International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 / https://doi.org/10.14445/22315381/IJETT-V70I12P242

Volume 70 Issue 12, 439-449, December 2022

Review Article

Technical Considerations for the Design and Selection of Improved Cookstoves: A Review

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Received: 24 August 2022 Revised: 13 December 2022 Accepted: 20 December 2022 Published: 24 December 2022

Abstract - *It is critical to examine strategies to use energy more efficiently because it is becoming increasingly expensive and scarce. This paper critically evaluated the various approaches and fundamental factors that must be considered when designing and testing improved cookstoves for sub-Saharan Africa. The choice of materials, whether the stove had a stack or not, and the height of the stove, which is thought to have a significant impact on emissions control and combustion, were all carefully considered. Three to five improved cookstoves were thought to be necessary for water boiling testing and field trials. It was determined to be appropriate to conduct a systematic assessment of the hood method, which is frequently used to evaluate the emissions of cookstoves and their efficiency. A discernible difference among the improved cookstoves was discovered to minimise the number of cookstoves for laboratory experiments in the case of comparative studies on biomass cookstoves. This review gives further information about the selection of biomass cookstoves and their design; and emission control strategies that can be used in future research on carbon capture from biomass stoves*

Keywords - *Biomass combustion, Biomass cookstove, Emission control, Emission, Particulate matter.*

1. Introduction

Improved cookstoves can benefit numerous villages and townships throughout Africa and beyond. Currently, more than three billion people still use open fires and basic stoves that burn solid fuels for cooking. [1] [2] [3] and more than a billion people are denied access to power. [4] [5] [6] [7] [8] [9]. According to estimates, indoor air pollution from open fireplaces is to blame for 4.3 million preventable deaths per year from cooking, and that solid fuel combustion accounts for 25% of black carbon emissions. In 2021, the number of people without access to electricity increased by 2% globally, with Sub-Saharan Africa accounting for the majority of the rise[4]. The literature on numerous improved cookstoves created and manufactured by many unlicensed craftspeople and fewer licensed enterprises throughout Sub-Saharan nations is either hard to find or scarce. However, many fields of emissions control on improved wood cookstoves (IWC) and other traditional stoves have been included to entirely deliberate pertinent issues about material components of the improved cookstoves, choice of wood used as fuels or that is transformed into charcoal (carbonization of wood), emissions control, and carbon capture methodologies that are supposed to support the advanced biomass cookstoves [11]. Many developing countries have recently made significant efforts and attempt to design improved cookstoves with carbon emissions and other particulate matter levels that are lower than those of conventional ones.

Furthermore, the bulk of improved biomass cookstoves being produced is being done by persons with no experience in engineering or science. As a result, efficiency and emission studies are rarely conducted. And for those designed by scientists or engineers, it is typically evaluated against a traditional stove (a fire made of three stones), as was the case with [12] [13] [14]. Hence the result is either biased or skewed towards the new model. This study provides a concise and comprehensive summary of the various stove designs, stove selection criteria, post-carbon capture, and emissions control procedures for improved biomass charcoal cookstoves. Materials, stoves with or without stacks, and stove heights-all of which are thought to have a significant impact on combustion and emission control-were all carefully evaluated. Three to five enhanced cookstoves are thought to be necessary for water boiling tests and field trials. It was determined to be appropriate to conduct a systematic assessment of the hood method, which is frequently used to evaluate the emissions of cookstoves and their efficiency. A discernible difference among the upgraded cookstoves was discovered to minimise the quantity of cookstoves used in laboratory comparison studies while comparing biomass-improved cookstoves.

2. Materials and Methods

For the review and compilation of this work, a thorough desk study on multiple documents was carried out about better-improved cookstove designs, fuel selection criteria, and testing procedures both inside and outside of Sub-Saharan Africa. A report by [15] advised that doing a full desk study evaluation is worthwhile to get a theoretical understanding of the methods and processes utilised to choose stoves for distribution. This review begins with a broad overview of how biomass is utilised in Africa and beyond. It then follows on to various research studies on better cookstove designs and the criteria for picking fuel, which has changed over time due to their availability. Discussions and future possibilities conclude this review. Fig 1. Provide a summary of the research approach employed in this article.

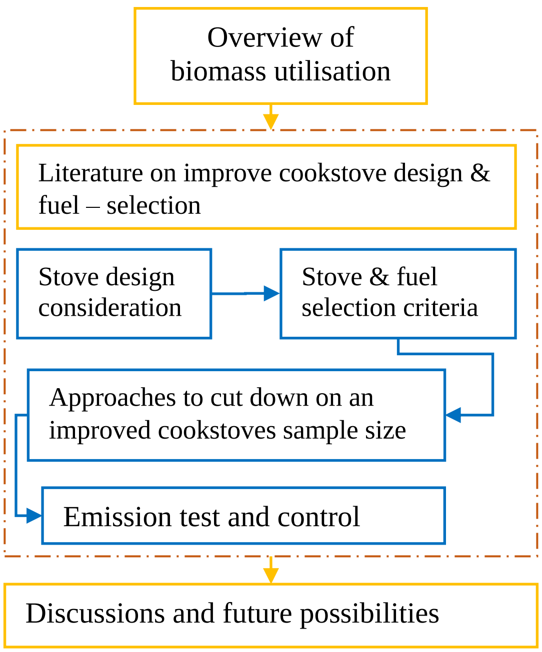


Fig. 1 Description of arrangement of the review paper

2.1. Overview of Biomass Utilisation

The vast majority of people living in underdeveloped countries worldwide do not have access to cutting-edge energy services for social and economic growth. [16]. Because of this, the majority of people only use traditional wood fire stoves for their daily cooking and crafting needs, which have been deemed unhygienic, harmful, and ineffective [17], [18]. A traditional three-sided stone fire's solid fuel use has contributed to around 1.6 million premature deaths, or 4% of the world's illness burden [19], [38]. The design of biomass cookstoves has been a hot topic for a while and has made significant progress toward cleaner and more effective cooking than the traditional three firestone stoves [21].

2.2 Stove Design Consideration

Open fires used in prehistoric times and three-stone fires were replaced by improved cookstove designs, which allowed for the development of more sophisticated improved cookstoves. [22] and yet, despite all of their efforts, many designers focused more on emissions reduction than energy conservation, as presented in table 1. In order to adequately explore both emissions and fuel savings, it would have been crucial to focus on energy conservation or savings when building stoves. According to [12], when the swirl vane burner is incorporated into the design of the combustion chambers, the configuration may eliminate 54% carbon monoxide generation while using coconut shell as fuel while also providing clean combustion and increasing efficiency by 4.7%. Heat and mass transmission are substantially impacted by swirl vane burner, and this was also endorsed by [24]. Furthermore, a study by [25] asserted that when designing biomass stoves for good heat efficiency and low emissions of harmful gases and particulate matter, a thorough comprehension of a number of fundamental scientific theories, such as heat transfer, fluid flow, pyrolysis, and combustion, as well as the intricate relationships between them, is necessary. Each of the variables mentioned above and how they relate to one another must be thoroughly modelled to accurately estimate a biomass stove's performance. The geometric proportions of the stove must always be specified in order to achieve a specific range of operating conditions for the stove with the highest appropriate thermal efficiency and the fewest hazardous emissions.

The vast majority of gasifier stoves available today are forced draft types with electric or battery-powered fans that utilise a few particular feedstocks [26]. On the one hand, the initial price of the stoves is increased by these items, but on the other, the need for energy to charge the battery and the requirement to replace the battery regularly raises the stove's running costs. In remote places, these variables further compound the difficulty of upkeep, as presented by the authors in [22]. Therefore, while designing these biomass cookstoves, the cost is very important to the end users, especially the poor in developing nations. However, this need not at all impact the stove's technical design. However, the stove must be designed to accommodate alternative fuel supplies.

Furthermore, according to [28], a steady-state simulation of energy exchange between the bottom of a pot and hot gas and a cook stove's wall or between a pot's sidewall and a shield was demonstrated. The model predicts that cookstove wall insulation increases the thermal performance of the pot by around 30–40%. The insulation effect, the results of which indicated comparable tendencies to the experiments.

Table 1. Some characteristics of specific gasifier cookstove designs

Stove type	Basic description of how it works	Thermal efficiency	Related emission
Down-draft (co-current), Gasifier Stove (Forced-draft)	A pipe is used to transport air further into the oxidation zone's throat.	The efficiency of gasification was 85 %. Temperature of gas:700℃, Firepower between 2-7kW	creation of a gas that burns cleanly.
Stove with Downdraft Gasifier	Reactor with a gasifier and two burners. Highly flammable gas is generated in 0.5 to 1 minute.	At 9℃, 5 litres of water needed 12 to 15 minutes to reach boiling. η:35%	Black carbon 10-50μ/m^3
Forced draft rice husk gasifier stove	For gasification air supply, a 13W downdraft fan is used. 2kg/h is the maximum fuel consumption rate.	H:18-25%	stable, smokeless combustion
Gasifier stoves with an updraft and a downdraft	Natural draft, community cookstoves erected in a tribal residential school.	When compared to a typical fuel-wood stove, it saves 50% of the fuel and 35% of the cooking time.	stable, smokeless combustion
Business Gasifier Stove (Cross-draft)	1.1-meter-high mild steel chimney with a natural draft and precast cylindrical brick lining parts for small eateries. Have space for three pots.	Maximum efficiency obtained: 31.8%. firepower: 8.4kW	

Source: Sutar et al, 2014

Thus, this suggests that the combustion chamber has a bigger influence on combustion. Considering this when designing the improved cookstove chamber is crucial because the fuel size significantly impacts the stove's performance.

Additionally, a report shows that gasifier cookstoves are superior to biomass-burning cookstoves and produce significantly fewer emissions. All-natural draft cookstoves with gasifiers are available in some models. It has been revealed that forced draft and gasifier operations offer reasonable performance compared to the customary open flames made of three-sided stone.

2.3 Stove and Fuel Selection Criteria

Several criteria are used to select improved cookstoves, as in the case of [29]. They claimed that improved cookstoves were built centrally, required no assembly, were portable, and were designed to burn wood. Their performance for the water boiling test had to be greater than or equal to a 50% reduction in particulate matter ($PM_{2.5}$). These requirements were also supported by [44].

However, the water boiling test performance of the improved stoves cannot be the sole reason for selection. It is essential to note that the selection criteria for the enhanced cookstoves should also include the material's thickness and the metal or material's thermal conductivity.

Furthermore, the size and method of fuel feed-in into the combustion chamber, as well as their heights, are all necessary and paramount criteria for stove selection and could significantly alter the firepower and fuel consumption rates, even though the majority of stoves are made of metal casing. Some have a metal, brick, or ceramic liner. It is also reported by [50] that because it is so difficult to discern between conventional and improved cookstoves, the two types of biomass stoves now used in almost all developing nations, no attempt is made to establish any criteria for choosing them. However, the most important

In addition, Edwards et al. [32], in comparison to outdated cookstoves or traditional stoves, offered the following helpful selection criteria for a model design of better cookstoves to lower indoor air pollution (IAP) concentrations in homes: factor in choosing a cookstove is to choose a fuel that can be used in both conventional and improved cookstoves.

2.3.1. Cross-Sectional

After introducing improved charcoal cookstoves within the same geographic area, it is crucial to quantify the IAP in homes with conventional stoves (ICC). Thus, the performance of improved cookstoves is influenced by environmental conditions. This is the rationale behind the decision to base the improved cookstoves on early discoveries from science.

Table 2. Benefits and drawbacks of various research methods for evaluating the efficiency of improved cookstoves

Statistical design	Benefits	Drawbacks
1. cross-sectional	• Some planning is necessary. • It doesn't call for follow-up in a specific family.	• Calls for a substantial sample size of stoves • Because homes with conventional stoves may differ from those with improved cookstoves, selection bias cannot be avoided.
2. Earlier & later (i.e., Before & After (without control)	• a very little sampling of all potential designs is necessary. • decreased internal variation in the household (decreases variability as a result of the same household being used).	• It must be followed up after several months. • To prevent seasonal impacts, caution must be exercised. Changes in the fuel utilised, moisture content, and ambient temperature, for example, might alter the amount of pollution emitted without being caused by the stove's design.
3. before & after with control.	• It is possible to quantify the stove's impact independently of seasonal changes and other factors that affect indoor air quality.	• A huge sample size is necessary • operating in locations without an improved cookstove is necessary and frequently poses a political hazard.

Sources: Edwards et al., 2007

2.3.2. Earlier and later (Before and After)

Before and after using the stoves in the same household area, indoor air pollution from both conventional and improved cookstoves must be considered.

2.3.3. Before and After with Control Group

For conventional stoves, the interior air pollution must be measured once more inside the same families.

Additionally, [32] offered the following benefits and drawbacks in table 2 of study designs to evaluate the efficacy of enhanced cookstoves in 2007.

2.4. Approaches to Cut Down on an Improved Cookstoves Sample Size

The majority of the three methods suggested by Edwards et al. [32] for reducing the sample size of improved cookstoves are as follows:

- Alter the preferred noticeable difference.
- The variation coefficient should be changed (COV - reduce variability).
- Modify the design.

One of the simplest ways to reduce sample size is to choose a greater visible or detectable difference. Thus it is preferable to choose one so that you are content with a larger visible difference. An obvious difference in interior air pollution of 80 or 90% would not be unthinkable for the typical scenario where the standard stove does not include a chimney, but the superior cookstoves do. There are only 10 participants in each category. for example, at a difference of 90% and a COV of 0.7. Choosing a 60 or 70% reduction might be rationally conservative if one is certain that the enhanced cookstove is operating correctly and that the area is free of other similar sources of pollution; they should make a judgement in this scenario. It is advisable to keep track of all homes that do not consistently use better cookstoves for research and practice purposes, as well as transitional implementation patterns where households with improved cookstoves utilise traditional cookstoves for some cooking tasks. In order to make adjustments when reviewing the results, such as taking into account only a subcategory in which all homes were similarly using stoves, it is crucial to document these situations on the tracking or observation form accurately. However, wishing for such a stark change in appearance may not be accurate or feasible for other sorts of traditional or enhanced cookstove partnerships. For instance, some improved cookstoves rely on increased stove efficiency to reduce emissions rather than having a smokestack or chimney. Although a reduction in interior air pollution (IAP) of up to 50% has been claimed, the extent of indoor air pollution augmentation in such situations is not fully understood. Remember, however, that sample size requirements increase as variances decrease; for instance, 193 per group to detect 20% [32]. For better cookstoves that are substituted for outdated cookstoves that also include a smokestack or a chimney, the difference could be as little as 20–30%. The main consideration for selecting observable variance is somewhat dependent on the purpose of the study. For instance, one can argue that a cookstove specifically made to reduce indoor air pollution should at least reach a 40% reduction to be worthwhile, considering the time and resources needed. In this case, it may be justified to limit the sample size to 4, as we would deem the upgraded cookstove to have failed to achieve its goals, especially if it did not successfully lower indoor air pollution to this level. However, it is important to remember that with this sample size, it would be challenging to detect an improvement if the upgraded cookstove, for example, only managed a 30% reduction. However, if paired with additional benefits like large fuel savings and the quickest time for kitchen performance and water boiling testing requirements, 30%

might be sufficient for specific uses, for example. The important thing is to choose the sample size early on, though. In conclusion, two variables will determine which variance is visible: Resource limitations, i.e., a significant visible or detectable variance might not be attainable due to the multiple sample sizes it might require; Relating modern/improved cookstoves to outdated/traditional ones, i.e., some types of improvements will matter more than others. Unfortunately, because of the aforementioned reasons, the coefficient of variation (COV) in real-world scenarios may frequently be very high, averaging around 0.7. However, if possible, there is a strong incentive to lower the coefficient of variations (COVs). COV would fall from 0.7 to 0.5. For example, the sample size needed to demonstrate a 20% gain would decrease from 193 to 98, while a matched 40% enhancement in performance would decrease from 48 to 25. [32]. The sample number needed to show a 70% improvement would therefore drop from 193 to 5 if COV were further reduced from 0.7 to 0.4. A few of the improvements to indoor air quality happened in a relatively short amount of time. The emissions from the stove can vary based on whether the fire is just getting started or winding down, particularly if the kitchen door is opened and closed irregularly. Additionally, if the weather changes throughout the experiment or trial time, these variabilities can result in a marginal mistake. A prolonged measurement that lasts at least half a day (12 hours) can reduce variability and produce a superior result that aligns with most air pollution ethics and health guidelines. The variability may be further reduced by taking longer measurements, but the increment should be on a 12- or 24-hour cycle. A continuous monitoring system can be set up to run for multiple days, adjusting for differences on weekdays. Additionally, research has demonstrated that as sample periods are increased, the potential advantages of lesser inconsistency diminish [37] [38], but once more, the equipment required to conduct longer sampling investigations is crucial. Furthermore, adhering strictly to the standards for consistency, equipment launch, cleaning or dusting, placement, and other characteristics of employing measuring devices will limit variance and partiality in results when their methodology does not fulfil particular requirements mentioned in the recommendations. As long as protocols are followed, the equipment and processes should significantly reduce this source of variance, given the cost constraints and convenience of use.

2.5. Emissions Test and Control

According to [39], before and following the installation of an experiment with an improved cookstove (the Patsari stove), Metrics for carbon monoxide (CO) and fine particulate particles (PM2.5) were measured in a kitchen in Michoacán, Mexico, over a 40-hour period at intervals of one minute, at a coherent average elevation of 1.25 m above the floor, one meter away from the site of the primary combustion area that is orthogonal to the floor, and at least 1.5 m away from doors and windows. In order to monitor particle matter, a light-scattering nephelometer was designed and produced by the University of California, Berkeley (UCB) for use in rural homes burning biomass [40]. Although the University of California Berkeley could not select a specific cut-off point, the photoelectric sensor has been shown to have a greater agreement with hydrometric particulate matter ($PM_{2.5}$) samples used in remote households for the generalizability of the research trials [40]. It is extremely sensitive to particles having an aerodynamic diameter of less than 2.5 m. (PM<2.5 m) [42]. Using co-located $PM_{2.5}$, the regional office in Mexico calibrated UCB sensors for the mass response to particles. Five samples of hydrometric filters were taken from kitchens. [38] and by conducting controlled trials in a combustion chamber for inter-instrument sensitivity [40]. With a greater agreement between different UCB monitors, the mean percentage shift in mass estimates between identical UCB samples was only 14% [38].

Table 3. The number of participants needed in each category in cross-sectional methods to assess advancements over conventional stoves

The detectable difference in means	Measurement Coefficient of Variation												
	0.1	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**	**1.1**	**1.2**	**1.3**
10%	16	633	142	251	393	565	769	1005	1272	1570	1900	2261	2653
20%	4	16	36	63	98	142	193	251	381	393	475	565	663
30%	2	7	16	28	44	63	86	112	142	175	211	251	295
40%	1	4	9	16	25	36	48	63	80	98	119	142	166
50%	1	3	6	10	16	23	31	40	51	63	76	91	106
60%	1	2	4	7	11	16	22	28	36	44	53	63	74
70%	1	2	3	5	8	12	16	21	26	32	39	46	54
80%	0	1	2	4	6	10	12	16	20	25	30	36	42
90%	0	1	2	3	5	7	10	13	16	20	24	28	33
100%	0	1	2	3	4	6	8	10	13	16	19	23	27

Source: Edwards et al., 200

Table 4. Comparing the key inputs needed to determine carbon offsets

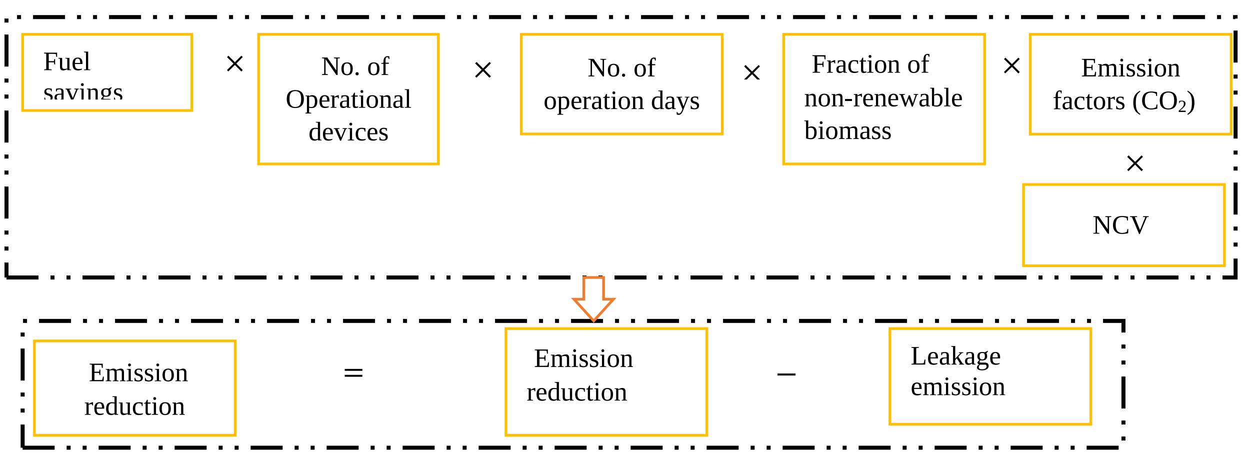
	Gold standards	Clean Development Mechanism	Johnson et al., (2009)
Emission factors	- IPCC's defaulting fuel-based models or those thoughts to be more appropriate (e.g., Field-based or laboratory-based) - There is no assumption of unlikelihood.	- The IPCC's default for fossil fuels is used to determine the fNRB fuel savings (such as kerosene).	- measured for both standard and improved cookstoves in a selection of households
Fraction of nonrenewable biomass	- There was no specific valuation method offered. - Regional or qualitative approaches are accepted - No ambiguity is implied.	- No specific valuation technique was offered.	- A lack of assurance brought on by small samples and inconsistent measurements. - Analyses at the local level using the C-WISDOM fuel-wood supply/demand model
Fuel consumption	- kitchen performance tests were conducted on a subsample of homes to collect the data. - Sample size and measurement consistency-related uncertainty	- No unlikely event is foreseen - No valuation approach was given.	- Improbability disseminated through model - measured in a sample of the consumption of households during KPTs
Carbon offsets uncertainty	- solely on the fuel compensation assessment's lower 90% confidence bound	No advice is given.	- Sample size-based uncertainty, measurement inconsistency, and 95 per cent confidence intervals based on the distribution of improbability of initial input

Source: Johnson et al., 2010

Using electrochemical CO2 equipment, the quantity of carbon monoxide was measured (HOBO® Onset Corporation Inc., Bourne, MA, USA). Four monitored combustion chamber co-locations were used to assess the responsiveness of carbon monoxide detectors, and gas benchmarks were used to calibrate the detectors' inter-instrument responsiveness (0.5 ppm, 10 ppm, 25 ppm, and 60 ppm) before being employed in the investigation. Both types of equipment had data loggers that allowed them to keep track of the data minute-by-minute throughout the whole measurement time. Additionally, it was noted that it could be challenging to use filter-based strategies to collect particulate matter, given the frequent observation of highly high PM2.5 concentrations during kitchen activities, particularly while cooking in settings using wood fuels [46]. However, using an updated formula to provide $PM_{2.5}$ readings comparable to filter-based collecting systems, each 10-s PM measurement was adjusted for relative humidity and changed to a PM 2.5 gravimetric equal [32]. Meanwhile, the variation between baseline and actual carbon dioxide corresponding emissions (usually traditional stoves or earlier models of improved stoves) and the research/project is known as carbon compensation for stove projects (typically the new type of improved stoves). Three crucial inputs must be assessed to convert these emissions into carbon dioxide equivalents: emission variables, fuel use, and the fraction of nonrenewable biomass fuels (fNRB). The Gold Standard approach considers carbon compensations, calculated as the difference between the baseline and study conditions' energy consumption and emission characteristics, with biomass energy savings allocated to the nonrenewable part [48]. There is no requirement for stove-specific specifications. The clean development mechanism technique assesses biomass fuel savings. It adjusts the proportion of nonrenewable biomass (fNRB) savings using the conventional fuel emission factor developed by the Intergovernmental Panel on Climate Change (IPCC). The evaluation procedures for the three main inputs for carbon dioxide equivalent savings are summarised in table 4 below. The Gold Standard and clean development mechanism techniques rely heavily on default inputs without considering how seldom they occur.

Furthermore, without properly considering the effect of their improbability on offset evaluations, substitution or default inputs are frequently used in the Gold Standard, and CDM approaches. A different strategy proposed in [49] has been added for comparison. It is based on a numerical sub-sampling example of fuel consumption and emissions in households with outdated or residences with conventional stoves and residences with improved stoves, as well as estimations of fNRB from rural communities. It spreads the necessary improbability in these assessments to provide the full improbability connected with a valuation of carbon compensations to the greatest possible extent. Because significant sponsors have faith in the accuracy of carbon compensations and because it forms the basis of a successful transaction, a thorough investigation of the unlikelihood in the compensation evaluations is necessary. On the other hand, neither the clean development mechanism technique nor the Gold Standard uses unlikelihood in their emission factors.

The Patsari improved cookstove project in Mexico from [50] served as an example. For controlling and testing emissions from biomass-fired stoves, an explicit extraction or removal hood approach was proposed [51]. It is advised that the extraction hood be positioned above the stove to allow the suction blower's extraction and control of the flue gas. Extraction should always be chosen to be strong enough to prevent emissions from leaking from the bottom of the hood and should be such that it is not too strong to have any negative effects on the burning or combustion flame because a high removal rate may negatively impact the burning characteristics of the stove. The sample gas enters a prefilter after passing through the probe and a heated sample line. Signal Model 3000M hydrocarbon analyser and Signal Model 4000VM NOx analyser, two independent heated analysers, were employed to analyse the emissions from the combustion chamber through the extraction hood. On the other hand, a digital combustion analyser (Testo 310 home combustion analyser) analyses stack temperature, flue pressure, and level of gases and would have been a viable option to conduct analyses on the emission gases. In addition to emissions, recording should be done frequently until the readings from the gas analyser return to levels close to ambient. In conclusion, it is typically necessary to select the lowest representative sample possible for a given research project, within a safety factor of 30 to 50%, to account for potential errors, mobility, cookstoves dropping out or not being included, lost information, etc. This is due to financial and logistical constraints, such as the need for transportation. In addition to statistical norms and recommendations, the sample size chosen reflects at least one significant choice made by the researcher, particularly that so little variance the researcher hopes to be able to discover or notice. The higher the sample size needed, the less variance one hopes to discover or identify. For instance, in most practical research, the sample size requirements may be too expensive to detect a 10% deviation. A 20% detection rate may be too ambitious in many cases, given the available resources. There are a variety of methods for lowering sample size requirements, including equally direct acts like lengthening the observation period and being extremely cautious with how the instruments and equipment are distributed. However, this research is necessary to draw conclusions about the effectiveness of the selected improved cookstoves for the majority of statistically sound individuals. To reduce and maintain low exposure levels, efficient cookstove design and production are also crucial. Obviously, even with proper maintenance, cookstoves in operation are likely to deteriorate over time [52]. Therefore, it is necessary to plan and build cookstoves such that high temperatures and pressure levels won't accelerate their degeneration. Additionally, it's crucial to understand whether elevation has any impact on the effectiveness of cookstoves' firing. One major factor could be improper stove usage. Burning emissions from the stove can enter the interior atmosphere if the right cooking pots are not properly positioned in the combustion chamber that covers the stove's cooking apertures. The same holds for gasoline insertion apertures. Consequently, the hood method is suited for testing stoves. However, it is crucial to assess the characteristics of any type of control charcoal cookstove since they might share knowledge about potential stove designs for neighbourhood homes. Additionally, the usage of biomass fuels is directly related to high biomass combustion leftovers or byproducts, such as particulate matter and carbon monoxide [53]. Consequently, this discovery was expected. In order to reduce emissions from charcoal cookstoves worldwide, it is essential to use cleaner energy (starting with wood and eventually switching to gas and electricity). This requirement should also be carefully considered when designing cookstoves and their chimneys. This finding is important even as the Global Alliance for Clean Cookstoves works hard to lessen the detrimental impact of indoor and household air pollution on health.



Source: The 2016 version 1.0 of the Gold Standard Simplified, AMS II. G, and TPDDTEC Cookstove Methodologies Guidebook

Fig. 2 parameters for project-level calculation of carbon reduction

The number of distributed cookstoves alone would not guarantee the efficacy of household air pollution mitigation initiatives; it also would not guarantee how many of those stoves are well-designed, regularly used, fully functional, and carefully maintained over time. The gold standard at the research level has defined the following standard parameters for assessing emissions:

In Figure 2, the net calorific value (NCV) of the biomass, the percentage of nonrenewable biomass, the number of functioning devices and implementation days, and an emission factor for the fuel avoided are used to evaluate and contrast the clean development mechanism (CDM), and Gold Standard approaches. [50]. As shown in Figure 2, there are a number of parameters that are relevant for the research-level estimation of emission reductions. The parameters' importance for the stated approach has been emphasised when appropriate. To make sure that the methodology is applicable and pertinent, it is advised to do so.

3. Discussion and Future Possibilities

Improved cookstoves can generally be divided into three categories: the conventional "three firestones" style, which often uses both wood and charcoal as fuels; improved cookstoves made particularly for wood combustion; and improved cookstoves made specifically for charcoal combustion. The choice of materials, particularly in terms of thermal conductivities and material thickness, can significantly impact how heat is transferred from the combustion chamber to the test fluid (generally water). Both designers and users must be aware of the feed-in fuels' method of operation. This design characteristic makes it easier to lower the firepower at the high-power cold start phase to a simmering temperature. Additionally, the performance of improved cookstoves is greatly influenced by the air control entering the combustion chamber. Taking into account these qualities when constructing improved cookstoves will be very beneficial in their use. The thermal conductivity of the materials that the better stoves are made of is equally essential, unlike in the case of [32], who simply divided the improved stoves into traditional and improved cookstoves regardless of how the fuels are fed into the combustion chambers. Although [56] explicitly suggested some excellent methods for a model designed for improved stoves, including cross-sectional, before and after, before and after with the control group, for selecting improved cookstoves for a set of indoor cooking activities, it was further suggested that, the strategies on how to reduce improving stove sample sizes for comparative studies in laboratory and field tests, as well as large difference detection and decrease the coefficient of variation (COV). However, airflow control systems in any of the improved stoves could have been a better option as a criterion. In practice, it is essential to reduce the number of cookstove sample sizes for all the categories of improved cookstoves for both laboratory and field works. It is advised that for comparative laboratory tests, there should be roughly equal amounts of combustion chambers designed and that the amount of charcoal used for each test, from the cold start high power phase to the simmering phase of the tests, should not exceed 5 kg for the heating of 2.5litres of water.

Additionally, it is advised that tinder be carefully chosen if it is not derived from a renewable resource. The material from which charcoal was created should be utilised as tinder for best practice and to minimise the loss of the parameters mentioned above; even though [32] [58] advocated using kerosene as tinder, it tends to change the combustion pattern, carbon emission, and other particulate matters (PM2.5). Impurities can negatively affect boiling points in the case of WBT since less attention has been paid to the quality of the water used to conduct testing. Impurities can therefore generate vast amounts of CO, PM2.5, and CO2. Additionally, care must be given when utilising the CO2 metre to obtain readings for the CO2, CO, and PM2.5 during the tests' simmer phase as opposed to their cold start high power phase, which begins when the water temperature reaches 100°C. As opposed to [32], who advised placing a stove 1.25m above ground but did not specify the location of the hood above the stove under consideration, positioning the hood at 0.5m above the stove is significantly better at capturing all gases that are produced from the stove chamber. It is preferable to use renewable resources like tinder instead of conventional fuel (kerosene) as a fire starter for future improved cookstove tests. In cookstove testing, this will lessen the irregular fuel combustion patterns. Since temperature, pressure, and the addition of a solute or solution can all impact the boiling point of water [60] [48], it is advisable always to use purified water and to check the ambient pressure before conducting any testing.

4. Conclusion

Due to the difficulty and scarcity of power in the majority of Sub-Saharan African homes, the social and economic challenges the populace faces will only worsen as the region's population grows. As a result, biomass cookstove use will continue to rise and become a more modern type of cookstove with increased population growth in every underdeveloped part of the world. It means that traditional open fires and biomass cookstoves will be widely used in Sub-Saharan Africa and beyond. If shown to be more effective in terms of emissions and thermal efficiency, more modelled complicated designs of biomass cookstoves may find a market in Sub-Saharan Africa and beyond. Once more, it may be challenging to categorize the original "three open firestones," as well as better cookstoves that regularly use both wood and charcoal as fuels and those better cookstoves that are explicitly constructed for burning charcoal and wood, respectively. The majority of biomass cookstoves, which are used for cooking, have been deemed dirty and inefficient. However, charcoal cookstoves stand out for a superior outcome and generate fewer smoke clouds.

However, if correctly designed and built, cookstoves are assessed using the water boiling test (WBT) approach that will determine the minimum emissions levels while also reducing fuel usage would assist biomass cookstove users in deciding what kind of cookstove and fuel will be used at home. To properly account for emissions before and during testing, it is always necessary to investigate these parameters on each selected cookstove using the hood method because CO, CO_2, and $PM_{2.5}$ vary from region to region (as a result of geographic location, agricultural work, and industrial activities). It is also suggested that the entire WBT be performed with distilled water.

Funding Statement

This research was financed by the World Bank (WB) through the Regional Center for Energy and Environmental Sustainability (RCEES), University of Energy and Natural Resources (UENR), Sunyani, Ghana

Acknowledgements

The authors want to give thanks to the World Bank and RCEES for their financial support. Our colleagues' thoughts and recommendations are also very appreciated.

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