Research Topic: A multi biomass fueled continuously running stove and its environmental and social impact

1. Executive Summary

Globally, 2.3 billion people in developing countries use solid biomass fuels such as wood, agricultural wastes, animal wastes, charcoal and nuts, as fuels on traditional open fire (three stone fire) to produce heat needed for cooking and heating (IEA, 2022b). Furthermore, about one billion people from sub-Sahara Africa (SSA) countries, Sierra Leone included, still use cooking fuels that are highly polluting. Ninety two percent of Sierra Leoneans use cooking methods that are inefficient and highly polluting (Stoner et al., 2021). On a commercial scale, heat needed to preserve fish and to remove moisture from the final stage of gari production is also polluting. Gari, made from cassava tubers, is a popular carbohydrate granular food product that is consumed in most West African countries, including Sierra Leone. Relevant to note is that wood is used as fuel, in a traditional open fire place that is highly polluting and inefficient in terms of fuel use and time.

Inefficient burning of biomass, though a renewable energy resource, can emit pollutants that are harmful to human health and the environment (WHO, 2021). Moreover, given that children, especially girls, spend about 5 hours per day collecting fuels for cooking, it exposes them to risks such as violence, sexual harassment and early drop out from school (IEA, 2021). Over the years, researchers have come up with more efficient thermal methods to reduce fuel usage and pollution. Simple cooking devices like liquefied petroleum gas (LGP) stove, electric hot plates and camp stoves could make improvement to their situation (Floess et al., 2023). However, lack of electricity poses a challenge to using electric devices and LPG is expensive, especially for rural settlements. Accordingly, there is need to proffer solutions to help solve these issues of health and environmental pollution and to improve lives. Improved cookstoves have shown to produce less pollutants and can reduce fuel usage by 20-75% if performance standards are enforced by regulators and observed by users (IEA, 2022).

Reviewed extant literatures have shown that the use of improved cookstoves can lead to less fuel usage and reduction in environmental pollution as less trees are cut down and burnt. For example, indoor air pollution caused by traditional three-stone fire stove are inefficient in fuel consumption, whereas improved cookstoves are better alternatives to address pollution and poor efficiency (Jung and Huxham, 2019). Notwithstanding the positive attributes, there is need for further improvement in the form of: ease of use, cooking time, combination of fuel feed methods, continuous operation and thermal efficiency. However, reviewed literatures did not reveal studies that have combined rocket and top-down up draft principles in cookstove design and production, especially in Sierra Leone. Additionally, a stove that is capable of using different solid biomass fuels and runs continuously with minimum tending is needed to help address these issues. Therefore, this study is proposed to come up with a design that can be used domestically, and commercially thereby creating potential for a sustainable and profitable business venture. A prototype of this proposed design has been produced and tested, and the results are encouraging. However, improvement is needed, hence the need for this study.

2. Aim and objectives

Consultation with academic experts, business entrepreneurs and review of existing literature in this field of study, resulted in raising five research questions and they are:

I. Can moisture content of fuel affect thermal properties of the stove?
II. Is there a relationship between design principles and processes adopted and performance?
III. What are the consequences on the users and the environment as a result of using diverse biomass fuels on the stove?
IV. What are the results of continuous operation of the stove?
V. Can a sustainable business venture be derived from the production of the stove?
VI. What are the effects on users and the environment as a result of using the stove?

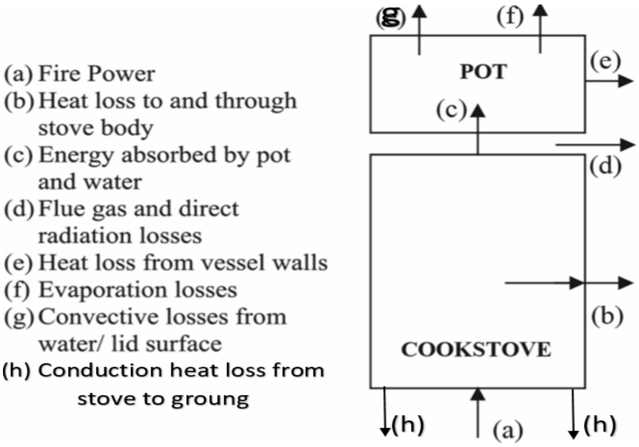
In order to provide answers to these research questions, objectives need to be constructed, based on the goal of the study. The goal of this study is: *to produce a stove that is designed to run continuously and proficient in using diverse solid biomass fuels*. Achievement of this goal is contingent on objectives designed for this purpose and they are:

I. To assess the effects of moisture content of fuel on the thermal properties of the stove
II. To evaluate the effects of design principles and processes on the performance of the stove
III. To find out the effects of using different biomass fuels on the users and the environment
IV. To explore the possibility of operating the stove continuously
V. To determine whether a business venture can be derived from production of the stove
VI. To find out whether collaborate with the private sector can lead to sustainable and profitable business venture leading to job creation
VII. To identify the implications of using the stove on users and the environment

Therefore, the achievement of these objectives will provide answers to the research questions leading to achievement of the goal of this study. This study will evaluate the effects of design principles and processes on performance of the stove. So, dependent and independent variables will be developed, wherein, design principles and processes is the independent variable, and performance of stove is the dependent variable. Therefore, performance will improve if design is made better.

3. Background, Rationale and Problem Statement

Burning solid biomass in biomass cookstoves converts chemical energy into thermal energy which provides useful heat for cooking and heating (Bushnell, 1987). Figure 3.1a portrays heat transfer contribution, while figure 3.1b shows steady state energy balance. In figure 3.1b, the total heat gain (32.1%) are those from convection and radiation, 17.5% and 14.6% respectively, whereas total heat loss is 67.8%. this value of heat loss is more than twice the heat gain. Furthermore, about a third (29%) of the energy produced is wasted. radiation heat losses account for 19% of heat loss (Zube, 2010). Therefore, reduction of these losses is one of the objectives of this proposed study.



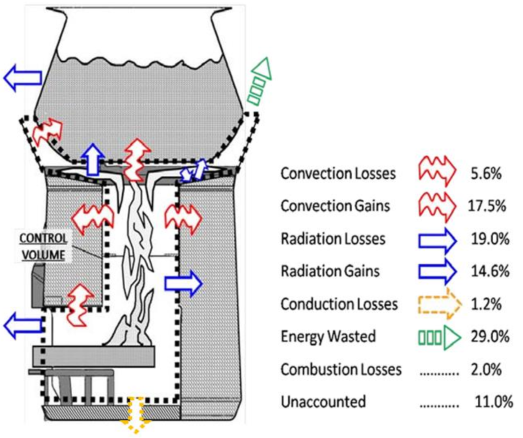


Figure 3.1a: heat transfer contributions
Source: Sutar et al. (2015)

Figure 3.1b: steady state energy balance
Source: Zube (2010)

There are several different types of improved cookstoves, for example, rocket elbow and top lift up draft (TLUD), (Anderson (2007). The rocket elbow stove works on continuous feeding of fuel, leading to more tending time while the TLUD stove is considered a gasifier and, smoke is prevented during cooking when no fuel is added (Bryden, 2010). Compared to the traditional three-stone fire stove, improved cookstoves are portable and can be used both indoors and outdoors, hence, they should be carefully designed to achieve better thermal efficiency (Zube, 2010). Researchers such as Geller (1982), Anderson (2007) and Verhaart (1982) focused on improvement on the structure of the combustion chamber and distance between the end of the stove and bottom of pot, as these factors are essential for better heat transfer. The proposed design of the stove for this study makes use of both rocket and tlud principles of burning solid biomass fuel to generate heat. It is important to note that efficiency of improved cookstoves do not always lead to reduced emissions. Some researchers have shown a positive correlation between efficiency and emission (Bhattacharya and Salam, 2002). However, when compared with traditional biomass cookstoves, improved biomass cookstoves are found to be more efficient, for they consume less fuel, 20 – 50% (Mukunda et al., 1988). Recent studies have shown that improved cookstoves are more efficient than traditional three stone fire stoves (Parajuli et al., 2019; Gumino et al., 2020; Mekonnen, 2020; Sutar, 2022). Rocket elbow stoves tests results, when compared to TSF, show a reduction in fuel saving of 41% with a reduction in CO and pm25 by 46% and 56% respectively (Anderson, 2007).

Problem statement - A major challenge faced by one-third of the global population is access to clean forms of energy for cooking (WHO, 2021). These people mainly reside in developing countries, including Sierra Leone, and they use biomass stoves for cooking and heating (IEA, 2022). Every year about 4 million premature deaths occur from illnesses resulting from household air pollution due to inefficient cooking practices (who, 2022). Studies have shown that improved cook stoves are more efficient in fuel consumption and emit less pollutants than traditional forms of cooking.

Different forms of cookstoves have been designed and fabricated across the globe to address energy efficiency and reduction in emission pollutions (Miandad et al., 2019; Das et al., 2021). Ahmad et al. (2022) found out that, compared to traditional three-stone fire place, improved cook stoves (ICS) have better thermal efficiency, lesser emissions with lower health risks.

Wonder stove is prevalently used for cooking and heating in big cities of Sierra Leone, especially the capital city, Freetown, and its environs. The stove uses charcoal as fuel, and hundreds of trees are cut down yearly to meet demand, leading to concerns on sustainably and the environment (IEA, 2022). Most Sierra Leoneans believe that wonder stove is the best for cooking as it emits little smoke. At first glance, these perceptions seem to be true. However, these claims fail to take into account ignition and cooking durations, including fuel consumption. Wonder stove takes longer time to ignite and its thermal efficiency is below that of improved cook stoves, and in essence, it takes more time to perform a cooking task (Kalbande et al., 2017). Furthermore, clay is used to make the combustion chambers of this stove (Chiu, 2023), which is mined at an alarming rate as hundreds of these chambers are made, weekly, to meet demand of customers. A continuation of this trend would pose sustainability issues of this material. Also, these clay mining sites become breathing ground for mosquitoes, an ensuing health issue for residents around the site. Therefore, once users start to rethink their perceptions towards these concerns, solutions to these problems can be provided.

Several studies have been done by various scholars (Geller, 1982; Anderson, 2007; Zube, 2010; Sutar, 2022; Shah et al., 2023) on the effectiveness of cook stove but none was specific on relationship between performance and principles and processes of design that would lead to continuous operation using diverse solid biomass fuel. Therefore, a solution is required that is sustainable, cheaper with potential for commercialisation. In this regard, a problem statement question is posed: what is the relationship between performance of a stove and its design principles and processes? The purpose of this study will be to produce a stove that runs continuously and proficient in using diverse solid biomass fuels. A stove with such attributes is expected to emit less pollutants and attract private sector participation that would lead to job creation. However, there are factors expected to influence performance, and this study will investigate such factors. Ultimately, this study is expected to provide solutions to the problems highlighted and to achieve the purpose of this study. Additionally, the review has shown that the use of improved cookstoves can lead to less fuel usage leading to a reduction in environmental pollution as less trees are cut down. Nevertheless, there is need for further improvement in the form of: ease of use, combination of fuel feed methods, thermal efficiency and environmental pollution. However, reviewed literatures hardly reveal studies that have combined both rocket and TLUD principles in cookstove design and production, especially in Sierra Leone. So, this study is expected to come up with a design that is capable of addressing these challenges.

4. Research methodology

4.1 Pre-feasibility studies undertaken

Pre-feasibility qualitative studies were conducted wherein face-to-face interviews were held with potential users, majority were women. Also, academics and business consultants in this field of study were consulted to obtain in-depth and relevant knowledge of the project. The results reveal crucial information such as involvement of potential users of the proposed innovation, and existing norms of cooking should be factored into the design in order to increase acceptance of the final product. Results from the pre-feasibility study led to prototype designs and fabrication of two types of biomass stoves (designs A and B) whose fuel consumption and thermal efficiency are better that those of TSF fire stove.

4.2. Implementation Phase – Conceptual framework, design and Production

The entire stove will be designed and produced by project team members, including some students in the faculty of engineering and architecture, using locally available materials and knowledge. Fabrication will be done in the fabrication laboratory at Fourah Bay College, University of Sierra Leone. A flexible and easily adaptable design and production processes will be adopted, so that various communities in the country, interested in replicating the product, can do it with minimum cost and efforts. A conceptual framework will be developed that will include both technological and social variables with the aim of constructing hypotheses that will help achieve the objectives of this study. One of the reasons for this framework is to associate the outcomes of this study with those pertaining to the United Nations 2030 Sustainable Development Goals pertaining to clean energy production.

4.3. Data Collection, Sharing and Archiving Methods

Both secondary and primary data will be collected during the study. Secondary data will be collected through text books, internet data base, journals on open access engineering sites and discussion and consultations with academic and business experts. Primary data will be collected in the field and in the laboratory during operation. In the field, primary data will be conducted through survey methods using qualitative and quantitative methods. Primary data in the lab will be collected during testing and operation of the stove and then recordings made for scientific and statistical calculations. Performance methods such as thermal efficiency, specific fuel consumption, fuel burning rate, payback period, cost-benefit analysis will be carried. Mathlab, ANSYS Fluent, HOMER, TRANSYS, Microsoft and Statistical Package for Social Sciences (SPSS) are the software to be used in analysing collected primary data. International and national regulation on handling collected data will be strictly adopted to protect privacy of participant and to also store collected data. Also, access to primary data will only be provided to relevant stakeholder and project team members.

4.4. Pictorial Representations of Design A and B

Figure 4.1a shows a 3-dimensional AutoCAD drawing of design A, while figures 4.1b, 4.1c and 4.1d show prototype photos of design A in operation. It is designed with a swinging combustion chamber that can be refueled whilst the pot is still on the stove.

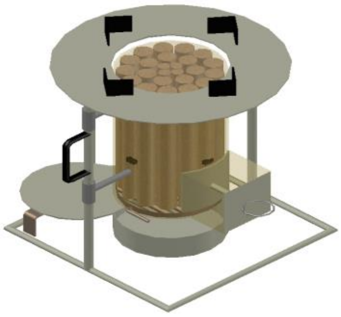


Figure 4.1a

Figure 4.1b

Figure 4.1c

Figure 4.1d

Design B is more flexible than design A, in the sense that it combusts different biomass fuels, including sawdust. It is built with an insulating medium and can be used for commercial and domestic purposes.

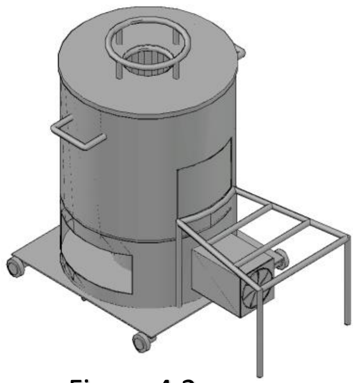


Figure 4.2a

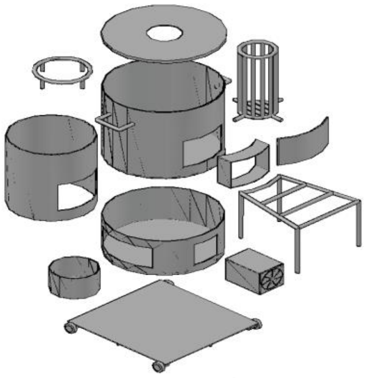


Figure 4.2b

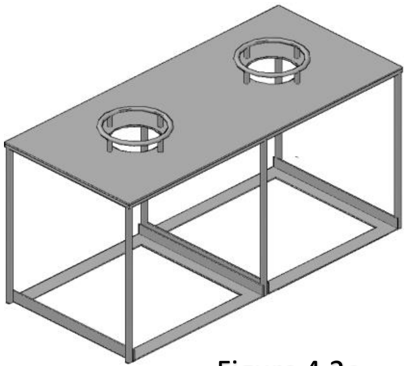


Figure 4.2c

Figure 4,2a shows design B on wheels, while figure4.2bshows all the parts of the stove in an exploded view. Figure 4.2c shows a table with pot sits to enable concurrent use of two stoves. Figure 4.3a shows the table housing two stoves, whereas figures 4.3b contains sawdust as fuel and 4.3c shows wood as fuel. The stove can be refueled and placed on a platform with bearings and then wheeled in position, see figure 4.3a, suitable for use in fish and gari drying businesses, it transfers heat at higher temperature.

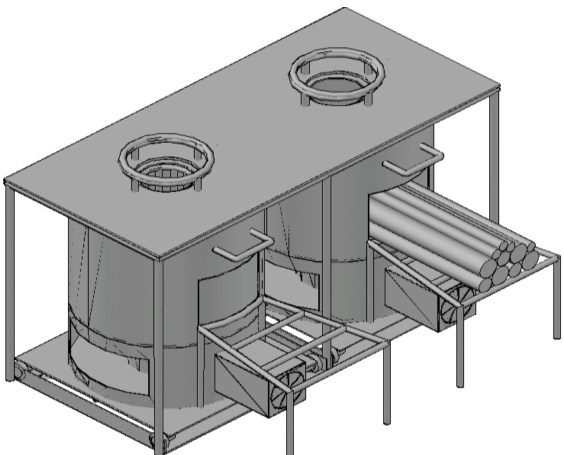


Figure 4.3a

Figure 4.3b

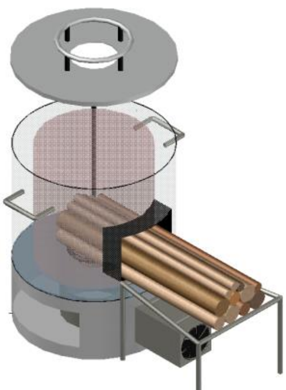


Figure 4.3c

Sawdust cookstoves produce smoke as burning of the fuel progresses, it turns to ash (which is lighter) and then falls and blocks the primary air hole, leading to heavy smoke. To solve this problem, a central shell (see figure 4.4a), with vertical rods on its circumference, was designed to hold burning sawdust in place in order to prevent smoke until complete combustion of the fuel. Figure 4.4b shows sawdust in stove, whereas 4.4c and 4.4d show cover and pot rest in position and initial burning stage respectively.


Figure 4.4a


Figure 4.4b


Figure 4.4c


Figure 4.4d

The stove can also provide heat energy to a steam boiler that turns a shaft of an electric generator to generator electricity, as shown in figure 4.5a. Sketched in figure 4.5b is a magnified view.

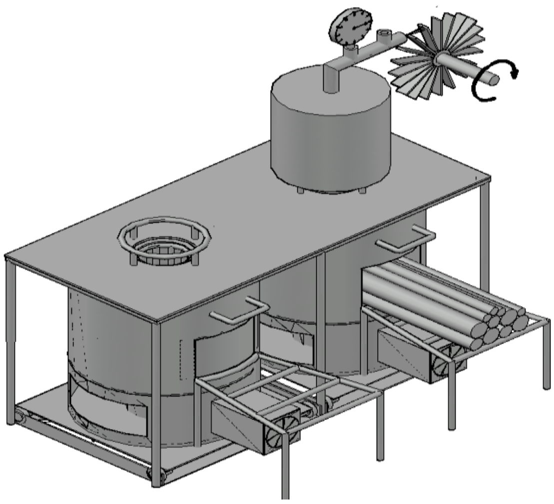


Figure 4.5a

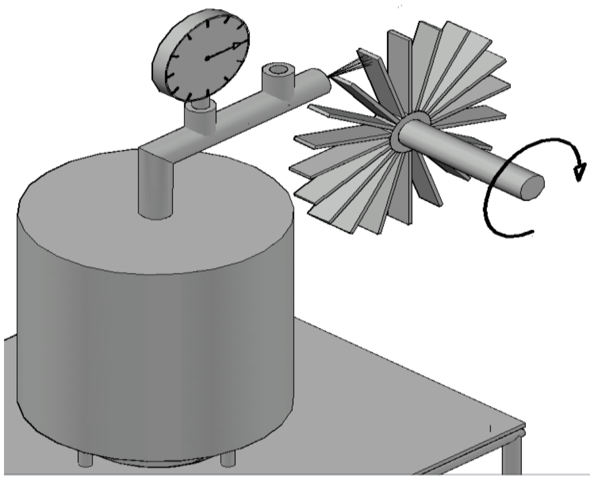


Figure 4.5b

Notwithstanding these encouraging results, further creative studies need to be conducted to come up with an innovative product that will address users' needs and further reduce pollutions, hence one of the objectives of this proposed study.

5. Outputs and associated Outcomes of the Project Management Strategy

The buy-in of intended users of the proposed project will lead to increased acceptance leading to sustainable solution. Additionally, involvement of experts and business consultants will be essential to come up with a business model that will be sustainable and profitable. This study will be based on both output and outcomes project management principles, and a framework is developed and shown in figure 5.1. The framework consists of five metrics, in which each of them subsumes different metrics, which represents deliverables that are needed to achieve the goal of the project. The greatest amount of funds will be spent on workers and equipment. Additionally, the type of inputs and how they are used are important, and will reflect on effectiveness and efficiency in the innovation and creative processes.

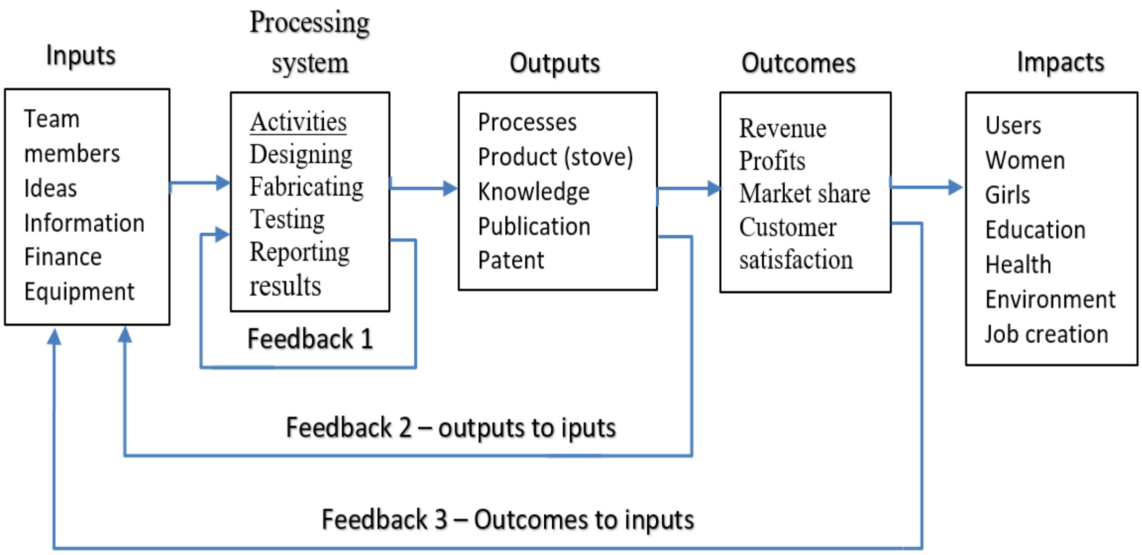


Figure 5.1: Creative and Innovation Framework

Interestingly, a product can be technically sound but is may not necessarily address the needs of users. Therefore, a balance will be struck between outcome and output to ensure the product is both practical and functional thereby leading to customer satisfaction and eventual product success. Private sector partners and students will be encouraged to focus on outcome of design by thinking creatively resulting in innovative and sustainable solutions to existing problems. It is expected to build capacity in communities and potential business organisations thereby transferring a range of knowledge and skills to participants with the aim of pursuing new development opportunities. This runs parallel to the human development perspective of the government. Sawdust is an organic material and part of renewable energy resources that is environmentally sustainable, therefore using it as fuel to generate heat energy will reduce fuel costs and reduce environmental pollutions. Disposal of sawdust will be better managed as lots of it will be converted to needed heat energy thereby reducing cost of disposal reduce wastes in landfills. Homes will benefits from using this product, as indoor air pollution will be reduced including cooking bills as a result of the design processes involved. Design is expected to lead to less fuel use, which will lead to lower deforestation as less trees are cut down thereby helping to address the issue of climate change. Design is expected to use less fuel, therefore women and children will spend less time collecting fire wood, resulting in availability of more time for schooling and other forms of education. As the stove is expected to produce less pollutants, health of workers that are directly involved in gari and fish drying will improve, for less pollutants are inhaled as compared to traditional drying methods. As less fuel is expected to be used, fish and gari producers are expected to make more profit. The research will provide additional benefits to the community such as jobs and decreased dependency on charcoal. Short-term employment such as computer aided design (CAD) technicians and metal workers, will be created during design and production of the stove whereas long-term employment is expected to be incremental which will result after the project is completed as potential business entrepreneurs will be involved. The project is expected to increase tax revenues for government given that employment will increase leading to an increase in personal income tax, municipal and payroll taxes

6. Dissemination of results and awareness campaign

6.1 Dissemination of project's results

The findings will be disseminated through stakeholders meetings in which findings of the study will be discussed. Also, virtual means such as radio, televisions, online newspapers and social media (WhatsApp, Facebook, tweeter, Histagram) will be engaged to achieve a wider audience. The intention of disseminating results is to target beneficiaries such as house wives, restaurant businesses, gari and fish drying businesses and potential private entrepreneurs. This is to improve better heat transfer method and to also spur up investment, as results from this study is expected to reduce fuel usage and reduce pollutants, government can design policies on restricting the use of traditional three stove fire and encourage the use of this improved stove thereby. Additionally, tax incentives can be offered to potential business entrepreneurs with the hope of investment in this product. The whole study will be published through peer reviewed journal that will be on open access as it will increase dissemination of the research and its outcomes. The final product will be patented to obtain copy right and prevent unlawful replication of the stove. Such patent will ensure that investors recoup their investments with some profits as a form of encouraging further investments.

6.2 Awareness raising campaign

People general associate wood burning as dirty due to visual reminder of smoke and its choking ability, in which case associate it with health risks. In this regard, public awareness will be raised to provide scientific explanation regarding the difference between gasification (process involved in improved stove) and burning of wood as is the case with three stone fire. Meetings with the media and stakeholders will be organised to address such concerns. The fears could also be mitigated by holding frequent public consultation and awareness building initiative with users and business entrepreneurs. The consultations could include explanation and discussion on the carbon neutrality debate and emissions of improved biomass stove. Burning wood, especially in a gasifier, releases the carbon dioxide that the tree absorbed during its lifetime, which is the same amount that would be released if the tree was left to decompose on the forest floor, therefore, the process does not add any new carbon to the existing carbon cycle.

7. Governance of Project

A team of specialists from the private sector led by the principal investigator will coordinate the implementation of this project. Various governance teams, on each activity of the project life cycle, will be established to provide direction needed for accomplishing objectives. Different committees will be formed such as financial management, public liaison, procurement, design and production and marketing. An internal resource audit team will also be established to encore that resources are managed efficiently. This team will help in stemming wastages leading to cost reductions. Advisory Services for Technology Research and Development (ASTRAD) is an entity of the University of Sierra Leone, consisting of engineers, management planners and consultants. ASTRAD will provide overall technical support for the project and, where required, obtain other outside consultants for the successful implementation of the project. They will act as a facilitator to seek collaborative working relationships between the ministry of education, importers of components and equipment to be used on the project. They will also be responsible for providing relevant input in the design and provide quality assurance for the final product. In essence, the project will be managed by a governance team constituting of experienced engineers, management scientists, economists, business administrators, marketers and financial analysts. Workers at facilities and estate department at Fourah Bay College will help in coordinating the work of the team members during all phases of this project. Local administrators and Traditional leaders will actively participate in workshops and decision-making processes, given that they have better knowledge regarding the culture of their communities. Implementation and performance tracking team will pay consistent visits to users of the project to ensure its correct use, and to find out whether stove is performing accordingly.

8. Suitability of host College

The University of sierra Leone subsumes three unique colleges: Fourah Bay College, College of Medicine and Allied Health Sciences and Institute of Public Administration and Management. Three advanced educational institutions are leaders in their respective field of studies. Fourah bay college is the only one amongst the three that offers engineering and architectural programmes at undergraduate and post graduate levels. In addition, it hosts an innovation hub and a fabrication laboratory that provides training to students in these areas of study thereby encouraging them to be innovative and creative. Worthy of note is that Sierra Leone institution of engineers act as moral guarantors for the college in terms of engineering ethics and provide some forms of regulations to private engineering practices. In this regard, FBC is uniquely positioned to host a research study of this nature.

9. Capacity building, community engagement and training

Training sessions on how to use the stove will be conducted for users as it would lead to greater uptake. Similarly, communities will be engaged continuously that will result in achievement of relevant information regarding skills and knowledge about the product and how it can be replicated for eventual income generation. The project will provide training for some technicians who will be sent to different areas where the stove will be used to provide help and relevant information about the product as and when needed. Some students from the Business Studies department in the university will be trained as marketers to enhance sales and increase uptake. Internship will be provided for students from areas where the product is to be used, which will culminate to skill and knowledge acquisitions. Capacity building on both individual and organisational levels will be essential for success of the product. Every student of the college will be encouraged to visit the project management office, the fabrication laboratory and innovation hub of the college to ask questions and hold discussions with project team members with the aim of realising a better grasp of the concept and workings of the project. However, active participation with practical involvement of post graduate and final year undergraduate engineering students will be given more attention. Collaborative workshops will be organised in communities involving stakeholders and private business institutions to enhance transfer of skills and technology, this is ensure that uptake of product even after closure of the project.

10. Monitoring and Evaluation

A well planned project is not enough. It has to be monitored to ensure that it delivers the intended outcomes. Monitoring, evaluation and control should be incorporated since the inception of the project so that all resources invested in the project yield required outcomes. This is because, results from completed products should be tracked and reported and then compared with those obtained during planning phase to find out whether changes are required to achieve better performance. Consequently, meetings with stakeholder, consultations, users and private sector participants have to be held to collect and analyse data, and then take corrective measures where required. Also, it is a learning exercise whose results can be applied in the planning and execution/implementation stage of future projects. Funding is also required during this phase of the research to conduct these activities. As replication of this stove is expected in different communities of the countries, monitoring will be important, as better cost estimates and procurement decisions will be made that will lead to increased efficiency. In keeping with established auditing procedures, all financial documentation; copies of invoices, payments to suppliers expenses incurred during meetings, travels, lodging and stipends will be securely kept for over six years after completion of the project. Additionally, audited financial statements will be provided, when required, even after completion of the project. Cautious tracking and recording of outcomes of this project after design and production will be carried out, as data collected will be essential for future project of similar field of study.

11. Gender, Ethics and Sustainability

Gender impartiality - A study that is gender blind is a biased and corrupts research and it can negatively affect validity and reliability of the results, leading to misrepresentation of social realities and even strengthening gender inequalities. Gender diversity is considered as crucial aspect of the rationale in this proposed research and it will be an operative concept in the stages of design and methodology, that is, from its conceptual stage to implementation and closeout stage. Structural factors such as norms, cultures and power relations that contribute to gender inequalities will be avoided to achieve results that are based on gender diversity, given that such inequalities can influence communication, implementation and strategies of the study. Gender sensitivity will be considered in the composition of the project team and composition of stakeholders. As a consequence, this study will adopt research methods and project action plan that will involve women in every aspect of the project, from feasibility to closure phase, with the aim of reinforcing gender perspective of the project.

Ethical Considerations - Every decision taking during this study will be based on ethical codes of the engineering profession of the nation and those form international bodies governing the profession, codes relating to treating team members and stakeholders justly and to avoid conflict of interest, respect intellectual property rights and exclusive information of others. Unethical engineering decisions can results in severe consequences on public safety and the environment. In this regard, this study will recognise ethical dilemmas and make informed decisions to improve lives and avoid actions that will lead to negative impact on businesses and the environment. This study hinges on the belief that ethical considerations in decision making are crucial to develop a sound sense of responsibility towards the environment and humans that aims at earning trust of the public towards the study and its findings. In this regard, a communication channel will exist to enable stakeholders to highlight matters of unethical practices by team members or consequences of operation of the product. The study will balance competing demands of safety, sustainability and profit making, and when it comes to decision making, the safety and wellbeing of human and the planer will be chosen over profits. Such decision is crucial to ensure that all actions taken during the course of this study are ethical leading to better and fair society. Community consultations will be undertaken with stakeholders on matters concerning the consequences of the study on their welfare and that of the environment.

Sustainability - Various measures, such as post-mortem meetings of stakeholder and visits to users to discuss possible successes and failures of the product with an aim of taking corrective measures to avoid failures and increase uptake of the stove. detailed operating and service manual will be provided to users and training programmes on how to use the product will be organized for better operation. Detailed impact analyses including environmental, social, financial and economic evaluations will be undertaken to help ensure that the product can still be in operation after closure of the project. Also, marketing plan will be developed by private sector participants to increase acceptance of the product. A mathematical and business model will be developed with dependent and independent variables to explain the principles and processes involved in design and construction of the stove and to make predictions of heat transfer and thermal efficiency. First aid, customer service and sales trainings will be undertaken by would be business entrepreneurs to increase existing customer loyalty and capture new ones.

12. Risks Mitigations Strategies

In order to ensure success of the project, risks have to be identified, monitored and mitigated. Risks management addresses issues that could endanger achievement of critical objectives. For this reason, a risk mitigation plan was developed.

Table 12: Project Risks and their Mitigations

No.	Description of risks	Proposed risk mitigation actions
1	Conflict between project team members	Members of various tasks, with different perceptions and interests will be encouraged to exchange relevant information to achieve goal
2	Project budget transfer	Timely transfer of Project budget to respective groups, ensuring project activities are realised
3	Decrease in motivation Overtime	Motivation plan will be constructed to reflect constant motivation of team members and make sure that work progress are monitored
4	Insufficient skill-set Staff turnover	Knowledge management systems will be created and made available to all members, and it will include: quality assurance methods, tutorials, manuals and waiting-list personnel.
5	Team member/s dropping out	Make use members with complementary skills
6	Unsatisfactory quality	Quality assurance and incremental testing methodologies will be effected
7	Expenditures and costs that are unexpected and unplanned	Institute a mechanism to redistribute and reschedule workload among available resources
8	Poor stakeholders cooperation	Detailed communication plan including regular phone calls and meetings to improve cooperation
9	Inadequate quality of deliverables	Deliverables plan will be effected, with timing schedule for feedbacks, comments and revision.
10	Information and events of the project not published by media	Dissemination plan will be defined with different broadcasting channels to widen the project outreach
11	Issues relating to product uptake	Effective promotion campaign and marketing plan
12	Participant showing low interest during product testing	Communication plan**:** motivation to encourage participation
13	Unreliable and Inadequate Methods	Appropriate modelling in development stage and tests condition in the fabrication laboratory
14	Needs and requirements of users are not fulfilled	Methodology on needs of users based on user centred approach. Use of iterative and training methods
15	Project implementation time frame deviates from expected time	Continuous monitoring of project progress and revision of risk management plan, and take timely response accordingly
16	Flawed managerial decisions leading to budget overruns and delays.	Develop managerial decisions plan to prevent errors that will lead to serious issues in the project.

Risk map

Figure 12 shows risk map representing the values of risks. The X-axis presents the Probability while the Y-axis presents the Impact. The first area (green) represents low end of the responses, which includes low values of probability and impact. The second area (amber) represents medium risks and is defined by average levels of probability and impact. The third area (red) represents high risk index, these risks would be fatal to the project (Brandl et al., 2019).

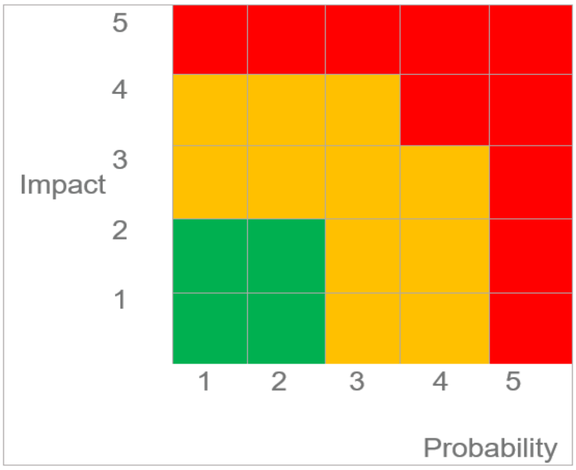


Figure 12: Risk Map

Risk response priorities - The response priority plan is divided into three level indicators that are defined by the expected risk index of the project. 1 – High Risk Index (red): consists of extreme impact and high or very high probability. Such occurrence might jeopardise the success of the entire project, therefore requires immediate response. 2 – Medium Risk Index (amber): consists of one parameter with a high value and the other with a low value. Although these risks are not fatal, they must be closely monitored and adjusted throughout the project. 3 – Low Risk Index (green): consists of two low value parameters. Events of this nature create only a local impact and probability on the project and can be corrected by team members, when eminent. The risk management team will prepare a plan to avoid significant project performance deficiencies due to risk occurrences. The team will monitors each of the high risk index events and the medium risk index events. Risk monitoring can be measured and calculated using these metrics, impact on project and Likelihood/probability to occur

13. Proposed project budget and expected dates

Table 5.1 shows estimated budget for the whole project that is broken down according to activities, initializing, planning, execution, monitoring, evaluation and control and closeout. From the table, the expected completed date was shortened as some activities were designed to run concurrently. For instance, establish terms of references, develop project management plan and work breakdown structure can be undertaken simultaneously with the feasibility study. This strategy will save time, leading to earlier completion time. The Gantt chart in figure 5 shows activities and expected start dates.

Table 5.1. Proposed project budget and expected dates

proposed project budget and expected dates				
	expected start date	duration (days)	completed date	estimated cost ($)
Stipend for project team members				12,000
Initialising				
set up and run project office and team	10/01/2023	40	07/03/2023	6000
develop a case and charter	01/03/2023	15	22/03/2023	100
undertake a feasibility study - identify stakeholders, risks, clarify budget	23/03/2023	48	14/04/2023	3000
establish terms of reference	02/04/2023	10	14/04/2023	100
Planning activities				
develop project management plan	28/03/2023	18	21/04/2023	200
develop work breakdown structure	11/04/2023	19	08/05/2023	200
develop financial, procurement, quality and marketing plans	29/04/2023	29	08/06/2023	1500
create risk plan, perform review	28/05/2023	11	12/06/2023	100
develop user and maintenance manual	05/06/2023	12	21/06/2023	100
Execution, monitoring, evaluation and control				
complete prototype and main project and perform tests, data collection and analyses	10/06/2023	92	17/10/2023	13000
testing and report on performance, train users	11/09/2023	55	27/11/2023	3100
track and control change	20/11/2023	30	01/01/2024	1000
manage media, change, risks and stakeholders' expectations	08/11/2023	42	05/01/2024	1500
Christmas break	18/12/2023	16	09/01/2024	
collect and analyse data	04/01/2024	20	01/02/2024	2000
procurement management	14/01/2024	18	07/02/2024	
publication of research findings	01/02/2024	48	09/04/2024	2500
Closing out				
hold post-mortem meeting	18/03/2024	8	28/03/2024	1500
perform project closure or close project contracts and disband resources	27/03/2024	18	22/04/2024	1000
review/verify project completion	15/04/2024	8	25/04/2024	1000
total				**49,900**

Important to note from this table is that, duration when weekends were included are greater than when they were excluded. For this proposal, durations for the working days were used to design the Gantt chart and the expected completion dates. See table 5.2, appendix A.

Figure 5: Gantt chart showing activities and expected start dates and duration