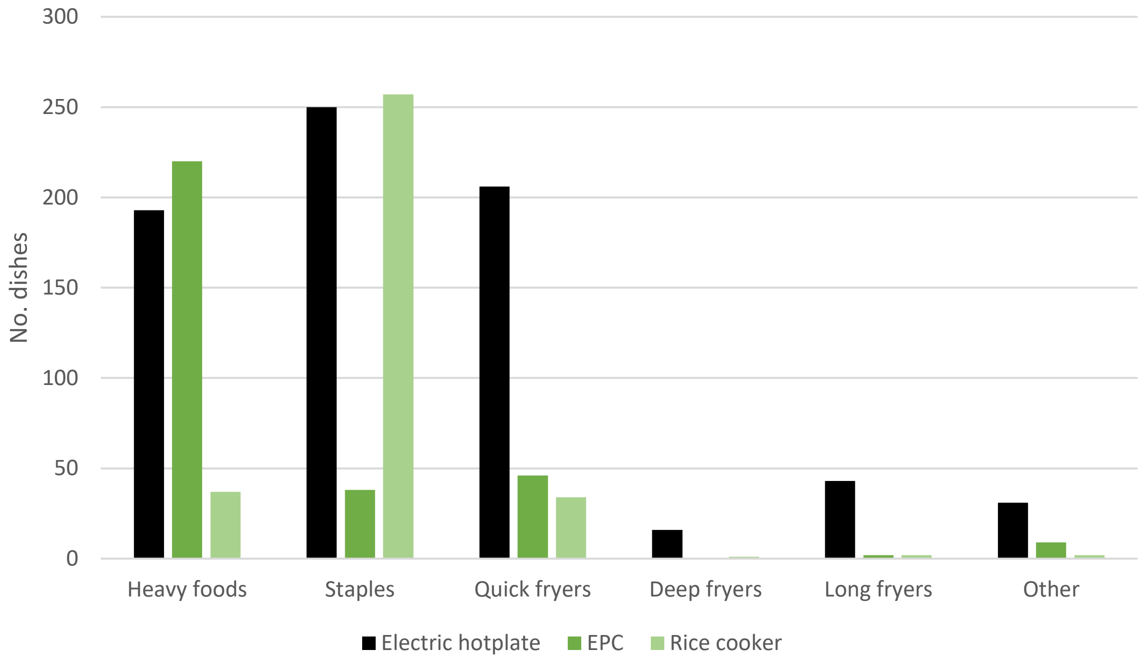

Figure 13: Number of each category of dish cooked on inefficient (hotplate) and efficient (rice cooker and EPC) appliances during the Kenya cooking diaries[8]. A full dish by dish breakdown of this data is available in *Appendix A - Typical Kenyan* foods*.*

However, the data also suggests that it is actually possible for urban Kenyan households to cook over 90% of their menu on an EPC. Referring to Table 2 and Figure 13, 'heavy foods', staples and quick fryers can all be cooked on an EPC, which together make up 91% of the urban Kenyan menu. With the exception of sausages, every dish in these 3 categories was cooked in an EPC at least once. For instance, there are 102 meal events for ugali with a hotplate, but there are also 105 events with a rice cooker and 11 with an EPC. As the cooking diary study only looked at the first month that participants used these appliances, it is likely that experimentation with cooking a broader range of dishes in the EPC didn't occur until the end of that period. What is more, as many participants were used to cooking on a 4-plate gas stove, the hotplate may well have often been chosen simply to allow more dishes to be cooked simultaneously. In contrast, poorer households with only a single burner cooking device tend to cook each dish one after the other.

Cooking solely on electricity across the three appliances was found to have a median of approximately 2kWh per household per day, whilst the 50% of the menu cooked on efficient appliances was had a median consumption of roughly 0.6kWh per household per day.

Table 3 shows the median daily energy consumption figures from the 100% electric cooking stage of the cooking diaries in each country. Using the rules described above (50% of the menu cooked on EPCs, using 50% of the energy of the hotplate), estimations are made for the median daily energy consumptions of these households of the EPC only. However, if the EPC were to cook 90% of the menu (with training and experience), total consumptions would drop further..

[8] 127 records for dishes cooked on microwaves and kettles already owned by some participants have been omitted.

Table 3: Measured and modelled energy consumption for 100% electric cooking on a mixture of inefficient and efficient appliances.

	No. complete days of data	Median daily energy consumption (kWh/ household/ day)	Household size (no. ppl)	Median per capita daily energy consumption (kWh/person/ day)
ZAMBIA				
100% electricity measured, median	99	1.63	7.9	0.21
Proportion of energy consumed by EPC cooking 50% of meals		0.55		
Total consumption if EPC at 90% of menu		*1.1*		*0.14*
TANZANIA				
100% electricity measured, (with EPC proportion modelled)	423	2.06	4.2	0.49
Proportion of energy consumed by EPC cooking 50% of meals		0.69		
Total consumption if EPC at 90% of menu		*1.44*		*0..34*
KENYA				
100% electricity measured, (with EPC proportion modelled)	431	1.4	3.1	0.46
Proportion of energy consumed by EPC cooking 50% of meals		0.47		
Total consumption if EPC at 90% of menu		*0.96*		*0.30*

User experience of EPCs

Whilst cost, driven by energy efficiency, may be a strong driver, if the cooker is not easy to use and the food is not as tasty as usual, households will be unlikely to adopt it. This section presents insights from the exit survey from the Kenya cooking diaries, which asked the households who had been using EPCs (plus rice cookers and hotplates) for a month, about their experience with this new cooking device.

'Heavy foods' such as beans or matumbo (tripe) that usually require boiling for an hour or more to soften are unsurprisingly rated as much easier to cook on the EPC than the hotplate (Figure 14). In contrast, foods that require manual heat control &/or a shallow pan, such as chapati or mandazi, are rated much easier on the hotplate.

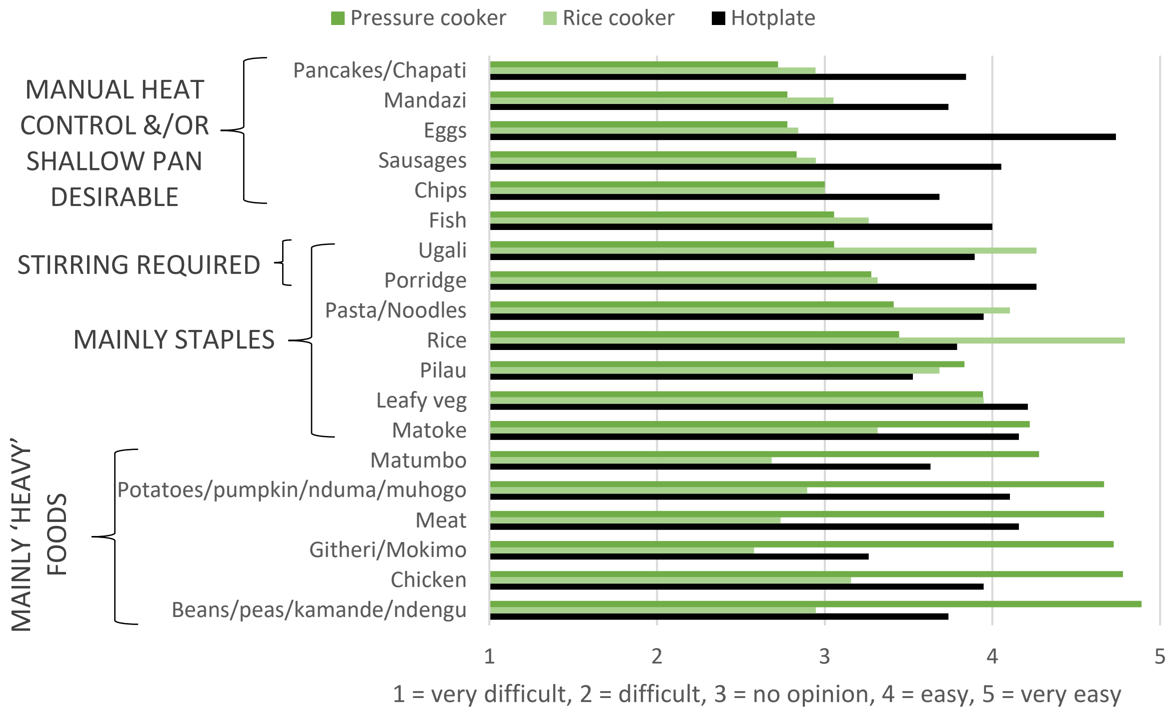

Figure 14: Average responses to the question from 20 trial households in Kenya: "how easy is it to cook each food on the eCookers?" Ranked by ease of cooking on an EPC.

Perhaps surprisingly to some, food cooked on electricity was rated as the tastiest, just ahead of LPG & charcoal (Figure 15). Wood & kerosene lag far behind. Figure 16 shows that whist some respondents missed the smokey flavour in specific foods, many did not miss it at all.

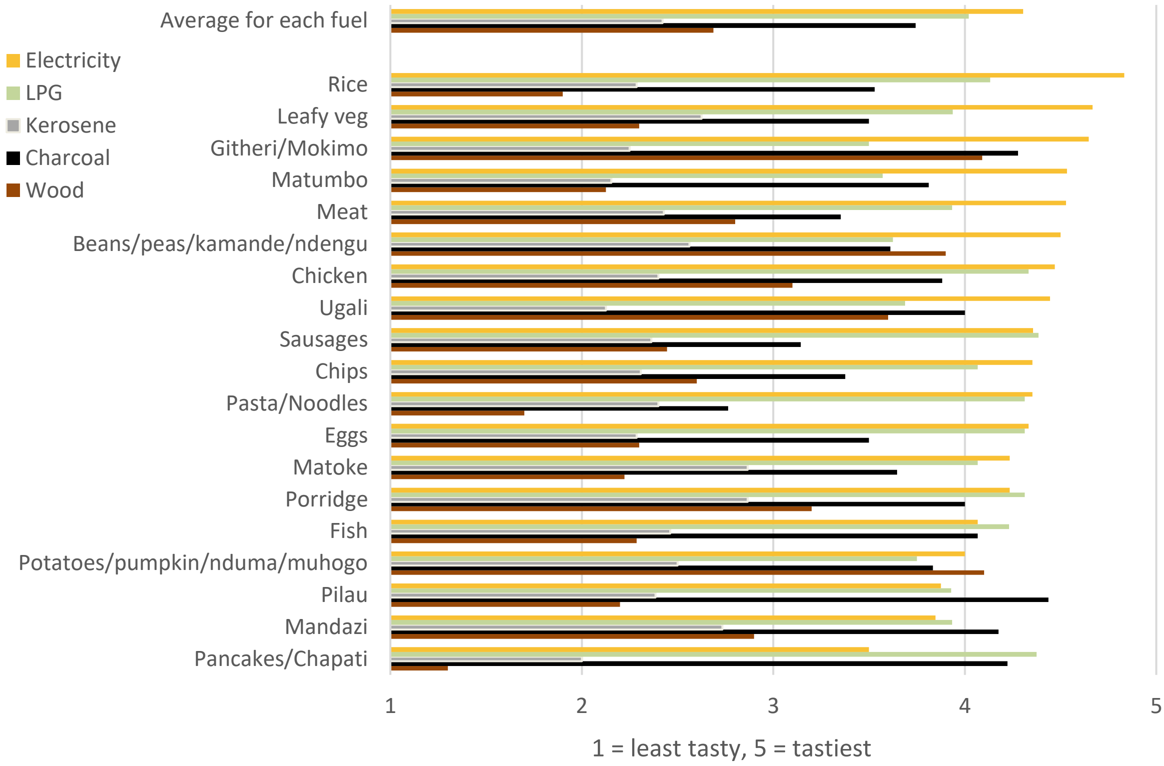

Figure 15: Average responses to the question from 20 trial households in Kenya: "Do foods taste different when cooked on different fuels? If so, please rank each fuel for each food." Foods ranked by tastiness when cooked with electricity.

Figure 16: Responses to the question from 20 trial households in Kenya : "Do you miss the smokey flavour of food? If so, for which dishes in particular?". Words sized according to the number of responses.

The automated control systems of the EPC & rice cooker makes cooking easier, enabling multi-tasking & preventing food from burning (Figure 17). Being able to cook faster & keep the kitchen clean are also both highly valued by the urban participants of the Kenya cooking diaries study, however, priorities may well be different in rural areas. Figure 18 shows that the rice cooker & EPC have clearly found a place in almost every participant's home.

Figure 17: Responses to the question from 20 trial households in Kenya: "What were the best/worst things about cooking with electricity?"

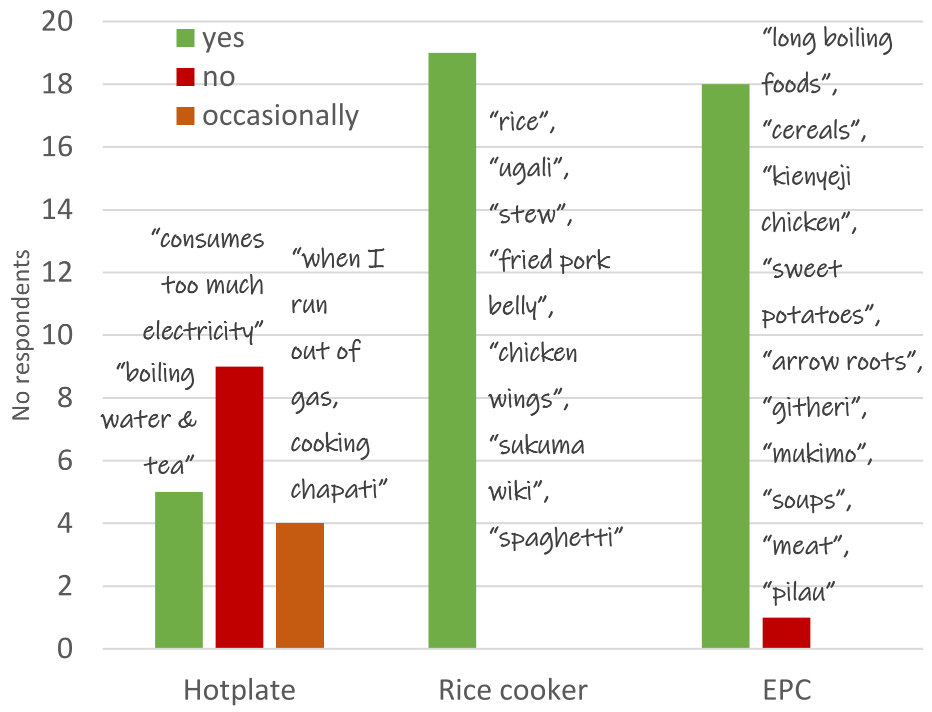

Figure 18: Responses to the question from 20 trial households in Kenya: "We are done with our survey and are leaving the cookers with you. Will you continue using the e-cookers or will you switch back to your old stove?"

Automatic vs. manual control

EPCs' automatic control systems make cooking certain dishes much easier, however the lack of manual control makes them undesirable for others. The EPC is the appliance of choice for long boiling dishes and many of the stapes, as it enables the cook to multitask, avoid burning the food and cut cooking times in half. Figure 15 suggests that existing models of EPC are already well suited to user needs, but there are clearly still minor tweaks, such as manual heat control, that could make them even more attractive. The heating element of an EPC is fundamentally the same as an electric hotplate, but controlled by a thermostat. Although most electric hotplates have the ability to control heat manually, they generally work on two principles, neither of which are satisfactory for frying:

1. turning the entire hotplate on and off using a thermostat, which when frying usually results in oscillation between burning and getting cold as the time delay between on/off cycles is usually several seconds; and

2. turning on parts of the heating coil independently, which results in uneven heating of the pan and means that only a few discreet power levels are available.

In contrast, LPG can be turned up and down almost instantly across a continuous range, from just keeping warm to full power. It is this manual controllability that makes LPG the fuel of choice for dishes that require fine control of the heating process, notably flat breads (e.g. chapati), quick fry dishes (e.g. sukuma wiki, kales) or deep fry dishes (e.g. mandazi).

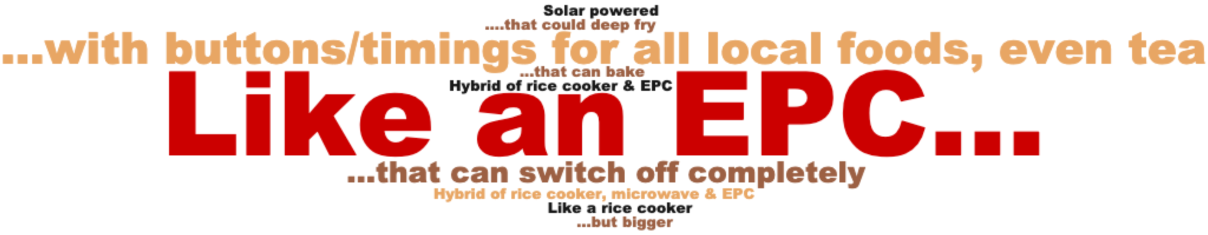

Figure 19: If you could design your own completely new eCooker, what would it be like?

Discussion

Importantly, the EPC seems to fit into East/Southern African kitchen routines where charcoal is typically most favoured, offering an attractive pathway to achieving 100% modern cooking when combined with LPG or electric hotplates. To date, many households who gain access to modern energy for cooking chose to continue purchasing charcoal for 'heavy foods', as they believe it is cheaper. Figure 11 shows that in highly deforested urban contexts such as Nairobi, this is no longer the case, as the price of charcoal has risen considerably. In such contexts. Even cooking 'heavy foods' with a hotplate is now cost comparable with charcoal. Doing so with an EPC is an order of magnitude cheaper and can cut the cooking time in half, both of which provide strong drivers to households who have partially transitioned to modern energy to stop buying charcoal and transition to a 100% modern cooking solution (see Figure 20**Error! Reference source not found.**).

Figure 20: Cooking diary participants in Nairobi, Kenya who used to fuel stack kerosene with charcoal and now use an EPC for the 'heavy foods' that were previously cooked on charcoal.

EPC design modifications that could open up new opportunities in East/Southern African markets

The evidence in this paper has shown that EPCs are clearly highly compatible with East/Southern African cooking practices, however, their potential is even greater. In European, North American and many Asian markets, EPCs are designed to be used alongside other modern cooking devices and are therefore optimised for a small range of dishes. In East and Southern African markets, it would be beneficial for EPCs to be able to cook a much broader range of dishes, so that households transitioning from charcoal are forced to light their stoves as little as possible. Table 2**Error! Reference source not found.** shows that 91% of a typical urban Kenyan menu can be cooked on EPCs already available on the market. However, Figure 13 shows that in practice, difficulties with accessing the pot to stir and the lack of manual heat control mean that everyday cooks typically only choose to use EPCs (or rice cookers) to cook half of their menu.

Several design modifications to the standard EPC designs available on the market today could open up new opportunities:

- *Deep frying* – most EPCs reach 120°C and simply cut the power, as the control system believes it is pressurised and adding more heat to the pot could be dangerous. Enabling deep frying simply requires adding an alternative set point for the control system at a higher temperature (175-190°C). This feature is already available on several models available on the market today already.

- *Manual heat control* – by enabling the user to control the amount of heat going into the pot when the lid is unlocked, the EPC may become the preferred choice for dishes that require fine control of heating, but can be cooked in a deep pot (e.g. sukuma wiki, scrambled eggs). This could be achieved very simply by having a variable thermostat that can be controlled by a knob on the front of the device, just like many hotplates. However, it is important that the time delay between on/off cycles of the hotplate is as small as possible to keep the temperature in the pot as constant as possible and avoid the food cycling between burning and getting cold. This could be achieved by using power electronics to vary input power continuously, such as PWM (Pulse Width Modulation), voltage transformers or thyristors. However, care would need to be taken to ensure that any distortion of the waveform is not detrimental to the grid that supplies it.

- *Highlighting how to cook local foods* – simply communicating to the user which foods can be cooked with the EPC and how can greatly increase the utilisation rate, likely even well beyond 50%, as over 90% of the urban Kenyan menu can be cooked in an EPC. This can be achieved in a number of ways, including clearly labelling the buttons or timer set points on the appliance itself with popular local foods, packaging EPCs with recipe books for local foods, or partnering with local distributors to engage local food bloggers and TV shows, or run live cooking demonstrations. The North American brand, Instant Pot, offers a great example of how developing supplementary resources and building a community of users can drive forward sales.

- *Battery-integration* – integrating a battery into an EPC that has been modified to run on DC power could unlock two completely new market segments, weak-grid and off-grid [22], [30]–[34]. Several DC EPCs have now appeared on the Chinese market; however, the authors are unaware of any that integrate a battery into the device. A 0.4kWh battery could enable efficient cooks to cook almost any dish, whilst a 1kWh battery would likely enable a full day's worth of EPC cooking (assuming the EPC is used for 50% of dishes, 80% DoD[9], 90% charge/discharge efficiency). A lead acid battery discharged to 80% DoD at a rate of 1C would likely degrade, making lithium iron phosphate batteries a more appropriate choice. Due to the higher cost of battery-integrated devices, a financing mechanism that allows users to pay back the cost of the device over time is likely to be necessary. Fortunately, pay as you go and micro-credit business models have spread rapidly across East Africa in recent years, meaning that a range of established solutions are now on offer, in particular in the solar lighting sector.

[9] Depth of Discharge

Conclusion

This paper has shown that there is a huge and largely untapped opportunity to market EPCs in East and Southern Africa. In particular, Uganda, Kenya, Tanzania, Ethiopia and Zambia are politically stable countries, where new energy-efficient products have already revolutionised other sectors such as lighting, and together are home to 38 million people who are grid connected yet still pay for polluting cooking fuels (charcoal and kerosene). The focus groups and cooking diaries carried out in East and Southern Africa have shown that EPCs are highly desirable to everyday cooks because they cook faster, allow multi-tasking, save money and keep the kitchen clean.

The evidence in this paper shows that EPCs are significantly more energy efficient than electric hotplates in both laboratory and real kitchen environments. The empirical data from the kitchen laboratory shows that EPCs can cook the most energy intensive dishes with just one fifth of the energy of electric hotplates. This is complimented by the results of the cooking diaries studies, which show that everyday cooks choose EPCs for about half of their cooking and that across the full range of dishes they were used for, they use approximately half the energy of electric hotplates. Cooking with both hotplates and EPCs was found to use approximately 2kWh per household per day, with the cook choosing to cook 50% of the menu on an EPC, which was estimated to use roughly 0.6kWh per household per day. However, analysis of the range of dishes that make up a typical menu and experimentation in the kitchen laboratory has shown that EPCs are capable of cooking over 90% of the typical urban Kenyan menu. Training and experience are likely to move the proportion of EPC use from 50% nearer to 90%. In poorer households which are used to only having one 'device' for cooking, the EPC is likely to be used for a greater proportion of the menu. To increase the utilisation factor even further, the design of EPCs could be modified to include deep frying, allow manual heat control and most importantly, clearly indicating how to cook local foods.

Developing battery-integrated DC EPCs could unlock two huge market segments: weak-grid and off-grid. Currently just a few factories (mainly in China) are manufacturing DC EPCs and the authors are unaware of any that are manufacturing battery-integrated DC devices. In the same way that the mobile phone unlocked a much larger market than land line phones, in particular on the African continent, DC battery-integrated cooking devices have the potential to open up huge new markets for electric cooking. As one of the most energy efficient electric cooking devices available that is culturally well matched to East and Southern African cooking practices, there is no doubt that the EPC will be the first of many DC battery-integrated cooking devices to reach scale across the region.

Forthcoming activities under the Modern Energy Cooking Services (MECS) programme (www.MECS.org.uk) that will support the development of EPCs for the East and Southern African markets include:

- Global LEAP Awards for EPCs – in collaboration with the Efficiency for Access programme, the Global LEAP Awards aim to identify the 'best in class' efficient appliances. Manufacturers are invited to submit their products for testing and appliances are rated by energy-efficiency, usability, durability and cost and to produce a consumer's guide. Past winners of Global LEAP awards have been supported to disseminate their products with cash prizes, access to grant funding and results-based financing schemes.

- Challenge funds – a series of challenge funds enable organisations with innovative ideas to take the next step towards developing commercially viable modern energy cooking products and services. This can include initial feasibility studies, design, prototyping, field testing, social marketing and more.

- New research methodologies and new contexts – further cooking diaries, focus groups, the kitchen laboratory and other innovative methodologies will be employed in more countries and across a broader range of society throughout Sub-Saharan Africa and South/Southeast Asia. This aims to offer a greater understanding how different cultures cook and what the key opportunities are for transitioning to modern energy for cooking are in each context.

References

[1] IMARC, "Multi Cooker Market: Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2019-2024," 2019.

[2] Sustainable Energy for All, "SEforAll.org," 2019. [Online]. Available: https://www.seforall.org/. [Accessed: 12-Jul-2019].

[3] WHO, "Household air pollution and health," 2018. [Online]. Available: https://www.who.int/en/news-room/fact-sheets/detail/household-air-pollution-and-health. [Accessed: 25-Mar-2019].

[4] S. Batchelor, E. Brown, N. Scott, and J. Leary, "Two Birds, One Stone—Reframing Cooking Energy Policies in Africa and Asia," *Energies*, vol. 12, no. 9, p. 1591, 2019.

[5] D. Ockwell *et al.*, "Can Pay-As-You-Go, Digitally Enabled Business Models Support Sustainability Transformations in Developing Countries? Outstanding Questions and a Theoretical Basis for Future Research," *Sustainability*, vol. 11, no. 7, p. 2105, 2019.

[6] KPLC, "Pika na Power," 2019. [Online]. Available: https://www.facebook.com/PikaNaPower/. [Accessed: 12-Jul-2019].

[7] Power Africa, "Development of Kenya's power sector 2015-2020," Nairobi, Kenya, 2015.

[8] EWURA, "Annual Report for the Year Ended 30th June 2016," Dar es Salaam, Tanzania, 2017.

[9] A. Eberhard, K. Gratwick, and L. Kariuki, "A review of private investment in Tanzania's power generation sector," *J. Energy South. Africa*, vol. 29, no. 2, pp. 1–11, 2018.

[10] Export.gov, "Tanzania - Energy," 2019. [Online]. Available: https://www.export.gov/article?id=Tanzania-Energy. [Accessed: 25-Mar-2019].

[11] EEG, "Tanzania Energy Sector Overview," Energy for Economic Growth Research Programme, 2016.

[12] World Bank, "World Development Indicators (WDI) | Data Catalog," 2019. [Online]. Available: https://datacatalog.worldbank.org/dataset/world-development-indicators. [Accessed: 12-Jul-2019].

[13] World Bank, "Getting Electricity - Doing Business," 2019. [Online]. Available: https://www.doingbusiness.org/en/data/exploretopics/getting-electricity. [Accessed: 12-Jul-2019].

[14] ZESCO, "Current ZESCO Tariffs," 2019. [Online]. Available: http://www.zesco.co.zm/customerCare/tariffs. [Accessed: 12-Jul-2019].

[15] KPLC, "Implementation of New Tariffs," 2019. [Online]. Available: https://kplc.co.ke/img/full/rZr6LLCjVqVw_1st November 2018 - Tarrifs.jpg. [Accessed: 12-Jul-2019].

[16] TANESCO, "Bei Za Umeme Zilizoidhinishwa," 2019. [Online]. Available: http://www.tanesco.co.tz/index.php/customer-service/tariffs/7-bei-za-umeme-zilizoidhinishwa/file. [Accessed: 12-Jul-2019].

[17] Umeme, "Power Tariffs," 2019. [Online]. Available: https://www.umeme.co.ug/tariffs. [Accessed: 12-Jul-2019].

[18] Ethiopian Electric Utility, "New Tariff," 2019.

[19] Adam Smith International, "Black gold — the real cost of charcoal in Africa," 2016. [Online]. Available: https://medium.com/@adamsmithinternational92/black-gold-the-real-cost-of-charcoal-in-africa-7d241a2f3084. [Accessed: 25-Mar-2019].

[20] S. V. Lall, J. V. Henderson, and A. J. Venables, *Africa's Cities - Opening Doors to the World*, vol. 15, no. 3. World Bank, UK AID, 2017.

[21] WHO, "Household energy database," *WHO*. World Health Organization, 2017.

[22] J. Leary, S. Batchelor, M. Leach, E. Brown, and A. Alsop, "eCook Global Market Assessment Where will the transition take place first ?," Implemented by Gamos, Loughborough University, University of Surrey. Funded by DfID, Innovate UK, Gamos, 2018.

[23] GOGLA, Lighting Global, and Berenschot, "Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data - JULY-DECEMBER 2016, PUBLIC REPORT," 2016.

[24] Instant Pot, "History of the Pressure Cooker," 2019. [Online]. Available: https://www.instantpot.co.uk/pressure-cooker-history/. [Accessed: 13-Jul-2019].

[25] S. Batchelor A Talukder, R Uddin, S K Mondal, S Islam, R Redoy, R Hanlin and M. Rezwan Khan; "Solar e-Cooking: A Proposition for Solar Home System Integrated Clean Cooking," *Energies*, vol. 11, no. 11, p. 2933, Oct. 2018.

[26] T. Couture and D. Jacobs, "Beyond Fire: How to Achieve Electric Cooking," HIVOS & World Future Council, 2019.

[27] J. Leary *et al.*, *The Kenya eCookBook: Beans & Cereals Edition*, no. September. Nairobi, Kenya: Available from: www.MECS.org.uk, 2015.

[28] R. Bailis and R. Edwards, "Kitchen Performance Test (KPT) Version 3.0," no. January, pp. 1–32, 2007.

[29] R. Bailis, D. Ogle, N. MacCarty, and D. Still, "The Water Boiling Test (WBT) Version 3.0," *Heal. (San Fr.*, no. January, pp. 1–38, 2007.

[30] G. Zubi, F. Spertino, M. Carvalho, R. S. Adhikari, and T. Khatib, "Development and assessment of a solar home system to cover cooking and lighting needs in developing regions as a better alternative for existing practices," *Sol. Energy*, vol. 155, pp. 7–17, 2017.

[31] S. Batchelor, E. Brown, J. Leary, N. Scott, A. Alsop, and M. Leach, "Solar electric cooking in Africa: Where will the transition happen first?," *Energy Res. Soc. Sci.*, vol. 40, 2018.

[32] E. Avila, G. Lawrence, J. Lin, N. Howard, B. Mohamed, and H. Ally, "The Desirability of Clean Cooking in Off-Grid Households," A2E1, Arusha, Tanzania, 2019.

[33] S. Batchelor *et al.*, "eCook Tanzania Country Report - Opportunities and Challenges in Tanzania," Dar es Salaam, Tanzania. Available from: https://elstove.com/innovate-reports/, 2018.

[34] J. Leary *et al.*, "eCook Zambia Prototyping Report," Available from: https://elstove.com/innovate-reports/, 2019.

Appendices

Appendix A - Typical Kenyan foods

'*Heavy'* foods like beans, meat stew or makande/githeri generally require boiling for 60 minutes or more. They are easy to cook on an EPC, which can offer significant energy & time savings over electric hotplates, or a rice cooker with moderate energy savings.

- **Githeri/mokimo** - beans & maize stew, usually wet fried/mashed potatoes with maize/beans/peas/pumpkin leaves. Many people will pre-cook (boil) githeri in bulk and wet fry portions throughout the week.
- **Beans/peas/kamande/ndengu** - beans/peas/lentils/green grams, usually stewed. Typically dried, so require rehydrating as well as cooking - some people soak before cooking, others just cook for longer. Many people will pre-cook (boil) in bulk and wet fry portions throughout the week.
- **Chicken, meat** – Usually wet fry (stew) or dry fry. Many people will pre-cook (boil) meat in bulk and wet fry portions throughout the week.
- **Matumbo** - Tripe, usually wet fried

'***Staple'*** foods and water that require boiling for 15 minutes or more can also be cooked on an EPC, with moderate energy & time savings or rice cooker with moderate energy savings.

- **Heating water** - for tea/coffee, bathing, drinking etc.
- **Pasta/noodles** - Boiled and then often wet fried.
- **Porridge** - Requires regular stirring, but perhaps not in the electric pressure cooker. Need to do more experimentation on this.
- **Potatoes/pumpkin/nduma/muhogo** - Nduma=arrow roots, muhogo=cassava. Usually boiled, sometimes wet fried. Will need to check process to differentiate boiled and stewed.
- **Matoke** - Bananas. Usually wet fried, sometimes boiled. Will need to check process to differentiate boiled and stewed.
- **Rice** - Just boiled.
- **Pilau -** A combination of meat stew and rice. May use meat stew/stock pre-cooked on a previous occasion, or may cook the meat especially for this dish. May involve some frying of onions too. Sometimes potato is even thrown in!
- **Ugali** - Kenyans usually bring water to the boil, turn down the heat, add maize flour, stir, repeating a few times, then leaving to simmer until the mixture has reached the desired consistency.

'Quick fry' foods can also be cooked on an EPC or rice cooker, but some households may be reluctant to try and/or there are limited energy savings.

- **Eggs** - Could be boiled, fried or omelette. If omelette, can often be combined with potatoes (chips mayai), which may need deep frying first.
- **Fish** - Typically wet or dry fried whole or in fillets.
- **Leafy veg** - Sukuma wiki, spinach, etc. Typically dry fried, sometimes with onions.
- **Sausages** – Typically shallow fried.

'Long fry and deep fry'foods are very difficult to cook on an EPC or rice cooker, as they require precise temperature control.

- ***Pancakes/Chapati*** - Shallow fried one by one in a shallow pan, as they must be flipped and swapped over many times. Requires low heat evenly distributed throughout the pan.
- ***Chips*** - Deep fried. If oil too hot, they burn, if too cold, they go soggy.
- ***Mandazi*** - Donuts. As above.

	Electric hotplate	EPC	Rice cooker	Totals	% efficient appliance (EPC + rice cooker)
Heavy foods	**193**	**220**	**37**	**450**	**57%**
Beans/peas	80	87	6	173	54%
Matumbo	3	8	0	11	73%
Githeri/mokimo	24	13	8	45	47%
Meat	50	80	9	139	64%
Pilau	4	2	4	10	60%
Fish	23	11	8	42	45%
Chicken	9	19	2	30	70%
Staples	**250**	**38**	**257**	**545**	**54%**
Ugali	102	11	105	218	53%
Potatoes/pumpkin	30	14	6	50	40%
Pasta/noodles	25	1	17	43	42%
Porridge	57	1	2	60	5%
Rice	36	11	127	174	79%
Quick fryers	**206**	**46**	**34**	**286**	**28%**
Sausages	10	0	0	10	0%
Eggs	86	1	1	88	2%
Leafy veg	110	45	33	188	41%
Deep fryers	**16**	**0**	**1**	**17**	**6%**
Chips	7	0	1	8	13%
Mandazi	9	0	0	9	0%
Long fryers	**43**	**2**	**2**	**47**	**9%**
Chapati/pancake	43	2	2	47	9%
Other	**31**	**9**	**2**	**42**	**26%**
Other	31	9	2	42	26%
TOTALS	**739**	**315**	**333**	**1387**	**47%**

Table 4: Number of each dish cooked on inefficient (hotplate) and efficient (rice cooker and EPC) appliances during the Kenya cooking diaries[10].

[10] 127 records for dishes cooked on microwaves and kettles already owned by some participants have been omitted.

Appendix B – Regional colour coding and two-letter country codes

AIMS
CV Cabo Verde
KM Comoros
MV Maldives
MU Mauritius
ST Sao Tome & Principe
SC Seychelles

CENTRAL AFRICA
CM Cameroon
CF Central African Republic
TD Chad
CG Congo
CD DRC
GQ Equatorial Guinea
GA Gabon

CENTRAL AMERICA & CARRIBBEAN
BZ Belize
CR Costa Rica
CU Cuba
DM Dominica
DO Dominican Republic
SV El Salvador
GD Grenada
GT Guatemala
HT Haiti
HN Honduras
JM Jamaica
NI Nicaragua
PA Panama
LC Saint Lucia
VC Saint Vincent & the Grenadines

CENTRAL ASIA & NORTH KOREA
AM Armenia
AZ Azerbaijan
BY Belarus
GE Georgia
KZ Kazakhstan
KG Kyrgyzstan
MD Moldova
MN Mongolia
KP North Korea
RU Russia
TJ Tajikistan
TM Turkmenistan
UA Ukraine
UZ Uzbekistan

EAST AFRICA
BI Burundi
DJ Djibouti
ER Eritrea
ET Ethiopia
KE Kenya
RW Rwanda
SO Somalia
SS South Sudan
SD Sudan
TZ Tanzania
UG Uganda

EUROPE
AL Albania
BA Bosnia & Herzegovina
BG Bulgaria
MK Macedonia
ME Montenegro
RO Romania
RS Serbia

INDIA & CHINA
CN China
IN India

MIDDLE EAST
IR Iran
IQ Iraq
JO Jordan
LB Lebanon
PS Palestine
SY Syria
TR Turkey
YE Yemen

NORTH AFRICA
DZ Algeria
EG Egypt
LY Libya
MA Morocco
TN Tunisia
EH Western Sahara

PACIFIC ISLANDS & PNG
AS American Samoa
CK Cook Islands
FJ Fiji
KI Kiribati
MH Marshall Islands
FM Micronesia
NR Nauru
NU Niue
PW Palau
PG Papua New Guinea
WS Samoa
SB Solomon Islands
TO Tonga
TV Tuvalu
VU Vanuatu

SOUTH AMERICA & MEXICO
AR Argentina
BO Bolivia
BR Brazil
CL Chile
CO Colombia
EC Ecuador
GY Guyana
MX Mexico
PY Paraguay
PE Peru
SR Suriname
UY Uruguay
VE Venezuela

SOUTH ASIA (EXCL. INDIA)
AF Afghanistan
BD Bangladesh
BT Bhutan
NP Nepal
PK Pakistan
LK Sri Lanka``

SOUTHEAST ASIA
KH Cambodia

SOUTHERN AFRICA
AO Angola

WEST AFRICA
BJ Benin

ID	Indonesia	BW	Botswana	BF	Burkina Faso
LA	Laos	LS	Lesotho	CI	Côte d'Ivoire
MY	Malaysia	MG	Madagascar	GM	Gambia
MM	Myanmar	MW	Malawi	GH	Ghana
PH	Philippines	MZ	Mozambique	GN	Guinea
TH	Thailand	NA	Namibia	GW	Guinea-Bissau
TL	Timor-Leste	ZA	South Africa	LR	Liberia
VN	Vietnam	SZ	Swaziland	ML	Mali
		ZM	Zambia	MR	Mauritania
		ZW	Zimbabwe	NE	Niger
				NG	Nigeria
				SN	Senegal
				SL	Sierra Leone
				TG	Togo

Table 5: Regional colour coding and two-letter country codes used throughout this report.