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Adoption of electricity for clean cooking in Cameroon: A mixed-methods field evaluation of current cooking practices and scale-up potential

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ABSTRACT

Over 61 % of Cameroonians continue to rely on polluting fuels for cooking with negative consequences for health and the environment. To understand current and potential use of electricity as a clean energy source for cooking (eCooking), we conducted a mixed-methods study among households from three major urban/peri-urban centres in Cameroon: Douala, Yaoundé and Mbalmayo. Survey data from 1509 households, followed by an intensive one week "cooking diary" with 25 primary cooks and 10 semi-structured qualitative interviews, provided detailed information on cooking behaviours and fuel choices. Liquefied petroleum gas (LPG) was preferred for daily cooking, with firewood or charcoal used for traditional dishes. Electricity was used only as secondary or tertiary fuel by 20 % ($n = 311$) of survey respondents and only used once a week or less, mainly to cook rice and pasta or boiling water. For those households using eCooking, the most common appliances were rice cookers and hobs; smart-meters attached to the eCooking appliances showed high voltage fluctuation (<160 V to 250 + V) which are suboptimal for sustained eCooking use. To scale up adoption of electricity for clean cooking policies for (i) subsidising cost, (ii) strengthening reliability of service provision and (iii) addressing safety concerns are needed in addition to awareness-raising of the benefits and practicalities of using eCooking appliances for everyday meals.

Introduction

It is estimated that in Sub-Saharan Africa (SSA) close to 1 billion people continue to rely on polluting fuels (e.g. firewood and charcoal) for their daily cooking resulting in substantial negative impacts on air quality and public health, environment (through deforestation) and climate (Stoner et al., 2021). Globally, a total of 2.3 million annual premature deaths were attributed to the exposure to Household Air Pollution (HAP) from domestic combustion of solid fuels and kerosene in 2019 (IHME, 2021). Cameroon is a lower-middle income country which has the largest economy in the Central African Economic and Monetary Community (CEMAC). Nearly 17 million Cameroonians (61.9%) cook primarily with firewood. The most common clean alternative for cooking is with liquefied petroleum gas (LPG) used by approximately 25 % of the population (INS, 2020). In Cameroon, exposure to HAP from cooking with polluting fuels resulted in an estimated 12,067 premature deaths (5.8 % of all deaths) and 624,292 disability-adjusted life years (DALYs) in 2019 (IHME, 2021). This substantive health burden is disproportionately borne by women and girls due to traditional gender-based roles around cooking, making exposure to HAP an important gender inequality issue. To address the global burden of disease from exposure to HAP, the WHO published Indoor Air Quality Guidelines for Household Fuel Combustion in 2014 with the explicit recommendation for scaling transition to clean, modern energy for cooking in low and middle-income countries (LMICs) in order to reach universal access for all by 2030 (WHO, 2014).

From 2013 to 2016, the Cameroonian government designed and launched a number of intersectoral master plans to support expansion of the clean modern energy sector, including the *Electricity Sector Development Plan* (PDSE) (MINEE, 2014), the *Masterplan for Rural Electrification* (PDER) (MINEE, 2016) and the *Liquefied Petroleum Gas (LPG) Masterplan* (a national strategy to bring clean cooking to 58 % of the population by 2030 (Bruce et al., 2018; Rubinstein et al., 2021). The political drivers for the LPG Masterplan were to reduce reliance on polluting solid fuels (and associated HAP exposure) to (i) reduce

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mortality and morbidity, (ii) protect forests, (iii) save time for women from reduced harvesting at no expense to climate and (iv) for energy security. A modelling study of the Cameroon LPG Masterplan demonstrated that achieving the 58 % national LPG adoption target would significantly reduce emissions of short-lived climate warming pollutants (e.g. black carbon and methane) produced by the combustion of solid fuels, leading to a global cooling of −0.1 m °C in 2030 (Kypridemos et al., 2020). This was in addition to the significant health gain including 28,000 deaths and 770,000 disability-adjusted life years (DALYs) averted by 2030 (Kypridemos et al., 2020). Despite these clear health and climate gains, research has shown that achieving this aspirational scale is hampered by the perceived cost of switching to LPG (for the initial equipment and recurrent fuel outlays) particularly in rural areas, where access to free firewood is common and road quality and LPG supply infrastructure might be limited (Pope et al., 2018a; Pye et al., 2020; Ronzi et al., 2019). If the Cameroon government is to achieve such an aspirational scale, consumer finance strategies and infrastructure expansion will need to be in place to support low-income earners to make the transition, as mentioned in the LPG Masterplan (GLPGP, 2018; Pope et al., 2018b).

Scaling adoption and use of electricity for clean cooking in Cameroon is considerably less advanced and more difficult to achieve, at least in the short to medium term (Stoner et al., 2021). The government has outlined a detailed and ambitious development plan to make electricity available to the majority of its population, although its use for cooking is not a primary focus. As of 2018, just under two-thirds (60 %) of the population had access to electricity (90 % of urban and 26.7 % of rural areas) (INS, 2020). The use of electricity as a clean energy source for cooking (eCooking) is not currently promoted nor included in any national policy target/ strategies concerning universal energy access (e.g. the Cameroon Sustainable Energy for ALL Action Agenda (SEforALL, 2020). As of 2018, only 0.8 % of the population reported using electricity as a primary fuel for cooking (INS, 2020). Based on a literature review of the energy sector in Cameroon, it is clear that the main goal of the Cameroonian Electrification Master Plan (PDSE) was to attain the capacity to produce and expand the electric grids needed to provide enough energy for the industrial sector and for future exportation (Rubinstein et al., 2021). In addition to lack of policy, there are a number of practical limitations in the transition to electricity for everyday cooking, documented in many other SSA countries. These include (i) the high cost of electricity rates and eCooking appliances in some settings (Grimm et al., 2013; Price et al., 2022) (ii) the lack of a reliable and consistent service provision of electricity needed for cooking (Cole et al., 2018; Lombardi et al., 2019; Meles et al., 2021), and (iii) a reluctance by the population to adopt electricity as a replacement of traditional fuels due to safety concerns, cultural preferences and perceived tastes (Rubinstein et al., 2021).

There is currently a strong drive to encourage global population transition from reliance on fossil fuels for domestic and industrial energy to clean renewable sources (ESMAP, 2020). This has been linked to the clean cooking agenda for SSA where currently the best available option for the scale-up of clean fuel to address the burden of disease from exposure to HAP is with LPG (Čukić et al., 2021; IEA, 2021; Pachauri et al., 2021; Puzzolo et al., 2020; Van Leeuwen et al., 2017). However, the rising fossil fuel prices post-Covid 19 could push LPG out of reach of many (Pachauri et al., 2021; Shupler et al., 2022) unless price control measures are put in place or bio-LPG local production gets scaled up (Chen et al., 2021). The potential of cooking with electricity, produced through renewable energy sources, has received much attention in this space with strong support from the international donor community (ESMAP, 2020; Leary et al., 2021a). Despite the expanding production of renewable electricity in many SAA countries, scaled adoption of eCooking has remained sub-optimal. In Uganda, for example, 92 % of on-grid electricity is generated through renewable sources (predominately hydropower) (Price et al., 2022) and is accessible to half the population but despite this, there is a low uptake of eCooking (with only 1.4 % of households reporting using electricity and/or LPG as their primary cooking fuel in 2020) (UNHS, 2021). To address this low uptake in eCooking, a discounted cooking tariff was introduced by the main utility service provider (Umeme) in 2021 to promote eCooking in the country (MEMD, 2022).

While local production of renewable electricity does not correlate with the uptake of eCooking (also in the case of Cameroon), it creates a favorable climate for attracting donors to invest and creates the supportive conditions necessary for scaling up eCooking. Reliable and sustainable generation of electricity (in addition to the production of sufficient capacity) are significant factors that affect population adoption of eCooking; many countries with high production of electricity through renewable energy sources still struggle to meet demand. External factors can also impact this capacity. For example in Zambia over 90 % of electricity is generated through hydropower (Luzi et al., 2019) and a lack of rainfall in 2014/15 led to an insufficient supply of electricity to meet demand (Kesselring, 2017). This led to a reduction in reliability of supply with 'load shedding' negatively impacting consumers years later (Njobvu et al., 2021). Accordingly, the Zambian government pledged to reduce cooking with electricity from 35 % to 20 % by 2030 in urban areas, with an ambition to expand LPG adoption for domestic use to lessen the burden of electricity on the grid articulated through their SEforAll cooking scenario goals for 2030 (MOE, 2019). In countries with sufficient capacity of renewable electricity, for example, Ethiopia, which generates on-grid electricity with 98 % renewable sources and where consumers have some of the lowest electricity tariff rates in SSA (Sieff et al., 2022), a scaled transition to eCooking has still been sub-optimal. Although there are established users of electricity in the country, there is still a very low uptake of eCooking as a primary source of cooking energy with only 4 % of households, nationally (Padam et al., 2018). In addition, fuel staking with other fuels (including polluting solid fuels) is common even in families that report primarily cooking with electricity (Padam et al., 2018). South Africa is unique in SSA, as the majority of the population have grid-connected access to sufficient electricity for cooking and heating (IEA, 2020). This widespread access has been facilitated through an abundance of availability of coal, allowing for subsidized coal-produced electricity. This has led to South Africa being one of world's most carbon-intensive economies (Alton et al., 2014).

Given the increasing interest in scaling eCooking from renewable energy sources in SSA and the lack of in-depth information on the current usage of electricity and electrical appliances for cooking in many of these countries, the main aim of the current study was to understand current and potential use of electricity as clean household energy for cooking in the urban and peri-urban context of Cameroon, where access to grid-electricity is high. The study had two specific objectives, namely (i) to explore current and aspirational use of electricity for cooking as an alternative to polluting solid fuels, and (ii) to monitor current cooking practices and fuel(s) use in order to explore barriers and enablers for scaling the adoption of electricity/ electrical cooking appliances in Cameroon.

Methods

Study setting and design

The study was conducted in the two main cities of Cameroon – Douala (commercial capital) and Yaoundé (political capital) – and in a peri-urban town on the outskirts of Yaoundé (Mbalmayo). The locations were chosen as the most likely to include households using electrical appliances for cooking in Cameroon. Within each city, four neighbourhoods were chosen to ensure the inclusion of communities with reliable access to electricity. Affluent neighborhoods in Douala were selected to increase the likelihood of identification of eCooking, including Kotto and Bonamoussadi. To contrast the use of modern cooking energy sources, two low-income neighborhoods were also selected (Makepe-Logpom and Logbessou). Likewise, in Yaoundé, two affluent

(Simbock and Biyemassi) and low-income (Etougebe and Akok Ndoe) neighborhoods were chosen for the study. The final study location, Mbalmayo, is a small town of 60,000 inhabitants located 48 km south of Yaoundé with good road and electricity access.

The study adopted a mixed-methods implementation research design conducted over three phases. Phase 1 involved a cross-sectional survey targeted at the primary cook of the household. The survey questions focused on fuel and cooking practices, current and aspirational use of electricity and eCooking appliances, perception of electricity and electric pressure cookers (EPC), as well as details of how electricity and LPG are used concurrently for cooking in households that have transitioned to clean energy. The survey questionnaire was adapted from three standardized questionnaires: (i) the WHO harmonized survey questions for monitoring household energy use for tracking progress in Sustainable Development Goal 7 (SDG7) (WHO, 2019), (ii) the World Bank Multi-Tier Energy Access Tracking Framework Global Survey (ESMAP, 2018) and (iii) survey questions developed by the CLEAN-Air(Africa) Global Health Research Group (Shupler et al., 2021).

Phase 2 incorporated detailed “cooking diaries” following an adapted standardized protocol developed for the assessment of eCooking in LMICs countries by the Modern Energy Cooking Services research consortium (Leary et al., 2019a). The cooking diaries were completed by a purposive sample of 25 households selected from Phase 1 as users of modern cooking fuels (LPG and electricity). This sample selection is consistent with previous MECS work in Kenya, Tanzania and Zambia (an average of 15–22 households per study) (Jones et al., 2021; Leary et al., 2019a,b,c). Participants registered their daily cooking activities (including the type of food, time of cooking and fuel/ energy used) recorded over a 7–10 day period. The recording length was slightly reduced from 14 days to maximize compliance in the study reducing the potential for bias in self-reporting and study fatigue, whilst capturing cooking activities carried out across the whole week (including weekends). To minimize the risk of bias, our field team was extensively trained to minimize impact on behavior, and direct observations that could alter cooking behavior were avoided. Self-reporting was conducted with a very familiar mobile phone application that all participants had installed on their phones (*WhatsApp*), and objective monitoring of electricity consumption for cooking was conducted through smart meter technology (see section 2.2 for further details).

Phase 3 included semi-structured qualitative interviews (SSI) conducted with a representative sample of 10 cooks who took part in the cooking diary study (spanning all types of eCooking appliances identified in the community). The SSIs explored the cooks' preferences of fuels/ appliances for cooking different meals, perceptions about the use of electricity for cooking, as well as barriers and facilitators for a transition from the use of solid fuels to clean modern energy.

Data collection

The study was conducted between April and August 2021 by trained field workers who had participated in previous data collection in the same study communities (Shupler et al., 2021). Phase 1 cross-sectional household surveys were completed in June 2021 and involved a target sample of 1500 households (500 from each location). The households were selected through (i) random cluster sampling in Douala and Yaoundé among pre-selected affluent and low-income neighbourhoods, and (ii) random sampling at the health sector level in Mbalmayo.

Survey data were collected electronically through smart phones used by the fieldworkers using Mobenzi Researcher software (https://www.mobenzi.com). Surveys were conducted in French or English, depending on the participant's choice of language.

Phase 2 ‘cooking diaries’ were completed in July 2021. Participants were selected from survey participants of Phase 1, if they (i) reported using at least one eCooking appliance, even if occasional usage, (ii) consented to have an electric-smart meter reader installed on the eCooking appliance that they mostly used, and (iii) owned a smartphone to self-report cooking activities as they were carried out administered through a bespoke survey recorded through the WhatsApp software (*WhatsApp Bot*). The survey was developed and hosted by the Access to Energy Institute (A2EI) for research purposes and included questions on daily cooking activities, type of fuel used for cooking, type of meal cooked, overall cooking time of the different dishes and the type of foods cooked, selected from a customized list of the most popular dishes for the selected study population (A2EIb, 2021). All participants received training in answering the *WhatsApp Bot* survey (i.e. answering simple questions using their standard Whatsapp Application on their smartphones – all participants were familiar with the App prior to the recruitment in the study).

Smart meter electric instruments (Model: DDZY1737, Chengdu Hop Technology Co., Ltd) were connected to the most frequently used eCooking appliance/stove in each household using electricity for cooking (one meter per household). The smart meters automatically captured data on electrical usage over 1 to 5-min sampling intervals during cooking (A2EIb, 2021). The *WhatsApp Bot* survey was used to record the smart meter readings before and after each cooking event (recorded according to the type of food cooked). Training in reading the display of the meters was provided to participants with the meters being left in situ for approximately 4 weeks. The smart-meter data complemented the self-reported information from the WhatsApp cooking diary answers and provided objective data on the use of eCooking over a longer timeframe, ensuring objective and reliable recording of data on cooking activities.

For LPG using participants, additional questions asked about the weight of the LPG cylinder before and after cooking. For this purpose high precision weighing scales (CAMRY, Model ACS30-JE-21B) were used to measure the amount of gas consumed per meal in each cooking event in which the LPG stove was used. Participants were fully trained on the day of recruitment and asked to keep the cylinders on top of the scales for the entire duration of the study as well as to record the cylinder weight from the scale display before and after each cooking event through the *WhatsApp Bot* survey. For all households, questions were asked about the meals prepared each day over a 7 to 10 day period. Participants were instructed and reminded to maintain their normal cooking routines during the cooking diary study.

For Phase 3, SSI were conducted to explore experiences of using various eCooking appliances as well as gas for cooking, with a focus on exploring perceived barriers and facilitators to scaling use of these clean cooking options. Participants were purposively selected to reflect a range of socio-economic status and family size, and based on (i) high compliance to the *WhatsApp Bot* diary survey, (ii) use of eCooking appliances, (iii) availability to join the interview. The interviews were conducted by trained fieldworkers fluent in both French and English and recorded digitally.

Data analysis

Data on household characteristics, fuel use and cooking practices were summarised using descriptive statistics and differences were evaluated using appropriate hypothesis tests for continuous (*t*-test/ Wilcoxon) and categorical (Chi-squared test) data. Multivariable mixed logistic regression was used to obtain adjusted odds ratios (aOR) evaluating the association between household characteristics and any use of electricity for cooking adjusting for potential confounders and the clustering effect of the different locations.

To evaluate the association between socio-economic status and use of electricity, the revised multidimensional poverty index (MPI) (Pacifico & Poege, 2017) was used with a score constructed based on key variables including level of education, paid job of the household head, monthly income, and ownership of a car, house, land and/or household assets (e.g. refrigerator, radio, television set, computer and internet connection). The score includes several overlapping domains of deprivation and collates into one consistent parametric class of multidimensional poverty (Vollmer & Alkire, 2020), and ranges from 0 (no deprivation) to 1 (total deprivation – based on all indicators included in the score). An arbitrary cutoff of 0.66 is used to define deprivation. All analyses were conducted using Stata v16 software (StataCorp. 2019. College Station, TX: StataCorp LLC).

The main results from Phase 2 (cooking diaries) were summarized in tables and graphs.

The SSIs (Phase 3) were recorded and transcribed verbatim. Preliminary codes were assigned to the transcripts and used to identify and describe the main themes from the interviews using thematic analysis (Guest et al., 2012).

Ethical approval

National Cameroon ethical approval was obtained from the Institutional Ethics Committee for Research in Human Health of the University of Douala on July 2020 and the Centre Regional Ethics Committee for Human Health Research (CRECHHR-Ce) N°1128 on 12/02/2021. Institutional ethical approval was obtained from the Central University Research Ethics Committees at the University of Liverpool on 18/03/2021.

Results

Phase 1: household surveys

A total of 1509 consenting primary cooks completed households surveys between April and May 2021 (Douala $n = 501$, Yaoundé $n = 507$ and Mbalmayo n = 501). Characteristics of respondents are shown in Table 1.

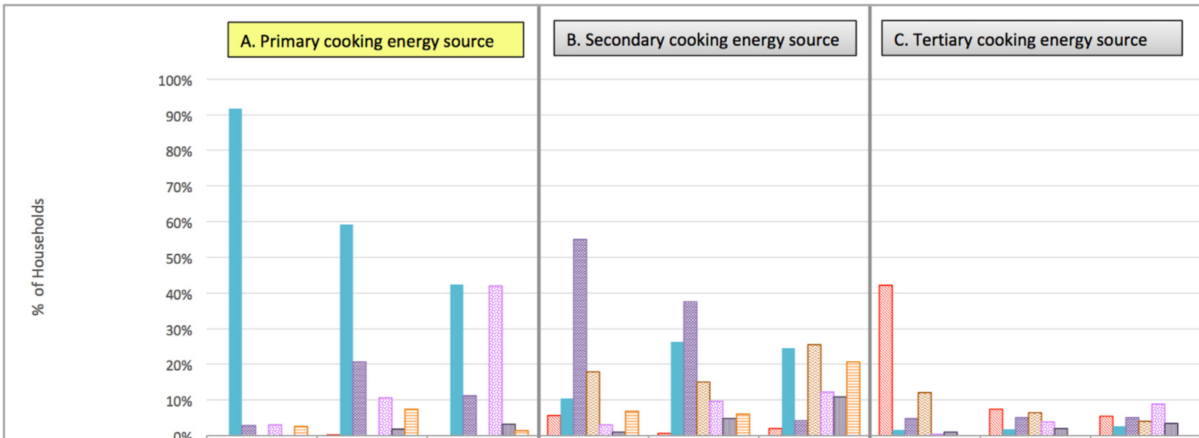
The mean age of the cooks was similar across the three settings at an average of 37 years. Whilst almost all cooks were female in Mbalmayo and Yaoundé (>95 %), in Douala 16 % ($n = 80$) of cooks were male. In addition, a higher proportion of participants from Douala had university educations ($n = 251$; 50.3 % vs $n = 112$; 22.3 % in Yaoundé and $n = 94$; 19 % in Mbalmayo) and were single ($n = 171$; 34 % vs $n = 81$; 16 % in Yaoundé and $n = 124$; 21.8 % in Mbalmayo). Whilst family size was similar across the three settings, participants from Douala generally had a significantly higher level of wealth than those from Yaoundé and Mbalmayo.

In terms of fuel/ energy source used for cooking (Fig. 1), LPG was used as the primary cooking fuel by 64 % ($n = 971$) of survey respondents, with almost all participants in Douala using the fuel (91 %). The next most common primary fuels were firewood (Mbalmayo – 41.8 %) and charcoal (Yaoundé – 20 %). In terms of choice of secondary fuel, charcoal and firewood were the preferred options (if not already used as a primary fuel) (Fig. 1B). Primary use of eCooking was reported by only one house (Douala). Electricity was mainly reported as a tertiary cooking energy source (not used routinely) and the majority of users were primarily located in Douala (42 %) (Fig. 1C).

Exclusivity of clean cooking with either LPG or electricity (with no secondary/ tertiary use of biomass) was generally low – slightly more frequent in Douala (19.2 % of households) than in Yaoundé and Mbalmayo (14.4 % and 14 % respectively). Exclusive biomass users (with no use of LPG or electricity at all) was significantly higher in Mbalmayo (34.7 %) than Yaoundé (16.3 %) with almost none in Douala (2 %) (Fig. S1). Overall one fifth of all surveyed households ($n = 311$; 20.6 %) reported occasional use of electricity/electrical appliances as a secondary or tertiary source of energy for cooking, reheating food or boiling water (Fig. S2).

Table 1
Socio-demographic details of study participants by location.

Characteristic		Douala	Yaoundé	Mbalmayo	*p* value
		n = 501	n = 507	n = 501	
Age; mean (SD)	Years	38.6 (13.1)	36.7 (11.7)	36.9 (13.1)	>0.05
Gender Female n (%)	–	421 (84.0 %)	498 (98.2 %)	479 (95.6 %)	<0.01
Education; n (%)	No formal	5 (1.0 %)	4 (0.8 %)	15 (3.0 %)	<0.01
	Primary	22 (4.4 %)	70 (13.9 %)	110 (22.2 %)	
	Secondary	221 (44.3 %)	317 (63.0 %)	277 (55.9 %)	
	University	251 (50.3 %)	112 (22.3 %)	94 (19.0 %)	
Civil Status; n (%)	Married	258 (51.5 %)	195 (38.5 %)	183 (36.5 %)	<0.01
	Partner	35 (7.0 %)	183 (36.1 %)	140 (27.9 %)	
	Single	171 (34.1 %)	81 (16.0 %)	124 (24.8 %)	
	Widow	29 (5.8 %)	44 (8.9 %)	47 (9.4 %)	
	Divorced	8 (1.6 %)	4 (0.8 %)	7 (1.4 %)	
Family Size; mean (SD)	Subject	6 (4.7)	6 (5.2)	6 (4.2)	>0.05
House ownership; n (%)	Yes	347 (70.1 %)	238 (47.0 %)	202 (41.2 %)	<0.01
Land ownership; n (%)	Yes	287 (57.3 %)	125 (24.7 %)	143 (28.5 %)	<0.01
Regular employment of head of household; n (%)	Yes	405 (80.8 %)	194 (38.3 %)	231 (46.1 %)	<0.01
Monthly income in CAF*; n (%)	51–200 K	6 (1.2 %)	86 (17.0 %)	151 (30.1 %)	<0.01
	201-300 K	224 (44.7 %)	251 (49.5 %)	171 (34.1 %)	
* CAF 1000 = $1.68 *Morningstar 2/4/22*	>300 K	131 (26.2 %)	34 (6.7 %)	24 (4.8 %)	
	Don't know	94 (18.8 %)	10 (2.0 %)	8 (1.6 %)	
	No response	46 (9.2 %)	126 (24.9 %)	147 (29.3 %)	
Head of household occupation; n (%)	Farmer	-	80 (15.8 %)	69 (13.6 %)	<0.01
	Gov. employee	38 (7.5 %)	70 (13.8 %)	83 (16.5 %)	
	Worker	114 (22.7 %)	59 (11.6 %)	48 (9.6 %)	
	Own company	196 (39.1 %)	113 (22.3 %)	133 (26.5 %)	
	Artisan	25 (5 %)	20 (3.9 %)	54 (10.8 %)	
	Housework	9 (1.8 %)	16 (3.1 %)	28 (5.6 %)	
	Retired	77 (15.3 %)	39 (7.7 %)	35 (7 %)	
	Self-employment	2 (0.4 %)	81 (15.9 %)	8 (1.6 %)	
	Unemployed	40 (7.9 %)	29 (5.7)	43 (8.6 %)	
Piped water; n (%)	Yes	272 (54.3 %)	278 (54.8 %)	139 (39.7 %)	<0.01
Toilet in home; n (%)	Yes	485 (96.8 %)	206 (40.6 %)	126 (25.1 %)	<0.01
Car; n (%)	Yes	224 (44.7 %)	82 (16.17 %)	43 (8.58 %)	<0.01
Air Conditioner; n (%)	Yes	200 (39.9 %)	9 (1.78 %)	5 (1.00 %)	<0.01
Computer; n (%)	Yes	318 (63.5 %)	150 (29.6 %)	146 (29.14 %)	<0.01
Access to electricity for lighting n (%)	Yes	501 (100 %)	504 (99.8 %)	488 (98.9 %)	>0.05

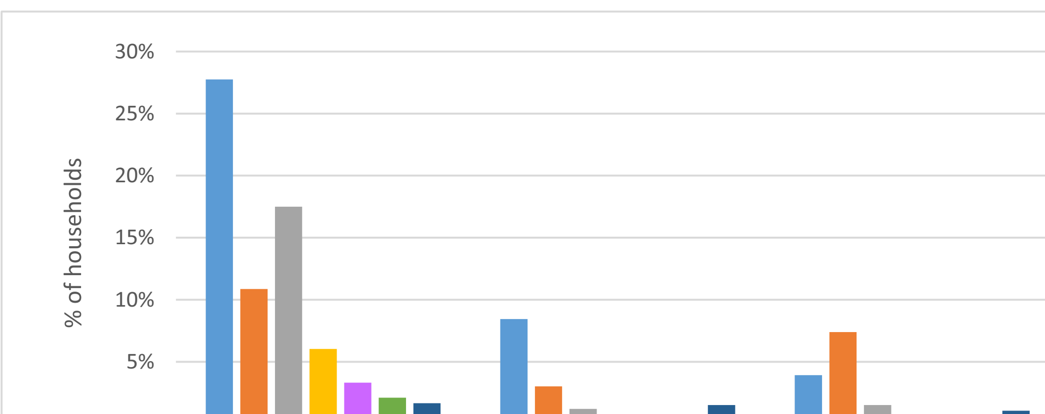


	A. Douala	A. Yaounde	A. Mbalmayo	B. Douala	B. Yaounde	B. Mbalmayo	C. Douala	C. Yaounde	C. Mbalmayo
Electricity	0%	0%	0%	6%	1%	2%	42%	7%	5%
LPG	92%	59%	42%	10%	26%	25%	2%	2%	3%
Charcoal	3%	21%	11%	55%	37%	4%	5%	5%	5%
Sawdust/woodchips	0%	0%	0%	18%	15%	26%	12%	7%	4%
Firewood	3%	11%	42%	3%	10%	12%	0%	4%	9%
Kerosene	0%	2%	3%	1%	5%	11%	1%	2%	3%
Other	3%	7%	1%	7%	6%	21%	0%	0%	0%

Fig. 1. Primary, secondary and tertiary cooking fuels/ energy by study location.

Households using eCooking mainly used microwaves ($n = 134$, 43 %), rice cookers ($n = 46$, 15 %), hotplates ($n = 31$, 10 %), and electric pressure cookers (EPC) ($n = 17$, 5 %) in addition to more commonly used appliances for boiling water (kettles ($n = 266$, 86 %) and electric coils ($n = 141$, 45 %)) (Fig. 2). Use of electrical appliances for 'cooking' was almost exclusively restricted to Douala (28.2 % for use of rice cooker, microwave, hotplate or EPC) compared to Yaoundé (4 %) and MBalmayo (4 %) $p < 0.001$.

In terms of uptake, 235 (46.9 %) of households in Douala reported using at least one of the above-mentioned eCooking appliances as



	Douala	Yaounde	Mbalmayo
Kettle	28%	8%	4%
Coilwater	11%	3%	7%
Microwave	17%	1%	2%
Rice Cooker	6%	0%	0%
Hotplate	3%	1%	1%
EPC	2%	0%	0%
Other	2%	2%	1%

Fig. 2. Use of eCooking appliances among current users stratified by study location.

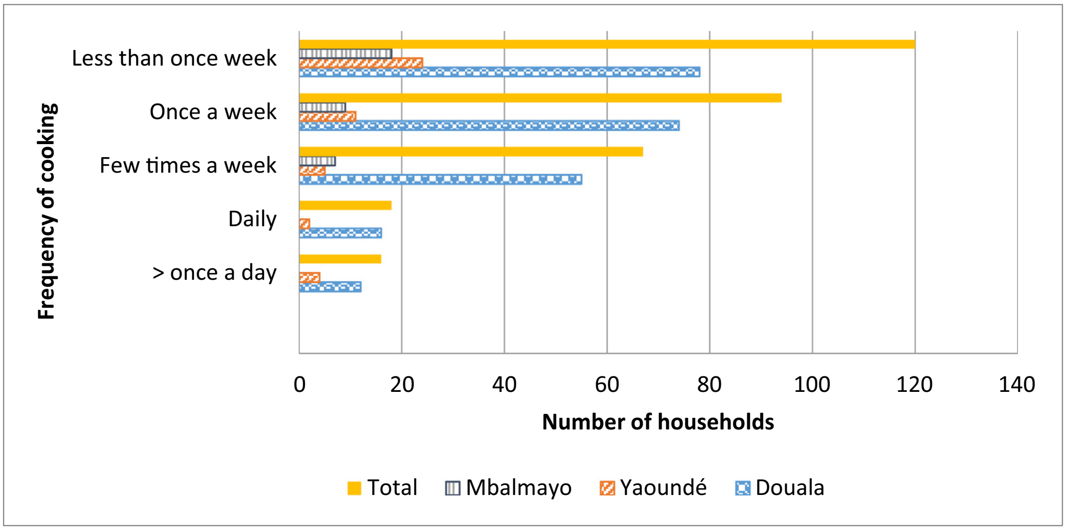


Fig. 3. Frequency of use of eCooking appliances[a] by study location ($N = 133$)
[a]Appliances include EPC, hotplates, rice cookers and electric stoves.

compared to 42 (8.3 %) households in Yaoundé and 34 (6.8 %) in Mbalmayo ($p < 0.0005$).

Only 133 households (8.8 % of total sample) actually used appliances for cooking and not boiling water or reheating food. Among these, only 30 households (22.5 %) reported cooking daily or more than once a day, 46 (34.6 %) indicated cooking few times a week or once a week and 57 (42.9 %) reported cooking less frequently than once a week (Fig. 3).

All studied households had access to electricity and were connected to the national grid, however 58 % ($n = 876$) indicated that their service was not reliable enough for cooking with electricity (Fig. 4). In terms of other perceived attributes of eCooking, the majority of respondents reported eCooking to be both clean (77.5 %) and quick (62 %); half reported cooking with electricity was easy, whilst less than a quarter indicated that it was safe (22.5 %) and <1 in 10 that it was affordable (7 %) (Fig. 4). When asked about aspirational use of an EPC (e.g. if it was both available and affordable), 60 % ($n = 906$) of participants indicated they would be willing to use it. Of the 21 % ($n = 317$) households who said they would not use an EPC, costs (51 %), safety (31 %) and satisfaction with current cooking (18 %) were cited as reasons.

Indicators of a higher education and greater wealth were significantly associated with an increased likelihood of using eCooking (Table 2) including having a university education (53.4 % vs 24.3 %), having regular employment for the head of household (75.2 % vs 49.7 %), ownership of house and land (58.5 % vs 50.2 %), higher monthly income (49.8 % vs 12.2 %), ownership of a car (48.9 % vs 16.4 %) and having a flushing toilet (89.7 % vs 44.9 %). Accordingly, households categorized as deprived (multidimensional poverty index (MPI)) were significantly less likely to use electricity ($p < 0.0005$).

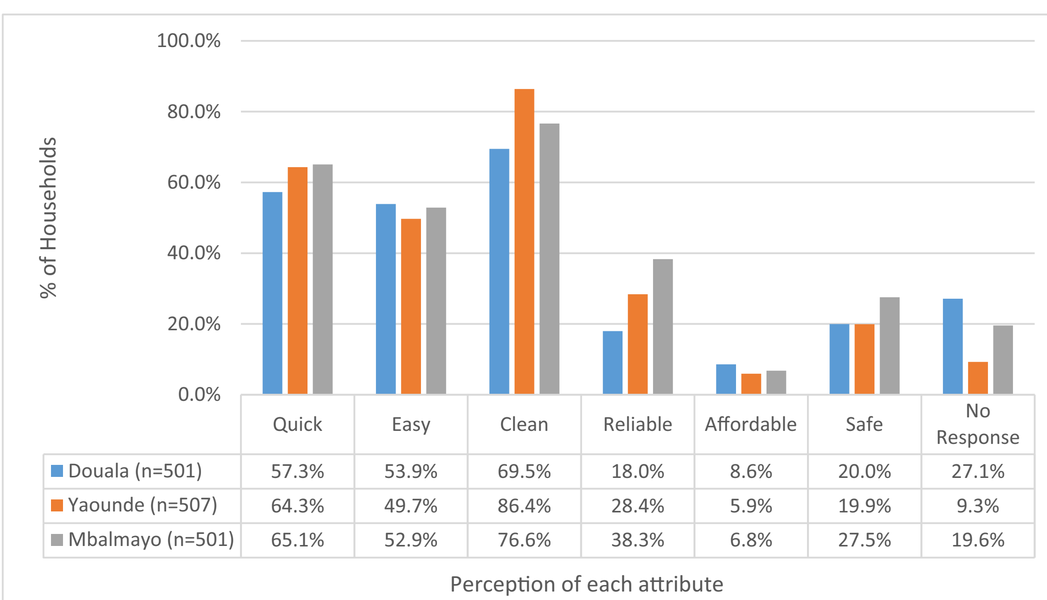


Fig. 4. Perceived attributes of cooking with electricity by study location.

Table 2
Household characteristics and use of electricity for cooking.

Characteristic		Electricity	No electricity	p value
		n = 311	n = 1198	
Age; mean (SD)	Years	37.71 (0.7)	37.34 (0.3)	0.645
Gender Cook n (%)	Female	273 (87.8)	1125 (93.9)	<0.01
Education; n (%)	University	166 (53.38)	291 (24.3)	<0.01
Civil Status; n (%)	Married /partner	214 (68.8)	780 (65.1)	0.220
Family Size; n (%)	1–4	98 (31.5)	415 (34.6)	0.583
	5–7	143 (45.9)	527 (43.9)	
	>8	70 (22.5)	256 (21.3)	
Primary fuel; n (%)	LPG	291 (93.5)	680 (56.7)	<0.01
	Biomass	14 (4.5)	411 (34.3)	
House ownership; n (%)	Yes	185 (59.5)	602 (50.2)	<0.01
Land ownership; n (%)	Yes	203 (65.3)	352 (29.3)	<0.01
Regular employment of head of household; n (%)	Yes	234 (75.2)	596 (49.7)	<0.01
Monthly income; n (%)	No response	23 (7.4)	296 (24.7)	<0.01
	<360 US$	57 (18.3)	540 (45.0)	
	360–540 US$	76 (24.4)	216 (18.1)	
	> 540 US$	155 (49.8)	146 (12.2)	
Piped water; n (%)	Yes	149 (47.9)	600 (50.1)	0.495
Toilet in home; n (%)	Yes	279 (89.7)	538 (44.9)	<0.01
Car; n (%)	Yes	152 (48.9)	197 (16.4)	<0.01
MPI deprived; n (%)	Yes	41 (13.2)	579 (48.3)	<0.01

In the multivariable analysis, several factors remained independently associated with the likelihood of using electricity for cooking. Having LPG as the primary fuel increased the odds >3.5 times; a higher monthly income had twice the odds of using electricity and being deprived reduced the odds by half (Table 3).

Results from the cooking diaries

The study recruited 25 users of eCooking appliances to complete the cooking diaries (Douala = 14, Mbalmayo = 6, Yaoundé = 5), of whom 22 (88 %) reported LPG as their primary cooking fuel. Details of the eCooking being used (with demographic information from respondents) are shown in supplementary material Table S1 and Fig. S3.

During the 7–10 days of the intensive diary study, a total of 340 cooking events were recorded using clean energy (either LPG or electricity) – just over half occurring for respondents in Douala (50.7 %), which were the majority of the sample. Most cooking was carried out with LPG (72 % of events), followed by the electric hotplate (11.5 %), rice cooker (8 %) and EPC (7 %) (Fig. 5). Use of electricity for cooking was restricted to only 3 or 4 times a week and 1 or 2 times on the weekends, so reheating food appears to be an important component of Cameroonian cooking practices. The preparation of traditional dishes requiring longer cooking time was usually done over the weekends.

Cooking times varied widely (median = 46 min (IQR 20–90 min)) across all the stoves/appliances used. For LPG stove use, cooking times were typically longer (median = 59.5 min (IQR 35–95)) than those using electricity (median = 30 min (IQR 5–60); $p < 0.001$ likely more related to reheating food than to the type of food cooked. For both types of energy, the peak time for cooking was between 9:00 AM and 1:00 PM (Fig. 6). The lower frequency of cooking at dinnertime was not device-type dependent, with few diary entries being made at all after 3 pm.

Although a wide variety of dishes were reported, the most common staple foods were rice, pasta with various sauces to accompany fish or

Table 3
Factors independently associated with household use of electricity for cooking.

Characteristic		Adjusted OR[a]	95%CI	p value
Age	Years	0.99	0.97–1.00	0.374
Gender Cook	Male			0.508
		0.83	0.49–1.42	
Education	Primary (ref)	1		0.21
	Secondary	1.53	0.78–3.0	0.11
	University	1.77	0.88–3.56	
Civil Status	Married /partner	1.13	0.77–1.67	0.505
Family Size	1–4 (ref)	1	-	-
	5–7	1.12	0.76–1.65	0.537
	>8	1.03	0.63–1.65	0.902
LPG as primary fuel	Yes	3.83	2.17–6.78	<0.01
Land ownership	Yes	2.40	1.69–3.41	<0.01
Regular employment of head of household	Yes	0.69	0.46–1.03	0.074
Monthly income in USD	<360 (ref)	-	-	-
	360–540	1.07	0.67–1.71	0.747
	> 540	1.90	1.17–3.09	<0.01
Toilet in home	Yes	2.36	1.35–4.14	<0.01
Car	Yes	1.66	1.15–2.40	<0.01
MPI deprived	Yes	0.46	0.29–0.64	<0.01

[a] Mixed logistic regression model controlling for the effect of location.

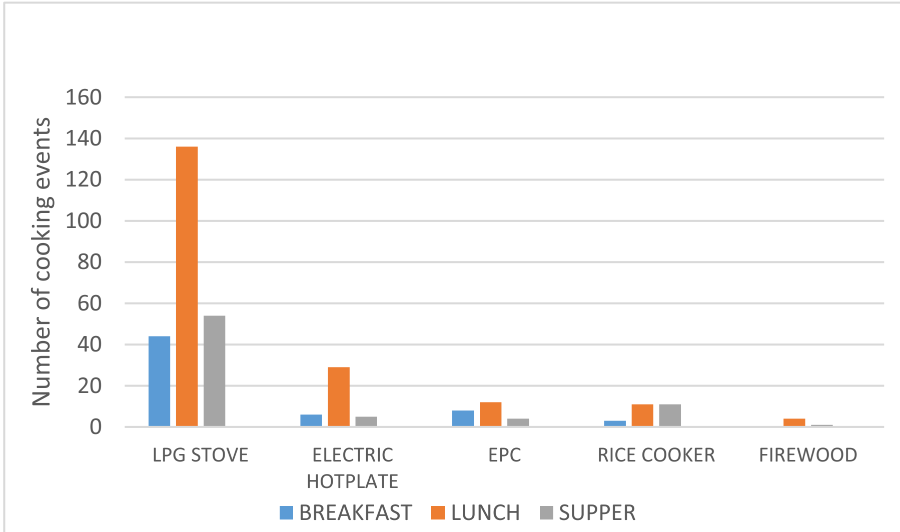


Fig. 5. Number of meals by fuel/appliance during cooking diary (*Whatsapp Bot* survey data).

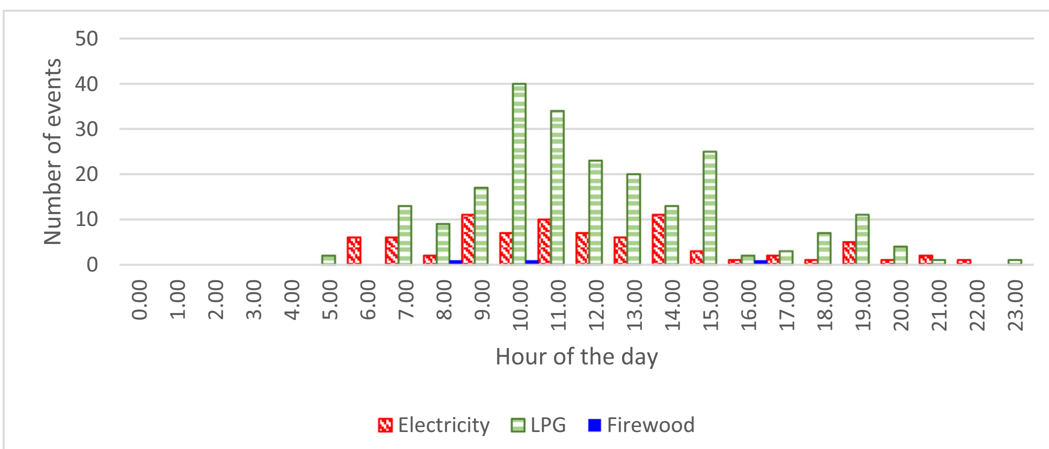


Fig. 6. Distribution of cooking events by time of day per energy source (*Whatsapp Bot* survey data).

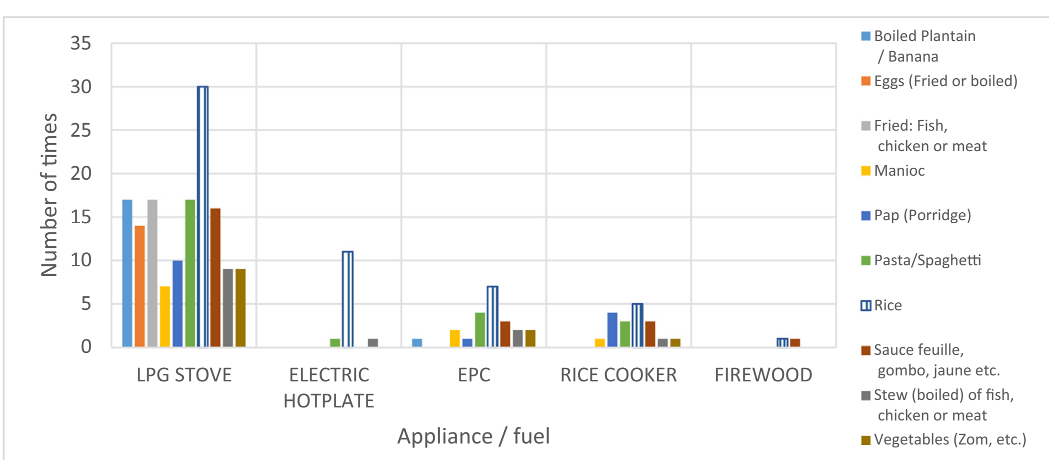


Fig. 7. Most commonly cooked dishes by type of fuel / appliance
Note: Rice cooker n = 10, Hotplates n = 9, EPC n = 1, based on compiled cooking diary survey data over 7 days.

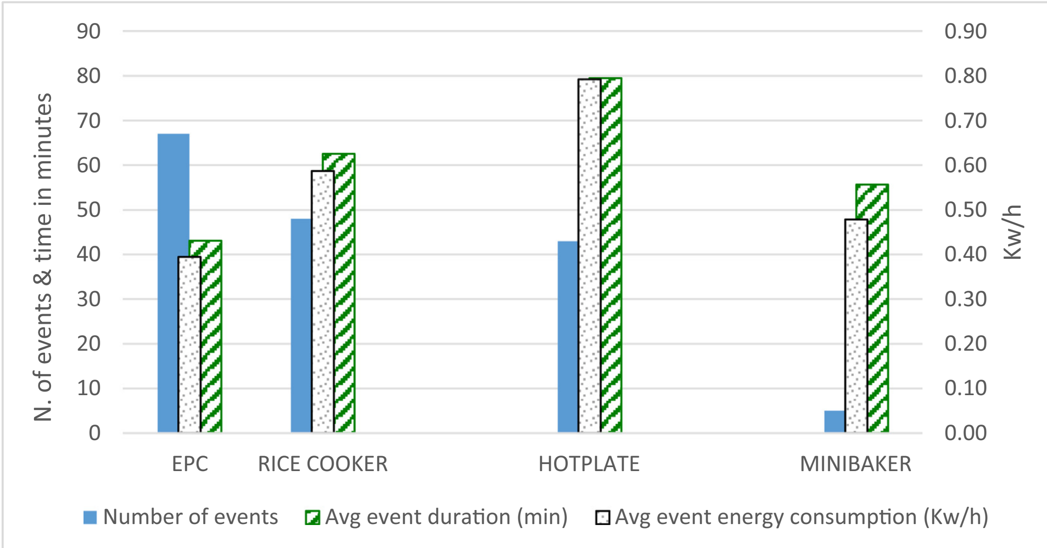


Fig. 9. Number of cooking events, average duration and energy consumption[a] by most common electric appliances
[a]Based on electric smart-meter readings over an average of 21 days.

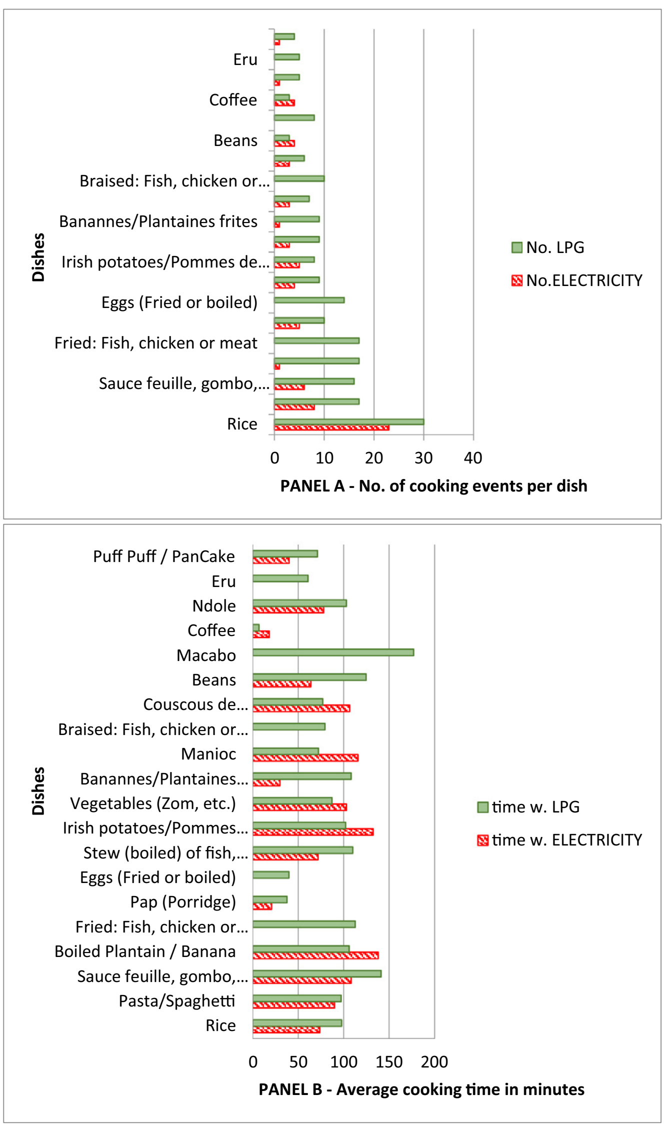


Fig. 10. Number of cooking events (panel A) and average cooking time (panel B) of dishes cooked at least 5 times in LPG stove or eCooking appliance.

meat with cassava (manioc), fried eggs and fried/boiled vegetables being the next most frequently cooked meals (Fig. 7). Fried eggs, porridge and pancakes were frequently cooked for breakfast, mainly using an LPG stove (although porridge was also reported to be cooked using an EPC (9 % of responses). While lunch typically involved a greater menu choice, cooked staple foods tended to be similar between lunch and dinner dishes, with rice, pasta, couscous and plantains (fried and boiled) being very common for both meals. Rice cookers were typically used to cook rice for both lunch and dinner, while the EPC and electric hotplate were more often used for cooking lunch, including rice, past and other vegetables (see Figs. 5 and 7).

Cooking diaries results linked to eCooking

In total, there were 208 cooking events with eCooking appliances recorded through the 20 active electric smart meters during data collection (three months). For 3 households there was no electric cooking activity recorded and another 2 had faulty meters. On average there were 0.18 cooking events with electricity per user per day. Most of the cooking took place in the morning and during lunchtime, and eCooking use mainly occurred during the lunchtime period (see Fig. S4).

Smart meter data collected from the primary electrical appliance used for cooking provided a detailed picture of the number of events, the average cooking time and the average energy consumption based on how individual users operate the device over time, (Fig. 9).

The distinctive character of the cuisine of Cameroon is illustrated by the different dishes cooked (Fig. 10). Based on *WhatsApp bot* responses, the self-reported cooking time is longer than the actual time during which energy is actually consumed. This is consistent with other studies, which also show a ~35 minutes average eCooking event (A2EIa, 2021).

The load profile of an average day showed the start of the cooking activities at about 5:00 am and the peak cooking time from 10:00 am to 2:00 pm, with the end of cooking activity around 10:00 pm (Fig. 11).

Further investigations of the electricity grid stability based on the data from the smart meters during the cooking diary study indicate that the grid showed an average voltage profile that fluctuated from being above 250 V to collapsing below 160 V, (creating risks for

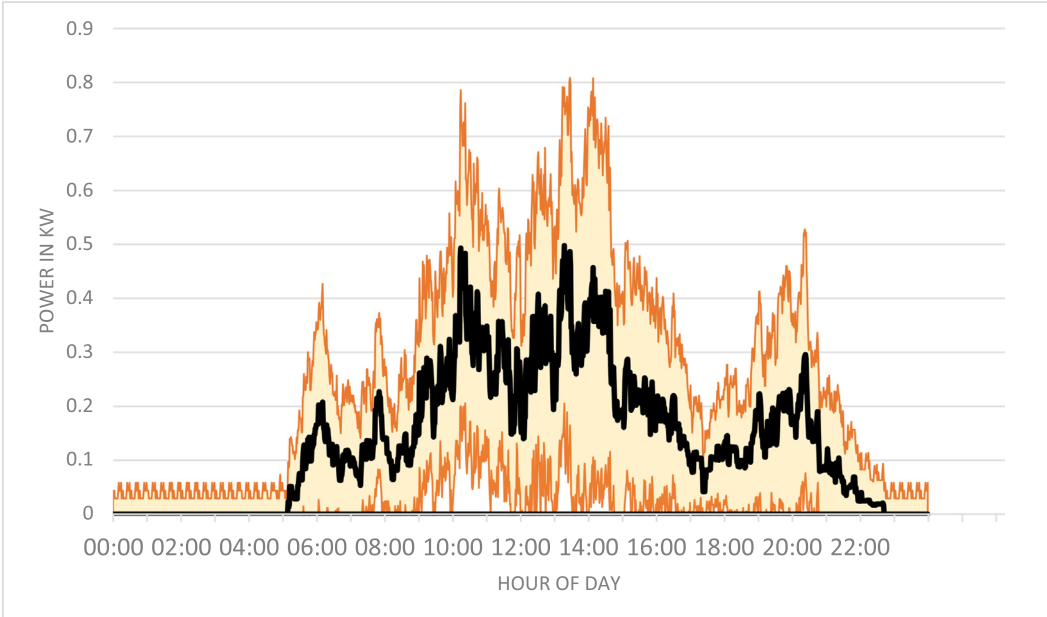


Fig. 11. Cumulative power profile of cooking diary study participants based on electricity smart meter data (24 h)
Note: The black line in the figure indicate the power profile over time; the orange lines represents the upper and lower bounds of the standard deviation.

appliances damage with voltage spikes over 230 V or inefficient power to cook with low voltages). The standard deviation of the voltage is represented as the filled areas above and below the curve (Fig. 12).

Summary of semi-structured qualitative interviews' main findings

Ten interviews were conducted (5 in Mbalmayo, 2 in Yaoundé and 3 in Douala), for a total of 8 female cooks and 2 male cooks. Of the participants who had completed cooking diaries, 6 had electric hot plates, the others an electric fryer, a rice cooker, and an EPC respectively, as their main electric cooking appliance. An extra participant from Malabayo who had an eCooking appliance at the time of the original survey but had subsequently sold it, was also included in the sample.

In terms of barriers to electric cooking uptake, some participants felt that use of eCooking appliances, like hotplates (perhaps bought second hand), were rather slow to cook and did not heat the pot evenly.

> "*Dish really takes a long time to heat up on the hotplate so I don't have enough patience, so I stop cooking, or I go to the gas or I go to the firewood.*" (Woman, 25 years, Mbalmayo)

> "*The pot exceeds the stove [burner] so there are sides of the pot that don't cook.*" (Woman, 22 years, Yaoundé)

The interviews highlighted the profile of the mother's role in introducing family members to cooking activities, promoting the transmission of common practices and traditions. Reluctance to changing cooking patterns learned from mothers was reported as a barrier as it discourages behavioral change to clean modern energy, with traditional cooking with firewood being passed down from generation to generation.

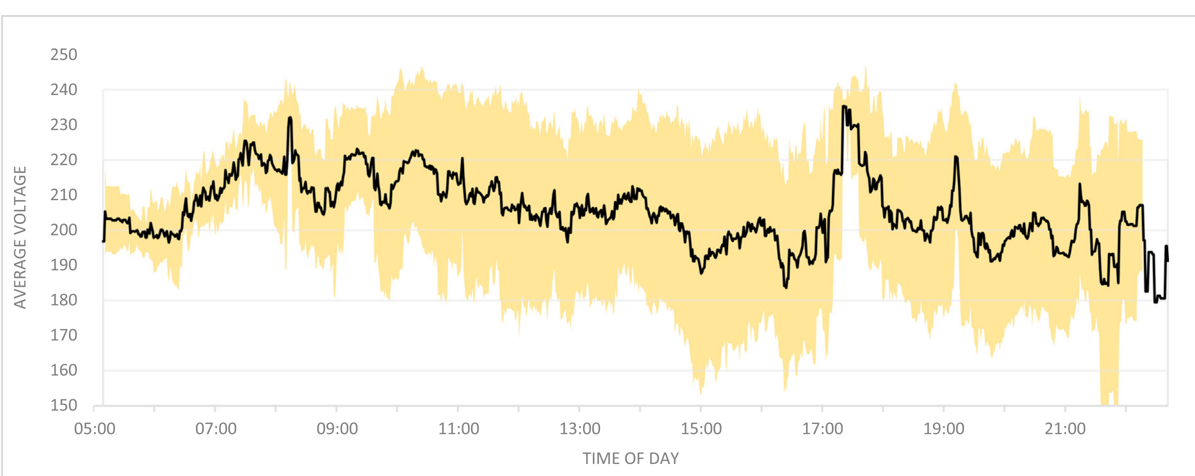


Fig. 12. Voltage curve based on electricity smart meter data from cooking diary study participants (mid June to mid August 2021)
Note: The black line in the figures indicates the average voltage; the orange area represents the upper and lower bounds of the voltage standard deviation.

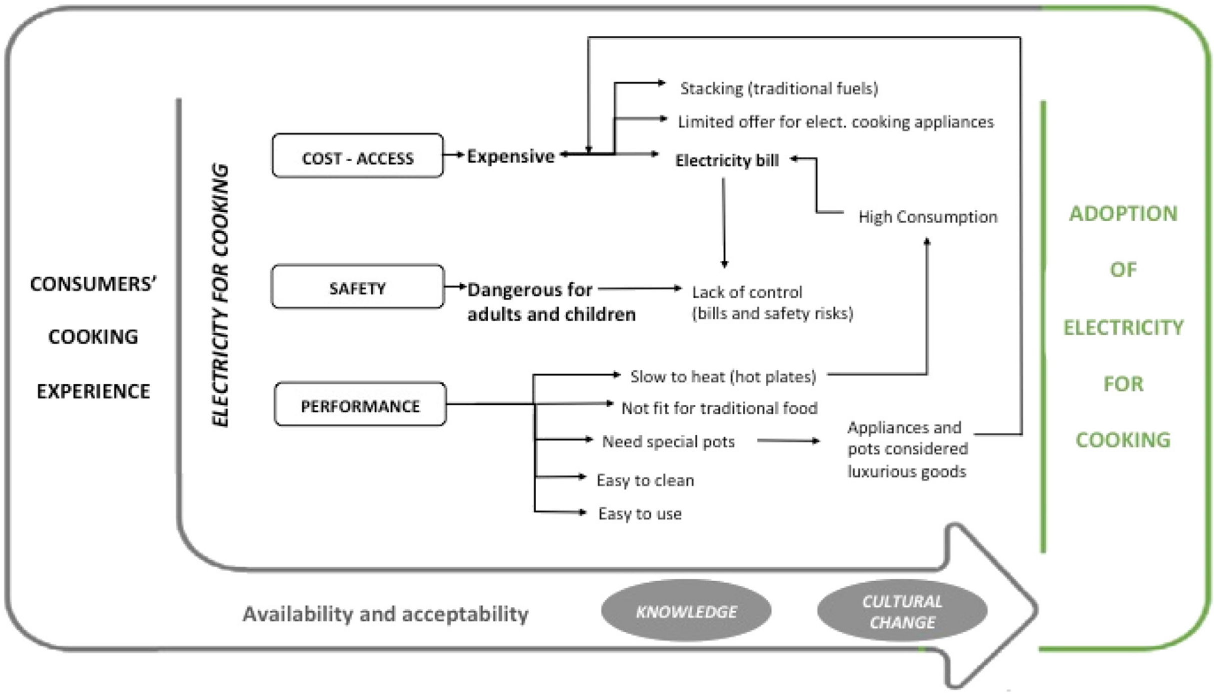


Fig. 13. Synthesis of main factors influencing the adoption of electricity for cooking.

"*My mother never used gas [...] because she is afraid of it. I learned to use gas myself, Mom taught me to use a wood fire.*"
[(Male, 29 years, Mbalmayo)]

*"I have never cooked koki [*steamed pudding-like meal wrapped in banana leaves and boiled*] on the Gas, nor fufu corn. These are very heavy foods and it takes a very long time to cook koki […]. If you don't cook fufu and koki on the fireplace, it will not have the kind of taste than when you cook with firewood".*
[*(Woman, 50 years, Mbalmayo)*]

In terms of enablers of uptake, some study participants reported use of eCooking appliances to be advantageous over traditional fuels from the ease of cleaning cooking pots and less discomfort related to the smoke generated when cooking with firewood.

"*Using the hotplate [...] does not blacken pots like a wood fire or a kerosene stove. So it's clean [...] you don't waste time saying you're going to wash and scrub, so you save time using the hot plate.*"
[(Woman, 23 years, Mbalmayo)]

"*On the plate the pot comes out the same as I put it, so that it does not blacken - and you can even prepare yourself inside the house well dressed, that's why the time that you normally use to wash the pots that you use in the wood fire there, you can use the time there to do other things, maybe rest.*"
[(Woman, 23 years, Mbalmayo)]

Technology knowledge emerged as a facilitator to the use of eCooking. Those respondents who had previous information on the benefits of using clean energy for cooking showed a better predisposition to adopt and sustain the use of clean cooking options.

"*I use electricity to cook mostly in the morning and in the evening. But I want to say for the time I have been studying with you people (Clean Air Africa) since you came with this project, the usage of firewood is gradually getting off my daily cooking habits with these studies you came and opened up our eyes and gave us some information and the disadvantages of using firewood. So before I used to mostly cook with firewood, but now am gradually getting out of it.*" (Male cook, 46 years, Douala)

Discussion

This study summarises mixed-methods research in urban and peri-urban Cameroon exploring the current and potential role of electricity for clean cooking in the country, focusing on major conurbations that are most likely to have the greatest potential to be using this energy (i.e. households with higher incomes and better access to grid electricity). Through quantitative surveys of just over 1500 households across three urban settings, it has been possible to identify current use of a range of eCooking appliances and their frequency of use. Through an intensive assessment of cooking practices in those households identified to be using eCooking appliances (including objective monitoring of stove/ fuel usage, it has been possible to understand the extent of cooking with electricity to gain an understanding of its potential for transitioning Cameronnian households away from traditional polluting fuels to eCooking.

Consistent with stakeholder interviews and findings summarised in a policy review of the Cameroon energy landscape (Rubinstein et al., 2021), our data indicate that current use of electricity as a primary cooking energy is extremely rare in Cameroon (even among the most affluent households), and it is also fairly uncommon for secondary use. Key barriers in transitioning to clean cooking with electricity identified in this study (and consistent with the policy review findings) include (i) the cost of eCooking appliances and ongoing costs of the energy for cooking, (ii) the reliability of electrical supply, (iii) perceived concerns over safety, and (iv) a reluctance to adopt eCooking as a replacement for traditional fuels or LPG. These demand side barriers are coupled with supply side constraints that include a lack of policy commitment to date to expand the use of eCooking in Cameroon (Rubinstein et al., 2021).

We found that <1 in 4 households had an electrical appliance (mostly for boiling water) and households using electricity typically did so as secondary or tertiary source of cooking energy with most indicating only occasional use (i.e. once a week or less). The use of hotplates was very rare and typically involved old and inefficient appliances. Two third of surveyed households (60 %) highlighted the unreliability of supply including frequent outages and an unstable power provision. A scaled transition to eCooking in Cameroon may be challenging from both supply and demand side, unless the supply inefficiencies can be fully addressed or battery supported eCooking can become an affordable reality for the country (Leary et al., 2021b; Manjia et al., 2015).

Use of clean cooking technologies and fuel stacking behavior

We identified considerable variation in usage of clean fuels (LPG) and energy (electricity) for cooking across the three study contexts, with the most affluent conurbation of Douala (i.e. with the highest educational and economic level) having greater adoption of modern fuels than the other urban settings of Yaoundé and Mbalmayo. In Cameroon, LPG is the preferred modern choice of primary cooking (verified across our surveys for all three study sites) and consistent with other study findings (Esong et al., 2021; Pope et al., 2018a; Pye et al., 2020). When electricity is used for cooking, it is typically for reheating food or boiling water.

However, affordability of LPG has been identified as a key barrier to adoption and also for more exclusive use with concurrent use of polluting fuels ('fuel stacking') (Hsu et al., 2021; Pope et al., 2018b; Pye et al., 2020; Ronzi et al., 2019; Williams et al., 2020). We found consumption of LPG in users to be 27.1 kg/capita/year in Douala, 20.2 kg/capita/year in Yaoundé and 19.5 kg/capita/year in Mbalmayo. These are high consumption levels but likely indicative of LPG being a primary but not an exclusive fuel used for cooking, especially in households of the latter two locations (GLPGP, 2018).

Barriers/enablers to eCooking in Cameroon: perceptions of households cooks

Barriers/enablers to the use of eCooking identified through the survey and the in-depth research components of the study are illustrated in Fig. 13. Perceived cost (of fuel/ energy and start-up cooking equipment) was the most frequently reported barrier in the potential adoption of eCooking. This was particularly in relation to (i) the opportunity-cost of gathering firewood for free where available, and (ii) the competitive price of LPG given national subsidies in Cameroon (Bruce et al., 2018; GLPGP, 2018). In addition to cost, other identified barriers included distrust/ dissatisfaction with the main electricity suppliers in both the quality of the supply and the amount charged. An example of the latter was highlighted for residents living in apartment block-buildings, where the electricity bill was shared for the entire building, with the landlord deciding on the payment split (in the absence of electricity meters). Instability/ unreliability of the electrical supply was reported as a key issue in the avoidance of eCooking, particularly in relation to main meals. As summarised in Fig. S3, lack of availability of eCooking appliances was also mentioned as a barrier to adoption (much of the equipment used by study participants was purchased through the second hard market and was of variable quality). Another reported barrier relates to concerns over safety, particularly for children, and the risk of electrocution whilst cooking. Finally, interviews revealed that participants were skeptical of the potential for eCooking to meet the requirements of all cooking activities, especially for larger families and traditional foods.

Our observation that there is second hand market for electrical cooking appliances in Cameroon is of note and indicative of an interest in eCooking (Rubinstein et al., 2021). The availability of these appliances, typically imported from Europe as part of bulk shipments, is likely to be opportunistic but shows an interest from consumers in adopting modern cooking technologies for households (Rubinstein et al., 2021).

Learnings from other countries

The barriers to eCooking in Cameroon identified by the study are not insurmountable. Whilst there are numerous reasons explaining the limited uptake of eCooking in SSA, (including political and cultural aspects, in addition to infrastructure and economic factors (Leary et al., 2021b), eCooking from renewable sources of the electricity is ultimately the "holy grail" for sustainable clean cooking in LMICs for the associated health, environment and climate gains (Goldemberg et al., 2018). There are examples in the SSA context where renewably generated electricity used for cooking has become fairly well established. In Zambia, for example, a third of the urban population (32.5 %) use electricity as their primary cooking fuel (Serenje et al., 2022). In East Africa, Kenya, is in the process of drafting an eCooking national strategy (MECS, 2022) and Uganda has potential to transition to eCooking given supply chains in Kenya where manufacturers of electrical appliances have a strong presence and eCooking is starting to become a realistic option for some (Price et al., 2022). According to a number of stakeholders, promoting potential cost savings of energy-efficient electrical appliances could well aid in the transition to eCooking; such strategies could be adopted by both electricity providers and associated partners as an effective tool to encourage consumers to use electricity for cooking in a sustained way (Price et al., 2022).

Conclusions

Through mixed-methods research conducted in urban and peri-urban Cameroon, this study highlights some important observations in relation to the potential for scale up of clean, modern cooking. Our findings indicate that current use of electricity as a primary or secondary cooking energy is rare in Cameroon (even among the most affluent households). If adoption of clean cooking is to be realised by the 2030 Sustainable Development Goals (SDG) time horizon, LPG appears to be an important fuel for the country. This is due to LPG being the fuel of choice for cooking among households that can afford the cost of the initial equipment and refills, and LPG being the main domestic fuel supported by the Cameroonian government with policy aspirations and a set target. Such aspirations were announced through the National LPG Masterplan in 2016, including a roadmap of changes to support the large-scale adoption of LPG by households (addressing national concerns over environment and public health) (Bruce et al., 2018; Rubinstein, 2021; SEforALL, 2020). Whilst electricity has a role to play, it is unlikely that it will feature as a primary/prominent source of cooking energy in the near future because of lack of explicit policy support and a national strategy for eCooking scale up, as well as the unavailability of widespread, reliable and affordable electricity in the country (Rubinstein et al., 2021; SEforALL, 2020).

Other 'demand-side' barriers to wider adoption include concerns over cost, a paucity of eCooking appliances (often being bought second hand through international import), safety concerns and cultural cooking norms. To achieve a significant scale in adoption of electricity for cooking in Cameroon, policies will be required to incentivize usage through affordability (e.g. subsidising the initial cost of eCooking appliances and electricity tariffs to power the technologies), in addition to ensuring wide accessibility and reliability of electricity across Cameroon's national territories. These policies will be needed in addition to well-targeted educational campaigns and promotional messages to raise awareness of how eCooking can meet the requirements of Cameroonian families, including addressing perceptions over taste, convenience and safety.

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CRediT authorship contribution statement

Fernando Rubinstein: Data curation, Formal analysis, Validation, Writing – original draft. **Bertrand Hugo Mbatchou Ngahane:** Methodology, Writing – review & editing, Supervision. **Mattias Nilsson:** Data curation, Validation, Formal analysis, Writing – review & editing. **Miranda Esong:** Investigation, Writing – review & editing. **Emmanuel Betang:** Investigation, Supervision, Writing – review & editing. **André Pascal Goura:** Investigation, Supervision, Writing – review & editing. **Vimbai Chapungu:** Writing – review & editing. **Dan Pope:** Conceptualization, Writing – review & editing, Funding acquisition. **Elisa Puzzolo:** Conceptualization, Validation, Writing – original draft, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esd.2022.09.010.

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