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Choice modelling of eCooking adoption by households in Ghana

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ABSTRACT

The use of electric cooking appliances, also referred to as eCooking devices, presents a practical and sustainable solution for achieving universal access to clean cooking facilities by 2030. A choice modelling analysis on the factors that influence the selection of an eCooker in Ghana has been conducted to facilitate market expansion for organisations seeking to offer clean cooking services. The study utilised Analytical Hierarchy Process (AHP), Fuzzy-TOPSIS, and Data Envelopment Analysis (DEA) methodologies to assess and rank electric cookers based on crucial factors such as kWh consumption rate, cooking efficiency, affordability, time-saving features, ergonomics, space utilisation capabilities, compatibility with cookware types, ease of cleaning and maintenance procedures, accessibility, among others. The rate of consumption was identified as the most critical factor, emphasising the significance of energy efficiency in the decision-making process. The analysis showed that the induction stove was optimal, considering both Fuzzy-TOPSIS and DEA evaluations. Although the induction stove may consume a considerable amount of electricity, its efficiency, performance, and other attributes make it the preferred choice. This study presents a systematic approach to assessing and ranking electric cooking stoves in Ghana, offering valuable insights for both consumers and policymakers.

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Clean cooking; energy access; ecooking determinants; ecook Ghana

Introduction

According to the International Energy Agency (IEA), 2.6 billion individuals depend on solid biomass for their cooking needs. Unfortunately, progress in this area has stagnated since 2012 and has fallen behind the population growth rates in certain regions. Putti et al., (2015) reports that the utilisation of biomass for cooking is anticipated to persist as the primary method until 2030 despite its severe health consequences recorded globally. Cooking with firewood causes about 4 million deaths each year, forest degradation, climate change as well as a decrease in biodiversity (Bouniol et al. 2023; Guizar-Coutiño et al. 2022). Additionally, the smoke produced from indoor biomass cooking has been linked with acute respiratory illnesses, cataracts, heart disease, and cancer, primarily affecting women and children who are more frequently exposed (Ahmad et al. 2022; Balmes 2015; Leary et al. 2019; Quinn et al. 2018; World Health Organisation 2022).

In Ghana, bioenergy constituted approximately 36% of the overall primary energy consumption for the year 2020. Notably, about 14% of the population presently utilises Liquefied Petroleum Gas (LPG), which is a Tier 4, while an additional 32% employ improved cook stoves (Tiers 2/Tier3) as their preferred choice for cooking in 2021 (SEforAll 2021). The surge in the utilisation of Tier 2 to Tier 4 technologies has mainly been attributed to the government's backing of LPG expansion, along with a burgeoning demand for improved cook stoves. Consequently, the proportion of households utilising LPG as their principal fuel for cooking has increased from 18% in 2010 to 25.3% in 2020, signifying the government's goal to augment the clean cooking penetration rate and attain a target of 50% by the year 2030.

It is, however, gratifying to note that electric cooking (eCooking) technology can be promoted within the stream of tier 4 and above technologies in support of the government's drive. ECooking has been recognised as a promising sustainable substitute for household cooking with the potential to alleviate the predicament linked to unclean fuel alternatives (Atela et al. 2021). Research indicates that utilising electric cooking methods can prove to be financially efficient and also have a positive impact on both humans and the environment (Kaputo, Mwanza, and Talai 2023; C. Zhang et al. 2023). In consideration to the electricity generation and consumption, comparison of wood-based cooking and eCooking showed that the eCooking equipment possess a relatively low marginal levelized cost of energy (Atela et al. 2021). Furthermore, geospatial techniques have also been employed to investigate the plausibility of electric cooking in remote areas, resulting in a comprehensive analysis demonstrating that incorporating eCooking into electrification planning can be economically feasible and environmentally beneficial, with reduced greenhouse gas emissions (Sánchez Jacob 2021).

Extensive research has been conducted to compare diverse electric cookstoves, and the findings have demonstrated that eCookers offer higher efficiency and reduced energy expenditures (Batchelor 2020a; El-Khozenadar et al. 2022).

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In actuality, despite the numerous advancements and progressive developments in eCooking, the concept has yet to gain widespread popularity in Ghana. Merely a small fraction of the population utilises it as their primary source of cooking fuel. As per Boateng et al., (2023) and Sarpong et al., (2022) work, a meagre proportion of Ghana's populace, thus less than 2%, employ eCooking. Nevertheless, several specialists propose that employing electricity as a means to cook in Ghana can be financially advantageous (Bawakyillenuo et al. 2021). A preliminary study conducted by MECS revealed that utilising electricity for cooking purposes incurred a 50% lower cost compared to the usage of gas or charcoal. Furthermore, Ghana boasts of a plethora of ecooking appliances available for purchase, including but not limited to induction cookers, multi cookers, pressure cookers, rice cookers, hot plates, microwaves, electric ovens, and halogens. As such, prospective users need not encounter obstacles when selecting their preferred eCook. The Ghana eCook book, crafted by the MECS, quantifies the conservation of energy, time, and money with energy-efficient electrical devices when preparing conventional meals. This implies that eCooking can sustain the authentic flavour of indigenous cuisine in Ghana. Against this backdrop, the authors grappled with the following queries: a) Despite electric cook stoves being available in the Ghanaian market and research demonstrating their cost-effectiveness, why do we observe limited adoption and usage rates? b) What factors influence adopters' decisions to utilise specific stove type? c) What insights can be gleaned from public determinants to inform future decisions on eCooking?

The study bridges a void in the scholarly literature by presenting empirical proof concerning the factors that influence the acceptance and utilisation of eCooking technologies in Ghana through choice modelling analysis. To achieve this goal, the present investigation employs the analytical hierarchy process (AHP) to prioritise the variables that impact the acceptance and utilisation of ecooking appliances among end-users. The most suitable device was identified by utilising the techniques of fuzzy TOPSIS (FTOPSIS) and Data Envelopment Analysis (DEA). These methods allowed for a comprehensive assessment of various devices, considering multiple criteria factors. The FTOPSIS technique involved the use of fuzzy logic to handle imprecise data and uncertainty in decision-making. Meanwhile, DEA enabled a comparison of different devices based on their efficiency in achieving optimal eCooker. Through these approaches, the optimal device was ultimately selected for both analyses, ensuring maximum effectiveness and performance for the intended application. The study further reviews the potential of PV-eCook systems to support decisions on eCooking within the country. The subsequent sections of this study are laid out as follows: Section 2 shows the primary classifications of eCookers in Ghana, elucidates the AHP configuration, and expounds on the methodologies employed for DEA and FTOPSIS. Section 3 presents results concerning consumer preferences for eCookers and the quantifiable effects of these determinants on optimal choices. Ultimately, Section 4 summarises key findings while addressing major policy implications; concluding remarks are presented in Section 5.

Literature on renewable energy systems for ecooking in Ghana

Given the current study's focus on eCooking, it is crucial to comprehend the clean energy scenarios and electricity production state. Historically, electricity generation in Ghana has been dominated by hydro and thermal sources. Nevertheless, there is a gradual increase in renewable energy due to decreasing costs of PV technologies and a concerted effort to diversify the mix. According to the national energy statistics bulletin, in 2000, hydroelectric power plants were responsible for producing approximately 92% of the country's electricity demand. In contrast, thermal plants generated only 8% (Energy Commision 2023). However, as of 2021, the generation mix has shifted significantly with hydroelectric power accounting for roughly 35.3%, while thermal sources now produce around 64% and renewables contributing 0.7% per the statistical bulletin. This shift may have implications on whether cooking with renewable energy is presently feasible given current capacity constraints.

With regard to biomass cooking initiatives, the National Energy Policy of 2021 discloses that the government has disseminated an impressive number of 800,000 improved biomass cook stoves across the nation. These stoves have been shown to reduce fuel wood consumption by up to 40% compared to traditional models (Ministry of Energy 2021). Additionally, the stoves can serve as a viable opportunity for promoting entrepreneurship in the briquette and pellet industries while endorsing waste-to-energy initiatives like briquette production (Ossei-Bremang, Adjei, and Kemausuor 2023).

Several private institutions and the government have initiated numerous small-scale renewable energy projects in Ghana. These small-scale consist of solar and wind power generation, battery storage, secondary diesel generators, and distribution systems with a capacity ranging from 30 kW to 55 kW (Adu-Poku et al. 2023). However, despite the presence of such installations, there is currently a lack of solar cooking technologies available for adoption and use by communities powered by solar energy (PV-eCook). In contrast to the situation with biomass cookstoves, PV-eCooking projects are still in the experimental phase within the country, an example includes the work done by Opoku et al. (2023). It is worth noting that in many developing countries without Feed-in-Tariff (FIT) policies, or where strict compliance with their implementation is lacking such as in Ghana, electricity generation from PV and PVT technologies requires either advanced storage or on-generation utilisation through load shifting to mitigate energy redundancies (Eze et al. 2022, 2023). Multiple studies have substantiated the viability of PV-eCooking for countries such as Ghana, and their research indicates that its feasibility is indeed achievable. Batchelor et al. (2018) suggested utilising excess energy generated by community solar PV mini-grids during peak sunlight hours, when the battery is fully charged, for cooking purposes. The same studies revealed an average surplus energy of 56.98–

Figure 1. Types of Electric Cookstoves in Ghana.

119.86 kWh/day that can be harnessed for eCooking, thereby supporting cooking loads in 26–54 households for African countries like Ghana. Therefore, as Ghana prepares to shift towards Tier 4 and above technologies in cooking, it is imperative to augment the investment in solar-powered infrastructure for electrification. The PV-eCook initiative holds immense potential to bolster the solar market in Ghana, enhance the rate of electrification, encourage clean fuel usage for cooking purposes and mitigate climate change risks associated with firewood consumption.

Methodology

Sampling eCook stoves in Ghana

Dominant cooking appliances in Ghana, shown in Figure 1 are taken from MECS, 2023. Based on previous studies, the four types of eCook stoves were evaluated for households with an average of four individuals. These included a) induction stoves, b) electric hot plates, c) electric pressure cookers, and d) electric rice cookers.

Data collection

To improve decision power, the eligibility criteria for the AHP ranking process included corporate sector workers who are likely to belong to the 2% of households in Ghana that use electricity for cooking, as well as university students. The process involved using around 42 input data to determine the rankings. Diversity in the choice of the participants was to ensure a transparent and structured process. This multi-party decision articulation was necessary for negotiating trade-offs and assessing potential conflicts in the criteria for selection ranging from affordability to convenience. The monthly consumption which was used to determine the tariff each respondent is likely to pay using Equation 1. Shortlisted determinants of eCooking adoption and usage for the AHP process was done based on literature review.

$$\text{Monthly consumption} = \text{Wattage} \times 30\,\text{minutes of cooking} \times 3\,\text{meals/day} \times 30\,\text{days/month} \tag{1}$$

Integrating proposed methodology

At first, AHP was used to compute the weights of criteria for optimal e-cook device selection. Then, the combined fuzzy logic and TOPSIS (FTOPSIS), and DEA methods are applied to prioritise the optimal alternatives according to the mentioned criteria. The different methodologies were employed to compare the results obtained. The approach for determining AHP, as stated by Ossei-Bremang and Kemausuor (2021), was employed. However, in this instance, the relative importance of the various criteria to the target was established based on a thorough literature review on the impact each criterion has on the ecooking appliance acquisition process. The procedures for FTOPSIS were carried out following the descriptions in Taylan et al. (2020). In the case of DEA, the method as described by Emrouznejad et al. (2023) and Ossei-bremang et al. (2023) was used in the current study. Both methods for ranking the optimal eCooker were compared to analyse the results obtained.

Criteria for selecting ecooking device

The AHP was used to determine the weight of the determinants of ecooking adoption following the summarised steps in Equation 2 to Equation 4:

(a) Determine the vector of priorities - λ_{max}. The prioritisation vector is derived by averaging the product of the decision criteria's relative weight matrix and the mean weight of said criteria, as per equation (2).

$$\lambda_{max} = \sum_{j=1}^{m} \frac{(c.k)j}{m.kj} \tag{2}$$

where: $(c \cdot k)j$ denote the components of the matrix vector obtained through the multiplication of matrix '*c*' with vector '*k*'.

(b) Calculate the coefficient of uniformity, denoted as 'CI', using Equation 3 as shown below:

$$CI = \frac{\lambda_{max} - m}{m - 1} \tag{3}$$

(c) Determine the consistency factor of the matrixes. The consistency factor of matrixes '*CR*' is calculated based on equation (4), as follows:CR

$$\mathrm{CR} = \frac{CI}{R} \tag{4}$$

$CR = CI$, if $m = 1$ or 2;

if $m >$; When evaluating the consistency relation, it is important to adhere to the following guideline: if CR is less than 0.10, then the matrix can be deemed consistent and thus confirms that the weight vector is accurately determined.

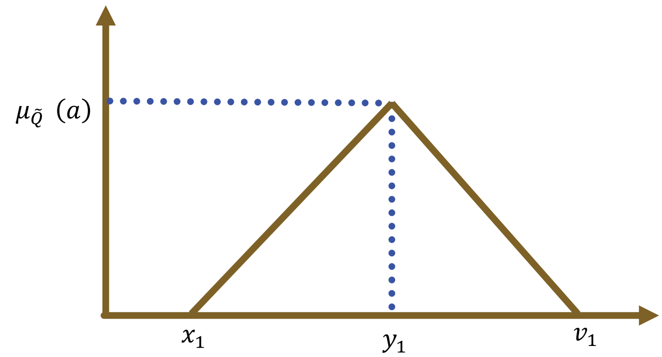

Figure 2. Triangular fuzzy numbers.

Managing vagueness and uncertainties

The management of ambiguity and vagueness in data was achieved through the implementation of fuzzy logic. The fuzzy logic system is comprised of three integral components, namely fuzzification, the rule base, and defuzzification. Fuzzification serves as the inaugural component in fuzzy logic by converting precise inputs into corresponding fuzzy values. The imprecise values are transmitted to the rule-based component and computed using fuzzy rules. The resulting fuzzy values are subsequently sent to the defuzzification unit, where they are converted into precise quantities. Typically, the input parameters for fuzzy logic include both control errors and their variations within a single sampling interval. Based on these variables, a rule table is generated within the rule-base unit of fuzzy logic.

A triangular fuzzy number (TFN) is also defined as $\tilde{Q}= (x_1, x_2, x_3)$where (x_1, x_2, x_3)*are*all real numbers and its membership function as shown in Equation 5.

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x < a \\ a - x/y - a & X \le a \le y \\ v - a/v - b & y \le a \le v \\ 0, & a \ge v \end{cases} \tag{5}$$

Certain operational protocols, including but not limited to summation, multiplication, reversal, and the calculation of distance between two TFNs as illustrated in Figure 2, Q $= (x_1, x_2, x_3)$ *and* $Y = (y_1, y_2, y_3)y1x1v1$ are stated as Equation 6 to Equation 9.

$$\check{Q} \oplus \check{Y}(x_1, x_2, x_3) \oplus (y_1, y_2, y_3) = (x_1 + y_1, x_2 + y_2, x_3 + y_3) \tag{6}$$

$$\check{Q} \otimes \check{Y} = (x_1, x_2, x_3) \otimes (y_1, y_2, y_3) = (x_1 y, x_2 y_2, x_3 y_3) \tag{7}$$

$$\check{Q}^{\check{-1}} = (1/x_1, 1/x_2, 1/x_3) \tag{8}$$

$$Z(\check{Q}, \check{Y}) = \sqrt{1/3\left[(x_1 - y_1)^2 + (x_2 + y_2)^2 + (x_3 + y_3)^2\right]} \tag{9}$$

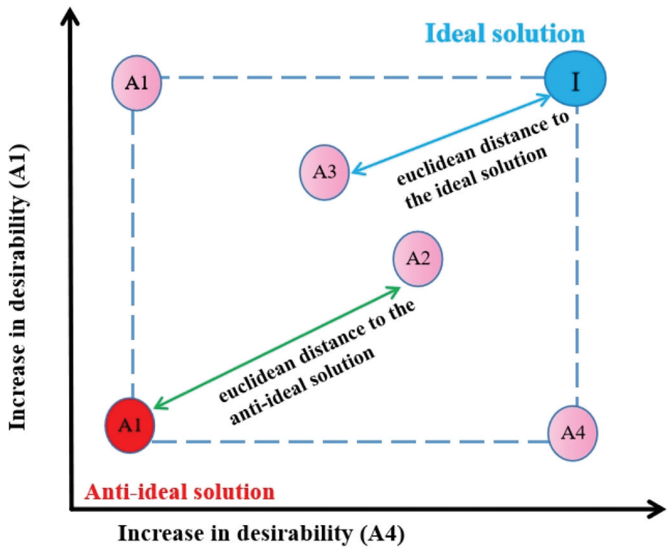

Figure 3. Deviation from optimal solutions.

Decision optimisation by fuzzy-TOPSIS

The TOPSIS approach relies on the premise that the optimal alternative should possess minimal proximity to the positive-ideal solution while maintaining maximum distance from the negative ideal solution. TOPSIS entails the formulation of a similarity index with respect to the positive-ideal solution and an assessment of remoteness from the negative-ideal solution, as illustrated in Figure 3. The optimal alternative is deemed to be the one that is closest to achieving ideal status. The distances involved can either be summed up in accordance with Euclidean principles or given weightings, thereby prioritising one of these two factors.

The TOPSIS algorithm steps used in the study can be classified as follows:

Step 1: Equation 10 was utilised to achieve a normalised and comparable scale for positive and negative indicators through a linear scale transformation.

$$\tilde{R} = (\tilde{r}_{ij})_{mxn} \quad (10)$$

The benefit criteria were subjected to normalisation through the application of Equation 11.

$$\tilde{r}_{ij} = \left[a_{ij}/c_j^*, b_{ij}/c_j^*, c_{ij}/c_j^*\right], where\, j = 1, 2, 3 \ldots\ldots.n \, and \; i = 1, 2, 3 \ldots\ldots.m \quad (11)$$

The cost parameter was normalised using Equation 12.

$$\tilde{r}_{ij} = \left[a_j/c_{ij}^*, b_j/c_{ij}^*, c_j/c_{ij}^*\right], where\, j = 1, 2, 3 \ldots\ldots.n \, and \; i = 1, 2, 3 \ldots\ldots.m \quad (12)$$

Step 2: The weighted and normalised decision matrix was derived through the utilisation of Equation 13. The significance weightage was duly represented as $\check{W}_j = \check{w}_1, w_2, w_{3,\ldots\ldots}, w_n$ i and $\sum_j^n = 1 \, then \, \check{W}_j = 1$, $V = \left[(v_{ij})_{mxn}\right]$ was the weighted normalised decision matrix where $i = 1, 2, \ldots.., m$ and $j = 1, 2, \ldots.., n$

$$V_{ij} = \tilde{r}_{ij} \, x \, \tilde{w}_j \quad (13)$$

Step 3: Equations 14 and 15 were also utilised to determine the positive (PIS) and negative ideal solution (NIS).

$$A^* = v_1^*, v_2^*, \ldots.v_n^* \; j = 1, 2.3, \ldots\ldots.n \quad (14)$$

$$A^- = v_1^-, v_2^-, \ldots.v_n^- \; j = 1, 2.3, \ldots\ldots.m \quad (15)$$

Step 4: The Euclidean distances for both (S*) and (S-) were calculated using equations 16 to 18.

$$S_i^* = \sum_j^n = 1, d\left(\tilde{v}_{ij}, v_j^*\right) i = 1, 2, \ldots., m \quad (16)$$

$$S_i^- = \sum_j^n = 1, d\left(\tilde{v}_{ij}, v_j^-\right) i = 1, 2, \ldots., m \quad (17)$$

$$d\left(\tilde{a}_{ij}, \tilde{b}_{ij}\right) = \sqrt{1/3\left(a1_{ij} - b1_{ij}\right)^2 + \left(a2_{ij} - b2_{ij}\right)^2 + \left(a3_{ij} - b3_{ij}\right)^2} \quad (18)$$

$$\tilde{a} = \left(a1_{ij}, a2_{ij}, a3_{ij}\right) and \, \tilde{b} = \left(b1_{ij}, b2_{ij}, b3_{ij}\right)$$

Step 5: The Closeness Coefficient (CC) that indicates the degree of similarity to an ideal solution was calculated using Equation 19.

$$CC^* = S^-/S^* + S^- \quad (19)$$

The different alternatives were then ranked based on the CC in a decreasing order.

Best eCooking appliance via DEA

The efficiency of decision-making units (DMUs) is evaluated in DEA through the examination of stove adoption determinants. Efficiencies calculated through DEA are comparative, meaning they are measured against the top-performing DMU (or multiple DMUs if there are more than one best-performing). The DMU that exhibits the highest level of performance is awarded an efficiency score of 100%, denoting unity. In contrast, the rest of the DMUs' performances range between 0 and 100% in relation to this optimal performance. The performance of the four DMUs was evaluated based on the input and output criteria outlined in Figure 4.

Assuming the most basic scenario, which involves a single input and output, the efficiency of these units can be expressed as a straightforward ratio:

$$\frac{output\ criteria}{input\ criteria}$$

The assessment of the comprehensive effectiveness of the DMU (eCooker) with its corresponding inputs and outputs was conducted simultaneously in the following manner:

Given the set of homogeneous units T_1, T, … … . T defined by u output criteria and v input criteria, the input matrix can be denoted as

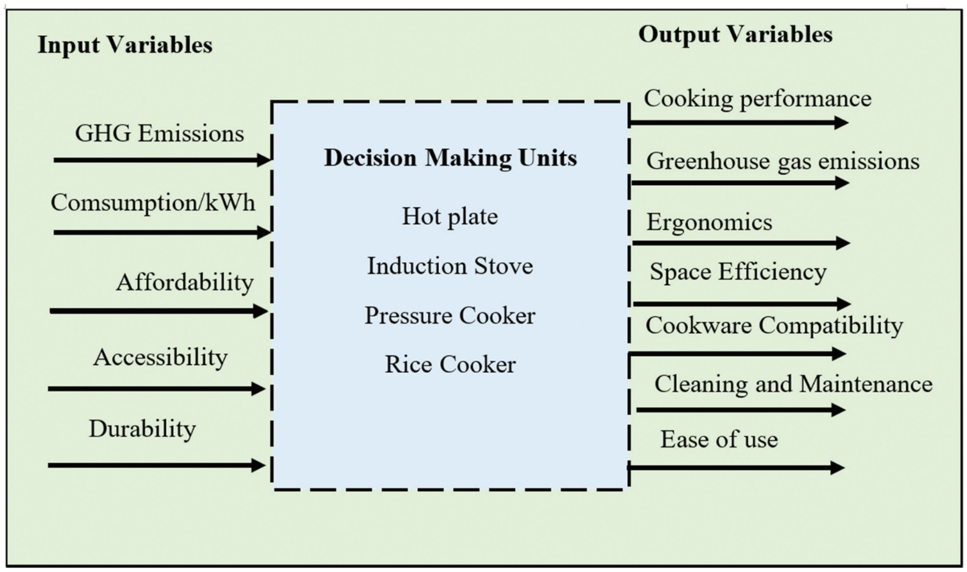

Figure 4. Structure of the performance evaluation of the decision-making units (DMUs).

$.w = \{w_{qs,}v = 1, 2, 3, \ldots .v, s = 1, 2, 3, \ldots, x\}$ with its output matrix as $h = \{h_{gs,}g = 1, 2, 3, \ldots .x, j = 1, 2, 3, \ldots, x\}$. Hence, the efficiency of a unit S_q can be computed as

$$\frac{\sum weighted\ output}{\sum weighted\ input} = \frac{\sum_g T_g h_{gv}}{\sum_s Z_J X_{gv}} \tag{20}$$

where $Z_j\ s = 1, 2, 3 \ldots, q$ represents the weight of the $s - th$ input criteria and T_i, i is the weight of the $i - th$ output criteria. The assessment of unit Tq through a DEA model involves maximising its overall score, while adhering to the constraint that the scores of all decision-making units must not exceed 100%, thus serving as an efficiency measure.

Techno-economic analysis of eCooking

An assessment was conducted to compare the techno-economic aspects of eCooking with other stove options currently available in the market, including LPG, charcoal stoves, firewood-powered stoves, grid-connected eCook stoves and PV-eCook. The evaluation was based on prevailing market prices. The consumption cost per person per day was determined using household tariffs by the public utility regulatory commission in 2022.

Results

Ecooker selection criteria

The adoption of electric cookers depends on various factors such as cooking efficiency, energy efficiency, heating effectiveness, safety features, and ease of use. According to the previous research, electric cookers that offer improved cooking efficiency and shorter cooking times are more likely to be favoured by consumers. Energy efficiency is another important factor for end-users, as it leads to cost savings and reduced environmental impact as well as ergonomic features. Additionally, ease of use, convenience, and user-friendly design have been reported to contribute to the adoption of electric cookers. Overall, these factors play a significant role in determining the adoption of electric cookers in the market by households. The criteria from I to xii as shown in Figure 5 was shortlisted from literature (Amoah 2019; Astuti, Day, and Emery 2019; Batchelor 2020b; Brown et al. 2017; Kizilcec et al. 2022; Leary and Fodio Todd 2019; Lombardi et al. 2019; Puzzolo et al. 2019; Scott, Leach, and Clements 2023; Y. Zhang, Xiao, and Zhou 2020; Zhao et al. 2019; Zhu et al. 2022). These criteria includes factors crucial for understanding the overall impact and utility of these appliances.

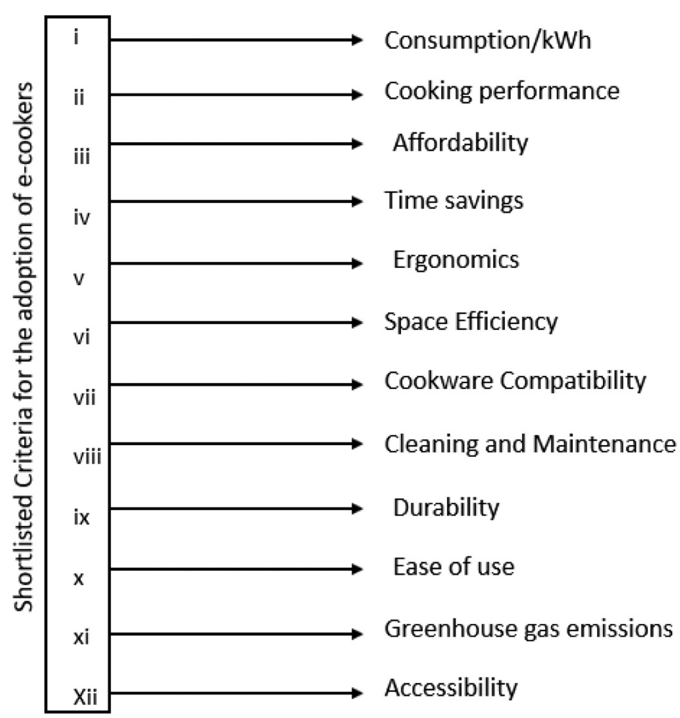

Figure 5. Shortlisted criteria for the adoption of eCookers.

Firstly, the *energy consumption* measured in kWh is a key indicator. eCookers vary in their energy usage based on design and usage patterns, with higher consumption leading to increased energy bills. The *cooking performance* of these appliances is equally vital. It's essential to realise that the energy efficiency of an appliance does not always correlate with its cooking performance. The performance depends significantly on the specific model and its features. *Affordability* plays a crucial role in the adoption of eCookers. While some consumers may prioritise cost, others might be inclined towards advanced features, like smart technology or superior cooking performance, despite the higher initial cost. *Time savings*, an important factor, is gauged by the speed at which a stove can cook a typical Ghanaian meal. Stove design must consider the principles of *ergonomics* to ensure maximum safety and comfort of use. Incorporating features such as cool-touch surfaces, child locks, and appropriate height and layout can significantly reduce the risk of burns, accidents, and injuries. *Space efficiency* is another significant factor. Stoves designed to fit into smaller kitchen spaces without compromising functionality are more likely to be adopted. *Cookware compatibility* is also essential. Stoves accommodating various sizes and types of cookware are preferred, as they allow users to use their existing pots and pans. *Cleaning and maintenance* aspects of stoves are crucial. Designs that simplify cleaning and maintenance, like easy-to-clean surfaces and accessible components, are more appealing. *Durability* is observed in some energy-efficient appliances, which may last longer due to reduced wear and tear from lower energy consumption. *Ease of use* is a crucial factor. Appliances with easy-to-use features for temperature, timer, and cooking mode are preferred. *Greenhouse gas emissions* are a significant environmental consideration. Appliances with higher energy consumption contribute more to greenhouse gas emissions, especially when the electricity is generated from fossil fuels. Energy-efficient appliances can help reduce the carbon footprint. Lastly, *accessibility* measures how easily and quickly an end-user can purchase a preferred stove from the market.

Together, these factors provide a comprehensive framework for evaluating eCookers, balancing performance, cost, environmental impact, and user experience

AHP weighting

The AHP results, as shown in Figure 6, indicated that the most important criterion was the consumption rate of the cooking appliance. The consumption/kWh criterion was the highest weight, indicating its significant importance in the context of the assessment. Affordability is the second most important criterion in this assessment. It signifies the importance of the cost or price of the product or service, with lower ranks being more desirable, implying that affordability is a high priority. Cooking performance ranks third in importance. This suggests that the quality and effectiveness of the product in terms of cooking are significant factors in the evaluation. Time savings are the fourth most important criterion. Ergonomics is the fifth most important aspect, which focuses on the comfort and usability of the product. Durability is moderately important, ranking sixth. It indicates that the longevity and robustness of the product are factors to consider but not as critical as some other criteria. Ease of use is the seventh in terms of importance. Cookware compatibility is the eighth most important criterion. Cleaning and maintenance rank ninth in importance. This suggests that ease of cleaning and maintenance is a consideration but not as critical as other factors. Space efficiency is the tenth most important criterion. Accessibility is the eleventh in importance. This could refer to how easily the product can be accessed or used, with a lower rank indicating its significance.

Greenhouse gas emissions are the least important criterion in this assessment, ranking twelfth. The rankings and weights indicate the relative importance of each criterion in the decision-making process, helping stakeholders prioritise their considerations when evaluating products or services related to these criteria in Ghana.

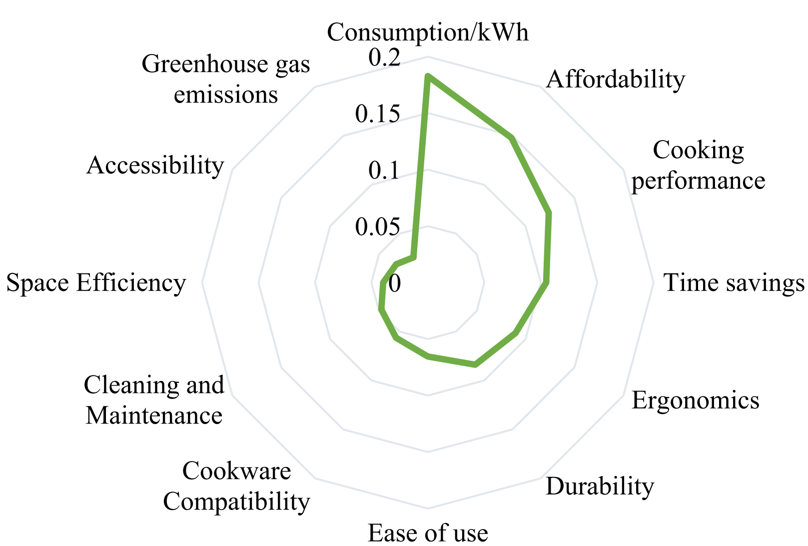

Figure 6. Weights of importance per AHP evaluation.

Table 1. The linguistic variables rating.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Hot plate	VG	F	VG	G	VG	G	VG	VG	VG	G	VG	VG
Induction Stove	VG	MG	VG	VG	VG	G	VG	VG	VG	MG	G	VG
Pressure Cooker	G	VG	G	VG	G	G	G	VP	VG	MG	VG	VG
Rice Cooker	VG	G	VG	G	MG	G	MG	VP	G	MG	G	VG

Table 2. Positive triangular fuzzy triangular numbers.

		Hot Plate	Induction Stove	Pressure Cooker	Rice Cooker
		A_1	A_2	A_3	A_4
Fuzzy decision matrix.	C_1	9,10,10	9,10,10	7,9,10	9,10,10
	C_2	3,5,7	5, 7, 9	9,10,10	7,9,10
	C_3	9,10,10	9,10,10	7,9,10	9,10,10
	C_4	7,9,10	9,10,10	9,10,10	7,9,10
	C_5	9,10,10	9,10,10	7,9,10	5, 7, 9
	C_6	7,9,10	7,9,10	7,9,10	7,9,10
	C_7	7,9,10	9,10,10	7,9,10	5,7,9
	C_8	9,10,10	9,10,10	0, 0, 1	0, 0, 1
	C_9	9,10,10	9,10,10	9,10,10	7,9,10
	C_{10}	7,9,10	9,10,10	5,7,9	5,7,9
	C_{11}	9,10,10	7,9,10	9,10,10	7,9,10
	C_{12}	9,10,10	9,10,10	9,10,10	9,10,10

Performance evaluation of eCookers

FTOPSIS ranking

The linguistic variables' rating and their range of positive triangular fuzzy number values were obtained in the matrix in Table 1. The use of linguistic terms involved the verbal expressions of the ratings of the determinants against the stove types. This methodology aided in comprehending their expression with greater clarity and precision by utilising fuzzy logic to eliminate any semblance of obscurity or uncertainty. This methodology proves especially advantageous when conducting extensive forecasting exercises, particularly in the context of end-users considering procurement. Furthermore, it is imperative to capitalise on emerging prospects as a means of acquiring an enhanced comprehension regarding end-user needs and preferences. By doing so, manufacturers may also be able to produce customised e-cook stoves that better cater to the specific needs and preferences of their consumers.

The positive triangular fuzzy numbers shown in Table 2 were subsequently utilised to assess and rank the alternatives. The information pertaining to the TFNs was additionally calculated to derive both the normalised decision matrix and the weighted normalised decision matrix. The final prioritisation of the alternatives was obtained based on the coefficient closeness (CC*) values illustrated in Table 3. In the implementation of the FTOPSIS methodology, hot plate is the most prioritised alternative following all 12 criteria for selection. The CC* indicates that hot plate was the option closer to the ideal solution, achieving the highest score, 0.72, followed by hot plate, pressure cooker, and rice cooker in that order.

DEA ranking

The scores of the weights obtained from the AHP ratings of the 12 criteria used to evaluate the performance of four different e-cook options were separated into inputs and outputs for the CCR output-oriented model, as shown in Table 4. During the AHP

Table 3. The final prioritisation of the alternatives.

	S^+	S^-	S^++S^+	CC*	eCooker	RANK
A_1	0.78	1.24	2.02	0.61	Pressure Cooker	**3**
A_2	0.98	0.79	1.77	0.45	Rice Cooker	**4**
A_3	0.77	1.37	2.14	0.64	Hot plate	**2**
A_4	0.53	1.35	1.88	0.72	Induction Stove	**1**

Table 4. Criteria and scores based on inputs and outputs for the CCR output-oriented model.

	Inputs					Outputs						
DMU name	1	2	3	4	5	6	7	8	9	10	11	12
Hot plate	0.12	0.11	0.1	0.07	0.08	0.07	0.09	0.09	0.09	0.05	0.06	0.07
Induction Stove	0.18	0.15	0.12	0.1	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.03
Pressure Cooker	0.03	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.12	0.15	0.18
Rice Cooker	0.07	0.08	0.09	0.1	0.12	0.15	0.18	0.03	0.03	0.04	0.05	0.06

Table 5. Summary of overall results from DEA.

DMU	Objective Value	Efficient
Hot plate	0.778	No
Induction Stove	1	Yes
Pressure Cooker	0.967	No
Rice Cooker	0.581	No

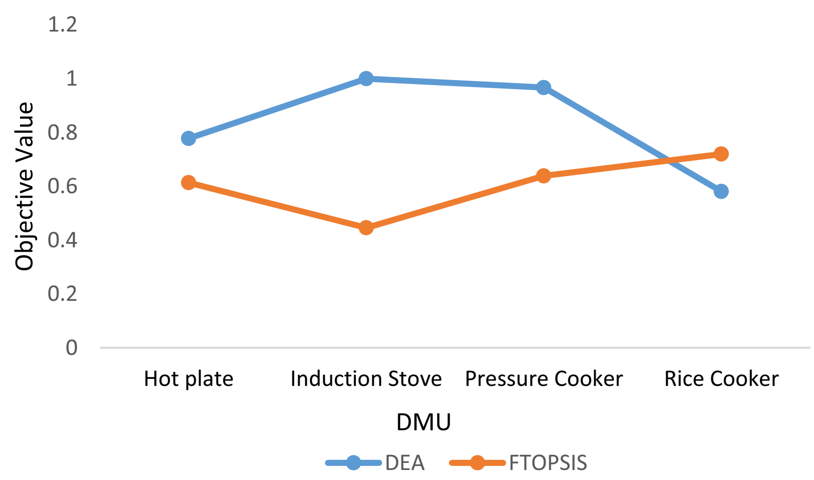

Figure 7. Comparative analysis of DEA vs FTOPSIS.

process, each respondent provided their individual opinions on the importance of these criteria, which were then averaged to determine their overall weight. Table 5 presents the final assessment of the DEA, which shows that the hot plate, rice cooker, and pressure cooker are identified as inefficient DMUs. The rankings in Figure 7 indicate that both FTOPSIS and DEA methods agree that the induction stove is the most efficient option. However, a detailed analysis of parameters reveals that each methodology has assigned different ratings to the DMUs based on their respective strengths and weaknesses.

Techno-economic analysis of eCooking

The economic implications of eCooking were assessed and juxtaposed with alternative cooking techniques in Ghana over a twenty-year period. The estimations for eCooking were derived from end-users who use national grid for cooking. The current landscape of diverse power generation sources for the national grid can be seen in Figure 8. Additionally, Table 6 presents an economic analysis of several cooking technologies that are analysed by their respective estimated costs per household on a daily basis using cost estimations in PURC, 2022. However, the data on PV-eCook in the table was obtained from the results of an experimental study by (Opoku et al. 2023).

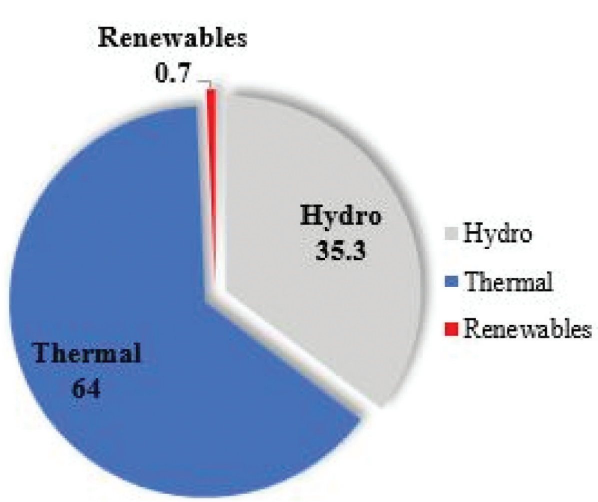

Figure 8. Electricity generation share in Ghana.

According to Table 7, the rice cooker is the most cost-effective option for daily fuel cost making it a prudent selection for users who prioritise their daily expenditure. Subsequently, the pressure cooker follows suit with a moderately low fuel cost. The hot Plate has a slightly higher daily fuel cost while the induction stove exhibits the highest among all available options.

Discussions

Determinants of eCooker choice

The results show a hierarchy of determinants that guide end-users in their selection of an e-cook stove, with the most crucial parameter being the primary consideration. As stated in section

Table 6. Cost of various cooking technologies in Ghana verse eCooking.

S/N	Technology	Fuel Used	Average cost of Cook stove ($USD)	Cost of fuel ($USD/ person/day)	Operations and Maintenance cost ($USD/ year)
1.	LPG	LPG	33.46	0.14–0.39	10–19
2.	Improved cook stove (Gyapa)	Charcoal	15	0.04–0.38	7–12
3.	Three stone	Firewood	Free	0.27	0
4.	Grid-connected eCooker	Grid electricity	37.36	0.16	22–30
5.	PV-eCooker	Solar	198 (Opoku et al. 2023)	Free solar radiation	16–20

Table 7. Economic analysis of the eCook stoves understudy.

S/N	eCook stove	Average cost of Cook stove ($USD)	Cost of fuel ($USD/person/day)	Average operations and maintenance cost ($USD/year)
1.	Induction stove	28.11–76.48	0.16	22–30
2.	Hot plate	19.68–31.01	0.14	13–18.5
3	Pressure cooker	45.48–59.53	0.11	22–33
4.	Rice Cooker	17.78–26.87	0.06	11.4–19

3.1, the consumption rate of the stove was deemed to be the most important factor for the end-users in reaching a conclusive decision on an eCooker. According to the product specifications of available models in the market, the consumption rates range from 1.25 kWh to 1.50 kWh for hot plates, 1.9 kWh to 2.85 kWh for induction plates, 0.7 kWh to 1.25 kWh for pressure cookers, and 0.60 kWh to 0.95 kWh for rice cookers. The induction cooking plate exhibited the highest level of consumption. However, future studies may show potential deviations in consumption rates when a stove is exposed to real-life cooking scenarios, such as preparing multiple dishes for dinner or cooking a meal for long hours. Based on the findings, it can be inferred that households with frequent or diverse cooking habits and longer cooking durations may incur greater electricity expenses than those with contrasting cooking practices. The correlation between the consumption rate and energy cost can be supported by Zhang et al. (2020). The previous work reported the higher the consumption rate of household, the higher the energy cost.In addition to the prospective exorbitant expenses incurred by household electricity bills when utilising an induction plate, it also requires the highest initial investment among available options in the market. The cost of a single-burner induction stove varies from GHC 340 to GHC 925, while an electric pressure cooker falls within the range of GHC 550 to GHC 720 making these two the most expensive ones on the market. Hot plates was the least expensive choice, ranging anywhere from GHC 215 and GHC 325 followed by rice cookers which ranged between GHC 238 to 375.

Therefore, in cases where financial constraints are a limiting factor for end users, it may be necessary to make a trade-off between the potential benefits of all available eCook options and opt for the most cost-effective alternative, particularly among the population of tertiary students.

In terms of cooking proficiency, the induction stove exhibited the most superior performance, followed by the pressure cooker. Conversely, the hot plate and rice cooker displayed comparatively poor results, thereby making the induction stove the most optimal choice. In terms of its durability, ease of use, compatibility with cookware, accessibility, and ease of cleaning and maintenance, the hot plate received a score of 1 out of 5 in this study. A score of 1 indicates excellent performance while a score of 2 means very good performance. A score of 3 represents good performance, a score of 4 suggests poor performance and a score of 5 denotes very poor performance. The induction plate, received a rating of 1 in the areas of ergonomics, cookware compatibility, ease of cleaning and maintenance, as well as time savings, durability and ease of use. However, it garnered a score of 5 for its accessibility, hence suppliers which intensify the effort of making it accessible for all due to it efficiency and versatility.

Talking of the pressure cooker, a rating of 1 was scored for time savings, making it perfect for those who are always on the go and in need of quick meal solutions. The pressure cooker also scored 2 in ergonomics, making it comfortable to hold and handle even during extended use. It durability was another strong point with a rating of 1. End-users reported that their appliances had lasted for almost 4 years. In terms of ease of use, the pressure cooker earned a score of 3, allowing even novice cooks to whip up delicious meals with minimal effort. It's also highly not compatible with other cookware, earning a rating of 5 in this category. Cleaning and maintenance was rated 3, same as accessibility. It can therefore be said that the pressure cooker may be an excellent investment for any home looking to save time and effort in the kitchen while still producing high-quality meals.

The time-saving feature of the rice cooker was rated with a score of 4, which is poorer when compared with the other options under study. Additionally, the ergonomics, durability, and ease of use were all rated at 3. This means that the device is user-friendly and can withstand wear and tear for extended periods. Cookware compatibility also scored a 5, meaning that it is not compatible with other cookware types commonly used in households. Furthermore, the rice cooker's ease of cleaning and maintenance also received a score of 2. Accessibility also only received a score of 1. This suggests that individuals are able to buy from local market due to its overabundance nature.

Optimal eCooker

Upon conducting FTOPSIS and DEA analyses, the induction stove proved to be the optimal choice. The results show that utilising an induction stove brings about multiple benefits. One of the most notable advantages is that it leads to faster cooking times, which ultimately translates into saved time and energy during meal preparation. This could be due to the fact that induction stoves have more precise temperature control and offer quick and fine temperature adjustment. Therefore, one can achieve the desired level of heat more efficiently and accurately, leading to quicker results. Overall, the use of an induction stove proves to be a practical and efficient choice. For compatibility with various types of cookware, the induction stove and the hot plate performed better than the pressure cooker and the rice cooker. The rice cooker and pressure cooker, are restricted by specialised cookware, this makes cooking traditional Ghanaian meals with varying portions and techniques somehow a cumbersome task when these two are used.

Based on the DEA analysis, it was evident that the pressure cooker, hot plate, and rice cooker did not meet efficiency standards since their respective objective functions were all less than 1. The most favourable option was the pressure cooker, followed by the hot plate and then the rice cooker.

However, according to FTOPSIS analysis, the second-best choice was actually the hot plate, with the pressure cooker coming in third and the rice cooker being deemed as least optimal.

Techno-economic benefits of eCooking

In general, the three stone technique is inexpensive but falls short in terms of sustainability and eco-friendliness. The cost of a grid-connected eCooker is moderate, and contingent upon the availability of grid electricity. However, while PV-eCookers may be costly to purchase initially, it has lower operational expenses due to their utilisation of free solar radiation. It has been found that the PV-eCooker is currently more than five times expensive in comparison to the grid-connected ecooker, despite having zero fuel costs and slightly lower operation and maintenance expenses. On the other hand, the conventional fuel-based stoves that use firewood are the cheapest among all cooking methods in Ghana. Nonetheless, they pose serious health hazards to the users and pollute the environment, which makes them an unacceptable option. LPG and improved cook stove, on the other hand, entail moderately higher costs but offer better environmental benefits when compared to three stone stoves.

In the end, the selection of the most financially efficient eCook stove hinges on the preferences of the user. If their main objective is to reduce daily fuel expenses, then opting for a rice cooker would be deemed as an economical alternative. However, if users are taking into account both daily fuel costs and yearly O&M expenses, they may find themselves drawn towards selecting either a rice cooker or a Hot Plate due to their appealing cost-effectiveness. The Induction Stove and Pressure Cooker, albeit boasting distinct functionalities, entail greater expenses which may render them more fitting for consumers who prioritise said features over economical advantages.

Policy information role of the government

The Ghanaian government bears a substantial obligation in the advancement of eCooking, particularly with regard to meeting worldwide objectives for clean cooking by 2030. To achieve this, several measures can be implemented by the governments and policy makers to encourage households to adopt eCooking appliances through the following ways:

(a) Offering incentives like tax credits and subsidies could lower the cost of eCooking appliances for households while also encouraging sustainable value for suppliers.
(b) Enhance the accessibility of eCooking in remote areas through off-grid solar power systems. Currently, photovoltaic technologies are experiencing a significant decrease in cost and can serve as a dual strategy to enhance the rates of rural electrification and augment the share of renewable energy within the generation mix.
(c) Enhance the research and development of PV-eCook stoves to expedite their adoption and utilisation.
(d) Promote demand and supply channels by raising awareness through various channels, including education programmes and public campaigns, individuals can make informed decisions about their cooking practices.

Conclusion

Acknowledging and managing trade-offs and contradictions is a crucial aspect of decision-making, particularly in a diverse environment where consumers may have different preferences and priorities related to electronic cooking. The study recognises the importance of this process in effectively addressing the complex challenges associated with eCooking. The eCooking devices used for the evaluation were the induction stove, hot plate, pressure cooker, and rice cooker. The selection of eCookers is influenced by various factors, and the hierarchy of determinants has shed light on the importance of consumption rate, affordability, and cooking performance. These three factors top the list of the determinants and it plays a critical role in determining which electric cooker to purchase. After conducting a thorough analysis, it was concluded that the induction stove proved to be the most favourable option. This decision was based on a combination of Fuzzy-TOPSIS and DEA evaluations, which provided valuable insights into the stove's overall performance and efficiency. After evaluating all factors, it can be confidently stated that the induction stove is the optimal choice in terms of functionality and cost-effectiveness. Despite its potential for high electricity consumption as discovered in the techno-economic analysis, the induction stove's efficiency, performance, and other attributes render it a favoured choice. The Ghanaian government will play an instrumental role in advancing the adoption of electric cooking, through the provision of incentives, investment in infrastructural projects, implementation of regulations, support for manufacturers and facilitation of educational programmes. As such, this study suggests that future research ought to account for the kitchen practice experiment via this stove in order to compare the outcomes derived from this evaluative model, especially for the Ghanaian scenario. Also, further studies should consider a life cycle assessment on the power generation sources used by households to validate the sustainability of eCookers and perform a detailed analysis of their levelized cost of heat (LCOE).

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Data availability statement

The data that support the findings of this study are available from the corresponding author, [R.N.O-B.], upon reasonable request.

Author's contribution

Rejoice Ntiriwaa Ossei-Bremang: conception and design, or analysis and interpretation of the data; the drafting of the paper; Fabian Eze: Critical revision for intellectual content; Kwame Anane-Fenin: Critical revision for intellectual content; Francis Kemausuor: Critical revision for intellectual content. All authors gave the final approval of the version to be published and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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