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Research Article

Analytical Hierarchy Process Applied to Clean Burning Cookstove Design Concept Selection

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Abstract

This study used the Analytic Hierarchy Process (AHP), a multi-criteria decision making (MCDM) method to evaluate six clean-burning cookstove designs - the Natural Draft Sunken Pot Rocket Stove, the Kirk Harris TLUD Stove, the Side Feed Bottom Air Forced Draft Stove, the Top Lit Forced Draft Stove, the Charcoal Stove and the SSM Jet-Flame Stove -for mass production in Cameroon, addressing the dual priorities of thermal efficiency and emissions reduction under the ISO/IWA Tiers of Performance framework. Building on a prior quantitative survey of cookstove performance, eight criteria— thermal efficiency, specific consumption, high and low power emissions (CO, $PM_{2.5}$), indoor emissions (CO, $PM_{2.5}$). —were used to assess the designs. Pairwise comparisons showed the charcoal stove as optimal for combustion efficiency (24% priority score) and the Kirk Harris TLUD stove as superior for minimizing emissions (37% score), demonstrating that design suitability depends on context-specific energy and environmental goals. The AHP methodology was validated through sensitivity analysis and a consistency ratio below 10%, confirming its robustness for structured decision-making. By systematically balancing technical performance, user needs, and environmental impact, this study underscores AHP's utility in guiding the selection of clean energy technologies. The findings provide policy makers and manufacturers with actionable insights to prioritise designs that meet regional priorities, whether fuel efficiency in resource-constrained environments or emissions reduction in health-sensitive areas. This approach supports scalable, evidence-based transitions to sustainable cooking solutions in Cameroon and similar contexts.

Keywords

Stove Design Selection, Analytical Hierarchy Process, Multicriteria Decision Making, Clean Burning Cookstove

1. Introduction

Currently, approximately 2.7 billion people in developing nations rely on biomass, such as animal waste, agricultural residues, and charcoal, for cooking and heating [1]. In Cameroon, this dependence on biomass as a primary energy source is particularly pronounced, especially in rural areas where access to modern energy services remains limited. Biomass

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accounts for nearly 74.22% of the total energy consumption in the country, with wood fuel and charcoal being the most widely used sources [2, 3]. In rural regions of Cameroon, over 90% of households depend on traditional biomass for cooking, highlighting the persistent energy poverty in these areas [4, 5].

Even in urban centers, where alternative energy sources like electricity and liquefied petroleum gas (LPG) are more accessible, a significant portion of the population continues to use charcoal and wood due to affordability and cultural preferences. This reliance on biomass has significant environmental and health implications, including deforestation and respiratory diseases caused by indoor air pollution. Despite efforts to promote cleaner energy alternatives, the transition remains slow due to economic constraints and entrenched energy practices.

The adverse environmental and health impacts associated with traditional cooking stoves have driven the development of advanced, safe, and efficient biomass cookstoves. Numerous alternative cooking technologies have been designed to deliver improvements over traditional stoves in terms of fuel efficiency and emissions [6, 7]. Recent studies have demonstrated the importance of evaluating cookstove performance across multiple criteria, including fuel efficiency, emissions reduction, and user acceptability.

For instance, Still, Bentson, and Li [8] tested 15 improved cookstove designs in accordance with the ISO/IWA Tiers of Performance, highlighting significant variability in performance across different designs and underscoring the need for a systematic approach to selection. Their study revealed that while some designs excelled in thermal efficiency, others performed better in reducing emissions, emphasizing the importance of context-specific solutions. Similarly, MacCarty, Still, and Ogle [9] evaluated the fuel use and emissions performance of 50 cookstove models in laboratory settings, identifying key benchmarks for performance. Their findings demonstrated the trade-offs between fuel efficiency, emissions reduction, and user acceptability, further reinforcing the necessity of a structured framework for comparing and selecting cookstove designs.

Given the growing number of cookstove designs available, selecting the most suitable option for re-design and mass production requires a robust and structured decision-making framework. The shift toward advanced cooking technologies with high combustion efficiency and low emissions is critical for achieving multiple objectives, including improved public health, reduced deforestation, and climate change mitigation. However, the diversity of available designs and the complexity of performance trade-offs necessitate the use of MCDM methods like AHP to ensure the selection of preferred cookstove designs. Multicriteria decision-making (MCDM) methods, such as the Analytic Hierarchy Process (AHP) which has been used in design concept selection [10, 11], have emerged over the years as one of the most popular MCDM tools for formulating and analyzing multicriteria decisions in wide range of application [12-16]. The large number of applications of AHP as a standalone methodology [10-12, 17-22] shows that researchers consider AHP as a credible methodology in its own right.

The AHP method can be implemented using various techniques, including the geometric mean, arithmetic mean, row sum of the adjusted Saaty matrix, reverse sum of Saaty matrix columns, row sum of the saaty matrix, and the Saaty method [23, 24]. In comparison to the Saaty method which provides the most accurate results, the geometric mean method in previous studies showed the least deviation (CI = 0.00010), followed by the row sum of the adjusted Saaty matrix (CI = 0.00256), reverse sum of Saaty matrix columns (CI = 0.00852), and row sums of the Saaty matrix (CI = 0.01261) [23].

A survey conducted among managers (Figure 1) revealed that the respondents viewed the Saaty method as the most complex and difficult to apply. In contrast, the geometric mean and arithmetic mean methods were considered the simplest. The Geometric mean method, which produces results nearly identical to the Saaty method, was chosen for this study to identify the preferred design clean-burning cookstove design for mass production in Cameroon due to its accuracy, simplicity and the fact that it does not require specialized software.

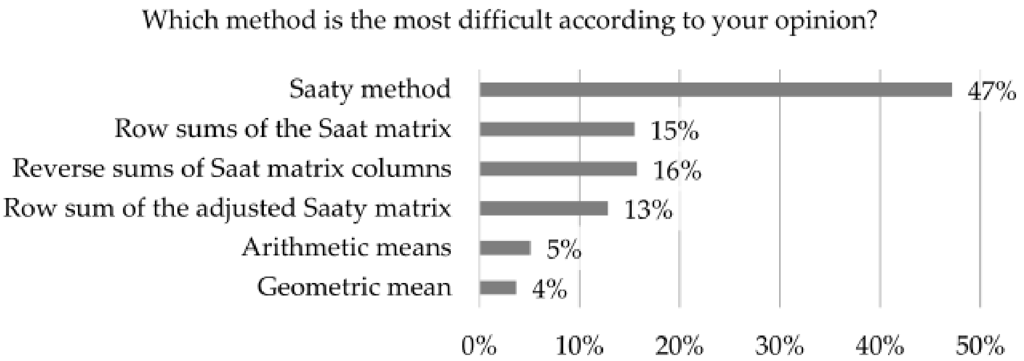

Figure 1. *Difficulty Levels of Methods in the AHP Process [23].*

2. Materials and Methods

The Analytic Hierarchy Process (AHP), developed by Saaty, is a widely used multicriteria decision-making (MCDM) method that uses mathematics and psychology to make and analyse complex decisions. AHP decomposes complex problems into a structured hierarchy comprising the problem goal, criteria, and alternatives. This structured approach enables decision-makers to systematically evaluate and prioritize options to identify the preferred solution that aligns with the problem's parameters.

The AHP method was applied in this study following these key steps: (1) establishing the hierarchical structure, (2) pairwise comparison of criteria, (3) computation of the weight vector using the geometric mean method, (4) conducting a consistency test to ensure the reliability of judgments, (5) data collection, (6) normalization of the decision matrix, and (7) final decision-making. The geometric mean method was employed to compute the weight vector, ensuring a robust and mathematically sound prioritization of criteria.

2.1. Setting up of the Hierarchical Structure

The hierarchy of the AHP method usually consists of the goal, the alternatives for achieving the goal and the criteria that apply to the individual alternatives of the goal. It is a so-called three-level hierarchy, whereby the peak is the goal (the 1 st level), followed by the criteria (the 2 nd level), and lastly, the alternative solutions to the problem (the 3 rd level). The hierarchical structure used in this study is as follows:

Goal: The overarching objective of the decision-making process. In this case, the goal is to select the best clean-burning cookstove design.

Criteria: The factors or attributes that will be used to evaluate the alternatives. These criteria should be relevant to the goal and measurable. For selecting a clean-burning cookstove, criteria considered in this research include: High Power Thermal Efficiency, Low Power Specific Consumption, High and Low Power CO, High and Low Power $PM_{2.5}$, Indoor Emissions of CO, Indoor Emissions of $PM_{2.5}$.

Alternatives: The different options or choices that are being evaluated. In this context, the alternatives would be the specific clean-burning cookstoves available on the market and freely available CAD drawings. the following six clean-burning cookstoves were selected: Natural Draft Sunken Pot Rocket Stove, Kirk Harris TLUD Stove, Side Feed Bottom Air Forced Draft Stove, Top Lit Forced Draft Stove, Charcoal Stove, SSM Jet-Flame Stove [25]. The structure of the AHP process is displayed in Figure 2.

The study assumes stable fuel (charcoal, wood pellets, dry wood, etc.) availability for the six stoves. For instance, charcoal availability in Cameroon, a premise based on its current dominance as a household energy source, particularly biomass accounted for 74.22% of the country's total energy consumption in 2018 [26]. This assumption is consistent with Cameroon's national development strategy 2020-2030 [27], which recognises the entrenched role of biomass in the energy mix, despite efforts to promote alternatives such as LPG.

In this study, two scenarios (prioritising thermal efficiency vs. indoor emissions) were explicitly designed to reflect different, aggregated priorities derived from stakeholder interviews, World health organisation health policy and empirical adoption studies [28-31]. While stakeholder interviews informed the weighting of criteria, the scenarios reflect dominant, policy-oriented priorities rather than exhaustive stakeholder segmentation.

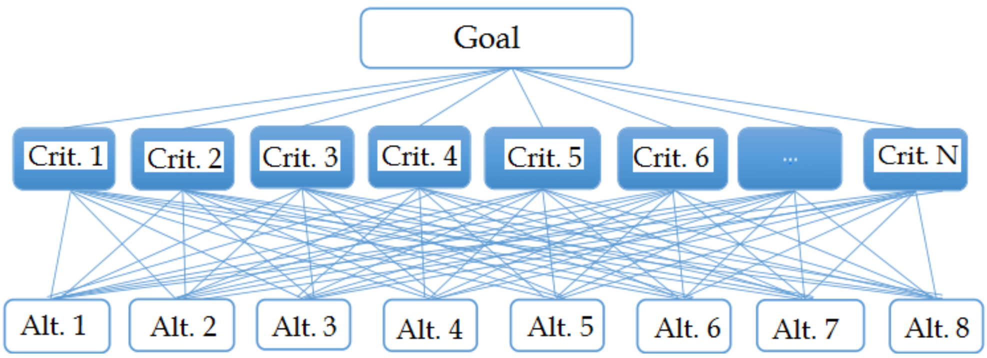

Figure 2. *AHP decision hierarchy of problem.*

2.2. Criteria Comparison

The *AHP* compare alternatives pairwise with respect to each criterion. Let $A = [a_{ij}]$ be the pairwise comparison matrix, equation (1), where a_{ij} is the element of row i column j of the Saaty's matrix, n is the number the evaluated criteria or alternatives; a_{ij} expresses the intensity of the preference of criterion i over criterion j. It holds that if criterion i is more important than criterion j, then $a_{ij} \in \{1, 2, 3, 4, 5, 6, 7, 8, 9\}$, on the other hand $a_{ij} =$

$(1/a_{ji})$ [32].

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} = [a_{ij}] \quad (1)$$

The relative importance between two criteria is evaluated on the basis of Saaty's scale, a numerical scale ranging from 1 to 9, as described in Table 1.

Table 1. *AHP scale for criteria comparison [12, 33].*

Scale	Relative importance of factor i compared to factor j
1*	Equally important
3	Moderately more important
5	Strongly more important
7	Very strongly more important
9	Extremely more important
2, 4, 6, 8	Intermediate values

2.3. Weight Vector Using Geometric Mean

After building the matrix A, the geometric mean of each row in the pairwise comparison matrix is calculated using the geometric mean method. The geometric mean method is considered to be a simpler method that produces almost identical results, and for which specialized programs are not needed [13, 32-34].

$$g_i = \left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}, i = 1, 2, \ldots, n \quad (2)$$

Where the geometric g_i determines the utility of individual alternatives. The geometric mean values is normalized to derive the weight vector w:

$$w_i = \frac{g_i}{\sum_{i=1}^{n} g_i} \quad (3)$$

Vector w gives the relative weights of individual alternatives or criteria.

2.4. Consistency Test

In order to check the consistency of the comparisons made by decision-makers, namely, the matrix A, AHP suggests a technique based on testing the consistency ratio (CR) which is calculated using equation (6). The pair-wise comparisons in a judgment matrix are considered to be adequate if the corresponding CR is less than 10%. If CR>0.1, the judgment made by the decision maker is inconsistent, as a result, the evaluations must be revised.

The consistency index (CI) will be estimated by computing $(A \cdot w)_i$, the i-th element of the matrix vector product $A \cdot w$ and approximating the maximum eigenvalue, λ_{max}, using equation (4).

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{Aw_i}{w_i} \quad (4)$$

Then, the CI and CR values are calculated by using the expressions:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (5)$$

$$CR = \frac{CI}{RI} \quad (6)$$

RI is a random index changing according the order n of the matrix as shown in Table 2. For example, a value of 1.41 was set for 8 criteria.

Table 2. *AHP scale for criteria comparison [12].*

Attributes	RI
3	0.58
4	0.90
5	1.21
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

2.5. Data Collection

Quantitative data for each alternative stoves with respect to the eight criteria were collected from literature survey. These stoves were tested under the LEMS emissions hood with the WBT 4.2.3 and were rated for performance using the 2015 IWA Tier system. The data was organised into a decision matrix where rows represent alternatives and columns represent criteria.

2.6. Decision Matrix Normalisation

The decision matrix was normalized to eliminate units and enable comparability by dividing each element by the sum of its respective column values. For benefit attributes (where higher values are preferred), equation (7) was applied, while for cost attributes (where lower values are preferred), equation (8) was used.

$$r_{ij} = \frac{x_{ij}}{max(x_j)} \quad (7)$$

$$r_{ij} = \frac{min(x_j)}{x_{ij}} \quad (8)$$

Here, x_{ij} is the value of alternative i for criterion j, and r_{ij} is the normalized value.

2.7. Final Decision

The last step is the selection of the preferred alternative based on the value of total utility. The final score for each alternative is the weighted sum of the normalized values across all criteria. It is obtained by summing the weighted normalized values for each alternative (S_i). Rank the alternatives based on their aggregated scores (S_i), as in equation (9). The alternative with the highest score (S_i) is the best choice.

The final step involves selecting the preferred alternative based on its total utility. The score for each alternative is the weighted sum of its normalized values across all criteria, calculated by summing the weighted normalized values for each alternative (S_i), as shown in equation (9). The alternatives are then ranked according to their aggregated scores (S_i), with the alternative having the highest score (S_i) being selected as the best choice.

$$S_i = \sum_{j=1}^{n} w_j \times r_{ij} \quad (9)$$

3. Result and Discussion

Two pairwise comparison matrices were developed using the scale in Table 1, reflecting preferences derived from stakeholder interviews, World health organisation policies, and empirical studies on cookstove adoption. These matrices evaluate criteria for selecting the preferred clean cookstove design under two scenarios: Scenario 1: prioritising thermal efficiency; Scenario 2: prioritising indoor emissions. These scenarios aimed to represent dominant policy-oriented objectives (e.g. energy efficiency to reduce deforestation) and health-oriented priorities (e.g. minimising indoor emissions) that emerged as common themes across stakeholder groups. For example, rural households and policy makers both emphasised fuel economy in surveys, albeit for different reasons (cost savings vs. environmental sustainability), while urban consumers and health advocates prioritised low emissions.

Scenario 1 prioritises high thermal output with very high importance over indoor emissions (CO and $PM_{2.5}$), reflecting stakeholder priorities and empirical evidence. Surveys of end-users and policy makers in Cameroon highlighted fuel economy and stove performance as critical drivers for mass adoption, consistent with studies in similar resource-constrained settings. Cameroon's national energy policy emphasises energy efficiency to reduce deforestation, justifying the focus on thermal output and fuel economy. Previous research [35] shows that thermal efficiency is strongly correlated with user satisfaction and adoption rates in sub-Saharan Africa.

In Table 3, high power thermal efficiency was rated moderately important over low power specific consumption, as both are critical, but thermal efficiency is slightly more influential for overall performance in many contexts. High power thermal efficiency was also rated strongly more important than emissions criteria (CO and $PM_{2.5}$), as fuel economy directly impacts household costs and adoption scalability. It was also ranked very highly over indoor emissions (CO and $PM_{2.5}$).

Low specific power consumption was rated moderately more important than emissions criteria, as fuel efficiency at low power levels remains important for user satisfaction. It was also rated as very important compared to indoor emissions (CO and $PM_{2.5}$). The emission criteria (high power CO, low power CO, high power $PM_{2.5}$, low power $PM_{2.5}$) were considered to be of equal importance as they collectively address environmental and health impacts. However, they were considered of moderate importance compared to the indoor emissions (CO and $PM_{2.5}$), which were considered of equal importance due to their direct impact on the health of users.

Scenario 2 emphasises indoor emissions (CO and $PM_{2.5}$) over thermal efficiency, based on Health evidence: WHO guidelines on indoor air quality [36] and studies linking $PM_{2.5}$ exposure to respiratory disease justify the increased importance of emissions. WHO air quality guideline for healthy air prioritises the reduction of household air pollution, in line with this weighting. Rural end-users interviewed in this study expressed heightened concerns about indoor air quality, particularly for women and children. This is reflected in the pairwise comparison matrix (Table 4), which captures the preferences of the decision maker, with more important criteria receiving higher numerical values and less important criteria receiving their reciprocal values.

In Table 4, indoor emissions (CO and $PM_{2.5}$) are given very high importance over high power thermal efficiency and strong importance over low power specific consumption. They are also rated as moderately important for the emission criteria (high power CO, low power CO, high power $PM_{2.5}$, low power $PM_{2.5}$). Meanwhile, high power thermal efficiency is given moderate importance over low power specific consumption, as both are critical, but thermal efficiency has a slightly greater impact on overall performance.

The pairwise comparison matrices in Table 3 and Table 4 were used to calculate the weight vector for each criterion, which guides the evaluation of the alternatives [13]. The results obtained using equations (1) and (2) are presented in Table 5.

Table 3. Pairwise comparison matrix (scenario 1).

Attributes	HPT Eff	LPS Cons	HP CO	LP CO	HP $PM_{2.5}$	LP $PM_{2.5}$	IE CO	IE $PM_{2.5}$
HPT Eff	1	3	5	5	5	5	7	7
LPS Cons	1/3	1	3	3	3	3	5	5
HP CO	1/5	1/3	1	1	1	1	3	3
LP CO	1/5	1/3	1	1	1	1	3	3
HP PM	1/5	1/3	1	1	1	1	3	3
LP PM	1/5	1/3	1	1	1	1	3	3
IE CO	1/7	1/5	1/3	1/3	1/3	1/3	1	1
IE PM	1/7	1/5	1/3	1/3	1/3	1/3	1	1

Table 4. Pairwise comparison matrix (scenario 2).

Attributes	HPT Eff	LPS Cons	HP CO	LP CO	HP $PM_{2.5}$	LP $PM_{2.5}$	IE CO	IE $PM_{2.5}$
HPT Eff	1	3	5	5	5	5	1/5	1/5
LPS Cons	1/3	1	3	3	3	3	1/5	1/5
HP CO	1/5	1/3	1	1	1	1	1/3	1/3
LP CO								
HP PM	1/5	1/3	1	1	1	1	1/3	1/3
LP PM	1/5	1/3	1	1	1	1	1/3	1/3
IE CO	1/5	1/3	1	1	1	1	1/3	1/3
IE PM	5	5	3	3	3	3	1	1

Table 5. Computed weights.

	HPT Eff	LPS Cons	HP CO	LP CO	HP $PM_{2.5}$	LP $PM_{2.5}$	IE CO	IE $PM_{2.5}$
Weights 1	0.382	0.207	0.086	0.086	0.086	0.086	0.034	0.034
Weights 1	0.170	0.100	0.054	0.054	0.054	0.054	0.257	0.257

In Scenario 1, high power thermal efficiency is the most important criterion with a weight of 0.382, followed by low specific power consumption (weight = 0.207). This ranking is based on the strong importance of high power thermal efficiency compared to indoor emissions (CO and $PM_{2.5}$). In contrast, in Scenario 2, Indoor emissions (CO and $PM_{2.5}$) is the most important criterion (weight = 0.266) and high power thermal efficiency is the second most important (weight = 0.155), reflecting the greater emphasis on indoor emissions over thermal efficiency.

The maximum eigenvalues (λ_{max}) for Table 3 and Table 4 were calculated using equations (3) and (4) and yielded values of 8.157 and 9.003, respectively. Table 4 has a Consistency Ratio (CR) of 0.02 (2%), which is well below the threshold of 10% [37]. This indicates that the pairwise comparison matrix in the first scenario is highly consistent, and the weights derived from it are reliable. Table 5 has a CR of 10%, which is considered acceptable according to [12]. To assess robustness, a sensitivity analysis was performed [34, 38] by varying the criterion weights by ±20%. The results showed stable consistency ratio in both scenarios. Therefore, the calculated weights are consistent and can be used in the evaluation procedure to determine the most appropriate clean-burning cookstove.

Data from a survey of clean-burning stoves tested in the laboratory emissions monitoring system using the WBT 4.2.3 and rated for performance using the 2015 IWA Tier System for each of the six alternative stoves [25], as shown in Table 6, form the decision matrix. Since the values in the decision matrix are on different scales, normalisation is necessary. By applying equations (7) and (8) to the data in Table 6, we obtain the normalised decision matrix shown in Table 7.

Table 6. *Cookstove selection decision matrix.*

	HPT Eff	LPS Cons	HP CO	LP CO	HP $PM_{2.5}$	LP $PM_{2.5}$	IE CO	IE $PM_{2.5}$
NDSP Rocket Stove	49.7	0.02	2.22	0.05	152.2	1.73	0.25	11.8
KHND TLUD Stove	45.2	0.023	0.01	0.01	8	0.1	0.001	0.73
SFBA Forced Draft Stove	47.1	0.01	1.76	0.01	47.2	0.47	0.16	4.5
TL Forced Draft Stove	42.7	0.01	0.35	0.04	37.4	0.06	0.22	3.9
Charcoal Stove	47	0.002	6.35	0.01	28.2	0.01	0.41	1.8
SSMJ-Flame Stove	40.6	0.032	2.82	0.09	26.6	1.133	0.39	5

Table 7. *Normalised decision matrix.*

	HPT Eff	LPS Cons	HP CO	LP CO	HP $PM_{2.5}$	LP $PM_{2.5}$	IE CO	IE $PM_{2.5}$
NDSP Rocket Stove	1.00	0.10	0.00	0.20	0.05	0.01	0.00	0.06
KHND TLUD Stove	0.91	0.09	1.00	1.00	1.00	0.10	1.00	1.00
SFBA Forced Draft Stove	0.95	0.20	0.01	1.00	0.17	0.02	0.01	0.16
TL Forced Draft Stove	0.86	0.20	0.03	0.25	0.21	0.17	0.00	0.19
Charcoal Stove	0.95	1.00	0.00	1.00	0.28	1.00	0.00	0.41
SSMJ-Flame Stove	0.82	0.06	0.00	0.11	0.30	0.01	0.00	0.15

Table 8. *Cookstoves ranking.*

	Scenario 1		Scenario 2	
	Overall Priority	**Rank**	**Overall Priority**	**Rank**
NDSP Rocket Stove	0.41	4	0.21	5
KHND TLUD Stove	0.55	2	0.84	1
SFBA Forced Draft Stove	0.43	3	0.29	3
TL Forced Draft Stove	0.41	5	0.25	4
Charcoal Stove	0.69	1	0.49	2
SSMJ-Flame Stove	0.36	6	0.21	6

The alternatives were ranked based on the sum of their weighted normalised scores and are presented in Table 8. If high thermal performance is prioritised over indoor emissions (CO and $PM_{2.5}$), the charcoal stove ranks highest. Conversely, when indoor emissions (CO and $PM_{2.5}$) are given higher priority, the Kirk Harris Natural Draft TLUD stove ranks first. These rankings are consistent with the 2015 IWA Tier System where, of the six stoves considered, only the charcoal stove and the Kirk Harris Natural Draft TLUD stove achieved performance metrics that fell within Tier 4. Table 8 explicitly highlights the superior performance of the charcoal stove in terms of thermal efficiency (weight: 0.382) and the Kirk Harris TLUD stove in terms of low indoor emissions (weight: 0.266).

Surprisingly, the charcoal stove that achieved all Tier 4 scores for total emissions, indoor emissions, and efficiency – the highest tier level defined by the ISO IWA 11: 2012 guidelines [25] came first in Scenario 1 and second in Scenario 2. When charcoal has the wood burned out of it, it can combust very cleanly, emitting almost no appreciable amounts of smoke. Even the CO can meet the Tier 4 standards when temperatures are hot enough. Charcoal can be a clean burning prepared fuel such as propane or alcohol. However, traditional charcoal is not a recommended option due to its inefficiencies and environmental drawbacks [25]: (1) 62.5% of energy is lost during the conversion of wood to charcoal, (2) the production process generates significant smoke, and (3) lighting charcoal releases harmful PM2.5 emissions. In contrast, the densification of biomass into briquettes [39-41] offers a cleaner, more sustainable alternative. These high-density, energy-efficient briquettes are produced using methods that significantly reduce energy losses, smoke emissions and overall environmental impact.

When criterion weights were varied by ±20% to assess the stability of the rankings, the analysis confirmed that the consistency ratios remained stable and the overall hierarchy of alternatives (charcoal stove and Kirk Harris TLUD) did not shift under these perturbations. This confirms the reliability of the methodology and reinforces the prioritisation logic. Prioritising the charcoal stove (for high combustion efficiency) is consistent with Cameroon's focus on reducing deforestation through improved fuel efficiency, as outlined in its National Development Strategy. The Kirk Harris TLUD (Low Emission Preference) stove supports Cameroon's public health objectives under the National Health Development Plan (NHDP) 2021-2025.

4. Conclusions and Recommendations

This study applied the AHP to evaluate and select the most appropriate clean-burning cookstove design for mass production in Cameroon, focusing on heat transfer and combustion efficiency. Six cookstove designs were evaluated against eight key performance criteria - high power thermal efficiency, low power specific consumption, high and low power CO, high and low power $PM_{2.5}$, indoor emissions of CO, indoor emissions of $PM_{2.5}$ - using the ISO/IWA tiers of performance framework.

The charcoal stove emerged as optimal for fuel efficiency (24% score), while the Kirk Harris Natural Draft TLUD stove excelled in minimising emissions (37% score), highlighting that design suitability depends on context-specific priorities. The AHP's robustness was validated by a consistency ratio of less than 10% and a sensitivity analysis, reinforcing its utility in structured decision-making for clean energy technologies. These results highlight that the preferred cookstove design depends on specific market requirements and the relative importance attached to each criterion. This study highlights the value of AHP as a structured and reliable decision-making tool for clean energy technology development, providing actionable insights for policy makers and manufacturers seeking to meet diverse user needs and environmental objectives.

However, AHP-derived priorities should serve as preliminary guidance, necessitating iterative refinement through pilot programmes and stakeholder engagement to address real-world complexities before scaling up production. To deepen environmental impact assessments, we recommend integrating Life Cycle Assessment (LCA) into future AHP frameworks, assessing criteria such as life cycle carbon footprint, material circularity, and disposal costs. Such hybrid analyses could align performance metrics with sustainability goals.

To accelerate adoption, policy measures are critical: tax incentives or grants for manufacturers could lower production barriers, while subsidies for low-income households—particularly in environmentally vulnerable regions—would enhance affordability. Pairing this with subsidized distribution of efficient charcoal stoves through existing initiatives could leverage established networks, ensuring rapid deployment where fuel efficiency is paramount.

These recommendations collectively bridge technical evaluation, environmental stewardship, and equitable access, offering policymakers and manufacturers a multifaceted strategy to meet diverse user needs and climate objectives. By embedding iterative feedback and targeted incentives, Cameroon and similar contexts can foster scalable, sustainable transitions to clean cooking solutions.

Abbreviations

NDSP Rocket Stove	Natural Draft Sunken Pot Rocket Stove
KHND TLUD Stove	Kirk Harris Natural Draft TLUD Stove
SFBA Forced Draft Stove	Side Feed Bottom Air Forced Draft Stove
TL Forced Draft Stove	Top Lit Forced Draft Stove
SSMJ-Flame Stove	SSM Jet-Flame Stove
HPT Eff	High Power Thermal Efficiency
LPS Cons	Low Power Specific Consumption
HP CO	High Power CO
LP CO	Low Power CO
HP $PM_{2.5}$	High Power $PM_{2.5}$
LP $PM_{2.5}$	Low Power $PM_{2.5}$
IE CO	Indoor Emissions of CO

IE $PM_{2.5}$	Indoor Emissions of $PM_{2.5}$

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Author Contributions

Tsapi Tchoupou Kevin: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing

Magnou Ekokem Belinda: Data curation, Formal Analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing

Annouar Djidda Mahamat: Resources, Validation, Writing – review & editing

Bienvenu Kenmeugne: Resources, Validation, Writing – review & editing

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Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Hayyat, U., Khan, M. U., Farooq, M., Sultan, M., Amjed, M. A., Liu, G., Alkhedher M. Recent developments and challenges in biomass cookstove, Energy Reports. 2024, 12, 2193-2208. https://doi.org/10.1016/j.egyr.2024.08.016

[2] Eba'a, A. R., Ngouhouo, P. J., Mvondo, A. J. P., Ngoungoure, M. A., Sufo K. R. Economic and social importance of fuel wood in Cameroon, International Forestry Review. 2016, 18(1), 52-65. https://doi.org/10.1505/146554816819683735

[3] Kidmo, D. K., Deli, K., Bogno, B. Status of renewable energy in Cameroon, Renewable energy and environmental sustainability. 2021, 6(2), 1-11. https://doi.org/10.1051/rees/2021001

[4] Pope, D., Bruce, N., Higgerson, J., Hyseni, L., Stanistreet, D., MBatchou, B., Puzzolo, E. Household determinants of liquified petroleum gas (LPG) as a cooking fuel in SW Cameroon, EcoHealth. 2018, 15, 729-743. https://doi.org/10.1007/s10393-018-1367-9

[5] Rubinstein, F., Ngahane, B. H. M., Nilsson, M., Esong, M. B., Betang, E., Goura, A. P., Puzzolo, E. Adoption of electricity for clean cooking in Cameroon: A mixed-methods field evaluation of current cooking practices and scale-up potential, Energy for Sustainable Development. 2022, 71, 118-131. https://doi.org/10.1016/j.esd.2022.09.010

[6] Dickinson, K. L., Piedrahita, R., Coffey, E. R., Kanyomse, E., Alirigia, R., Molnar, T., Wiedinmyer, C. Adoption of improved biomass stoves and stove/fuel stacking in the REACCTING intervention study in Northern Ghana, Energy Policy. 2019, 130, 361-374. https://doi.org/10.1016/j.enpol.2018.12.007

[7] Tsapi, K. T., Bisong, S. M., Soh, B. D. Design of Biomass Cookstoves Reliability Demonstration Test Plans; International Journal of Innovation and Applied Studies. 2024, 42(1), 62-74. https://ijias.issr-journals.org/abs.php?article=IJIAS-23-353-01

[8] Still, D., Bentson, S., Li, H. Results of Laboratory Testing of 15 Cookstove Designs in Accordance with the ISO/IWA Tiers of Performance, EcoHealth. 2014, 12(1), 12–24. https://doi.org/ 10.1007/s10393-014-0955-6

[9] MacCarty, N., Still, D., Ogle, D. Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance, *Energy for sustainable development*. 2010), 14(3), 161-171. https://doi.org/10.1016/j.esd.2010.06.002

[10] Shvetsova, O. A., Park, S. C., Lee, J. H. Application of quality function deployment for product design concept selection, Applied Sciences. 2021, 11(6), 2681. https://doi.org/10.3390/app11062681

[11] Zheng, X., Ritter, S. C., Miller, S. R. How concept selection tools impact the development of creative ideas in engineering design education, Journal of Mechanical Design. 2018, 140(5), 052002. https://doi.org/10.1115/1.4039338

[12] Chaibate, H., Hadek, A., Ajana, S., Bakkali, S. Analytical hierarchy process applied to pedagogical method selection problems, Education Research International. 2021, 2021(1), 6664758. https://doi.org/10.1155/2021/6664758

[13] Salehzadeh, R., Ziaeian, M. Decision making in human resource management: a systematic review of the applications of analytic hierarchy process. Frontiers in Psychology. 2024, 15, 1400772. https://doi.org/10.3389/fpsyg.2024.1400772

[14] Subramanian, N., Ramanathan, R. A review of applications of Analytic Hierarchy Process in operations management. International Journal of Production Economics. 2012, 138(2), 215-241. https://doi.org/10.1016/j.ijpe.2012.03.036

[15] Madzík, P., Falát, L. State-of-the-art on analytic hierarchy process in the last 40 years: Literature review based on Latent Dirichlet Allocation topic modelling. PLoS One. 2022, 17(5), e0268777. https://doi.org/10.1371/journal.pone.0268777

[16] Rawat, S. S., Pant, S., Kumar, A., Ram, M., Sharma, H. K., Kumar, A. A state-of-the-art survey on analytical hierarchy process applications in sustainable development. Int. J. Math. Eng. Manag. Serv. 2022, 7, 883-917. https://doi.org/10.33889/IJMEMS.2022.7.6.056

[17] Singh, R. P., Nachtnebel, H. P. Analytical hierarchy process (AHP) application for reinforcement of hydropower strategy in Nepal. Renewable and Sustainable Energy Reviews. 2016, 55, 43-58. https://doi.org/10.1016/j.rser.2015.10.138

[18] Waris, M., Panigrahi, S., Mengal, A., Soomro, M. I., Mirjat, N. H., Ullah, M., Khan, A. An application of analytic hierarchy process (AHP) for sustainable procurement of construction equipment: multicriteria‐based decision framework for Malaysia. Mathematical Problems in Engineering. 2019(1), 6391431. https://doi.org/10.1155/2019/6391431

[19] Almeida, D., Pradhan, N., Muniz Jr, J. Assessment of ISO 9001: 2015 implementation factors based on AHP: Case study in Brazilian automotive sector. International Journal of Quality & Reliability Management. 2018, 35(7), 1343-1359. https://doi.org/10.1108/IJQRM-12-2016-0228

[20] Czekster, R. M., Webber, T., Jandrey, A. H., & Marcon, C. A. M. Selection of enterprise resource planning software using analytic hierarchy process. Enterprise Information Systems. 2019, 13(6), 895-915. https://doi.org/10.1080/17517575.2019.1606285

[21] Soam, S. K., N, S. R., BS, Y., Balasani, R., S, R., Marwaha, S., Agrawal, R. C. (2023). AHP analyser: A decision-making tool for prioritizing climate change mitigation options and forest management. *Frontiers in Environmental Science*, *10*, 1099996. https://doi.org/10.3389/fenvs.2022.1099996

[22] Szabo, Z. K., Szádoczki, Z., Bozóki, S., Stănciulescu, G. C., Szabo, D. An analytic hierarchy process approach for prioritisation of strategic objectives of sustainable development. Sustainability. 2021, 13(4), 2254. https://doi.org/10.3390/su13042254

[23] Stofkova, J., Krejnus, M., Stofkova, K. R., Malega, P., Binasova, V. Use of the analytic hierarchy process and selected methods in the managerial decision-making process in the context of sustainable development, Sustainability. 2022, 14(18), 11546. https://doi.org/10.3390/su141811546

[24] Krejčí, J., Stoklasa, J. Aggregation in the analytic hierarchy process: Why weighted geometric mean should be used instead of weighted arithmetic mean. Expert Systems with Applications. 2018, 114, 97-106. https://doi.org/10.1016/j.eswa.2018.06.060

[25] Still D., Bentson S., Lawrence R. H., CFA Jr., Adams E., Andreatta D., Evitt D., Attenweiler C., Harris K. Clean Burning Biomass Cookstoves 2nd Edition, Aprovecho Research Center, 2021. https://aprovecho.org/news/a-new-edition-of-clean-burning-biomass-cookstoves/

[26] D. K. Kidmo, K. Deli, and B. Bogno. Status of renewable energy in Cameroon. Renewable energy and environmental sustainability. 2021, 6(2), 2. https://doi.org/10.1051/rees/2021001

[27] Ministry of Economy, Planning and Regional Development, National Development Strategy 202-2030, 2020.

[28] WHO. Air Pollution and Child Health: prescribing clean air. World Health Organization, 2018. https://www.who.int/ceh/publications/air-pollution-child-health/en/

[29] Champion, W. M., Hays, M. D., Williams, C., Virtaranta, L., Barnes, M., Preston, W., Jetter, J. J. Cookstove emissions and performance evaluation using a new ISO protocol and comparison of results with previous test protocols. Environmental science & technology. 2021, *55*(22), 15333-15342. http://dx.doi.org/10.1021/acs.est.1c03390

[30] Sutar, K. B.. Energy efficiency, emissions and adoption of biomass cookstoves. In Alternative Energies and Efficiency Evaluation. IntechOpen. 2022. http://dx.doi.org/10.5772/intechopen.101886

[31] Mekonnen, B. A. Thermal efficiency improvement and emission reduction potential by adopting improved biomass cookstoves for sauce-cooking process in rural Ethiopia. *Case Studies in Thermal Engineering*. 2022, *38*, 102315. http://dx.doi.org/10.1016/j.csite.2022.102315

[32] Siekelova, A., Podhorska, I. Imppola, J. J. Analytic hierarchy process in multiple–criteria decision–making: a model example, In SHS web of conferences. 2021, 90, 01019. https://doi.org/10.1051/shsconf/20219001019

[33] Mhlanga, S. T., Lall, M. Influence of normalization techniques on multi-criteria decision-making methods. In Journal of Physics: Conference Series. 2022, 2224(1), 012076. https://doi.org/10.1088/1742-6596/2224/1/012076

[34] Mazurek, J., Perzina, R., Ramík, J., Bartl, D. A numerical comparison of the sensitivity of the geometric mean method, eigenvalue method, and best–worst method. Mathematics. 2021, 9(5), 554. https://doi.org/10.3390/math9050554

[35] Belachew, A., Melka, Y. Preferences and adoption of improved cookstove from results-based financing program in Southeastern Ethiopia. Frontiers in Energy Research. 2023, 11, 1147545. https://doi.org/10.3389/fenrg.2023.1147545

[36] WHO. WHO Indoor Air Quality Guidelines: Household Fuel Combustion. World Health Organization, 2015.

[37] Pant, S., Kumar, A., Ram, M., Klochkov, Y., Sharma, H. K. Consistency indices in analytic hierarchy process: a review, Mathematics. 2022, 10(8), 1206. https://doi.org/10.3390/math10081206

[38] Bugingo, E., Ndimubenshi, E. L., Kamanga, C. T., Rugema, F. X., Habimana, O., Batamuliza, J. Application of AHP in Decision-Making: Case Studies and Practical Implementation. In The Art of Decision Making-Applying AHP in Practice. IntechOpen. 2024. https://doi.org/10.5772/intechopen.1006966

[39] Kpalo, S. Y., Zainuddin, M. F., Manaf, L. A., & Roslan, A. M. A review of technical and economic aspects of biomass briquetting. *Sustainability*. 2020, *12*(11), 4609. https://doi.org/10.3390/su12114609

[40] Yustas, Y. M., Tarimo, W. M., Mbacho, S. A., Kiobia, D. O., Makange, N. R., Kashaija, A. T., & Silungwe, F. R.. Toward adaptation of briquettes making technology for green energy and youth employment in Tanzania: A review. Journal of Power and Energy Engineering. 2022, 10(4), 74-93. https://doi.org/10.4236/jpee.2022.104006

[41] Eling, J., Okot, D. K., Menya, E., & Atim, M. R.. Densification of raw and torrefied biomass: A review. Biomass and Bioenergy. 2024, 184, 107210. https://doi.org/10.1016/j.biombioe.2024.107210

Research Field

Tsapi Tchoupou Kevin: Industrial Engineering, Reliability & Maintenance, Quality Management, Lean Six Sigma, and Digital Manufacturing

Magnou Ekokem Belinda: Operational Research, Bayesian Statistics, Biostatistics, Data science, Machine learning

Annouar Djidda Mahamat: Mechanical Behaviour of Materials, Material Characterisation, Material Properties, Material Testing, Fracture Mechanics, and High Temperature Materials

Bienvenu Kenmeugne: Design Engineering, Engineering Optimization, Solid & Applied Mechanics, Computational Mechanics, and Multiscale Materials Analysis