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Final Report

Title

Policy pathways for mapping clean technologies with energy access in the Global South – a case for rural communities' sustainable development.

Project team name

SENSouth (Sustainable ENergy SOUTH)

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Executive Summary

The Global South is in desperate need of modern energy to support its sustainable socio-economic development. Currently, over 1.5 billion people live without access to modern energy, crucial for the socio-economic development of the communities they live in. The huge deficit in modern energy has manifested in the use of dirty and environmentally harmful fuels, namely fuelwood (firewood), crop residues, charcoal, coal, dung *etc.*, mainly in rural communities. The use of these fuels has been linked to unsustainable living in the forms of climate change (due to the rise in global temperature) and health crises. While some of the cooking practices are responsible for climate change, the consequence of climate change has been shown to have a strong impact on the livelihood of the rural communities; flooding and desertification have increased the hours the women/girls used to collect firewood. Therefore, this study (research-to-action) examines the cooking space of the Global South with a specific focus on the rural communities in order to map alternative energy sources, technologies and supporting policies to drive clean cooking services for improved socio-economic development.

A systematic literature review was conducted in the space of cooking services and clean energy access to establish barriers, opportunities and drivers. The connection between clean energy and cooking services was identified with possible health impacts. In the same framework, the works related to environmental and socio-cultural impacts were systematically established. The policy issues related to clean energy cooking services drivers, barriers and opportunities are presented in the general context of rural communities in the Global South. The distribution of cooking technologies established from the review of the literature was presented and validated by engaging with stakeholders (energy/technology suppliers, end-users and interest groups) in the cooking space using Fiji, Ghana and Nigeria. This was an attempt to have a broad base understanding of rural community cooking space in order to articulate policy and business interventions to drive clean cooking services. To advance the understanding of the cooking space, a comparative analysis was conducted using data from existing literature and the stakeholder engagement (online survey and interviews); specifically for Fiji, Ghana and Nigeria. However, it is important to note that the cooking space is complex with major socio-cultural challenges in transitioning the socio-cultural norms (e.g. gender and kitchen structure) of traditional biomass cooking to cleaner cooking space; an area expected to be advanced beyond this work.

The general understanding of rural community cooking space was used to develop a generic, but holistic, business model that could drive clean cooking services. In the same reasoning, an attempt was made to present broad base policy pathways for the adoption of clean cooking services in the rural community for sustainable development. The policy pathways harmonise the major stakeholders in the cooking space; namely, government, NGO, clean energy developer, business services and end-user. The key highlights of the policy pathways could be presented as follows:

1. Mainstreaming gender into clean cooking policies and initiatives
2. Prioritising clean cooking fuels and technologies in harmonised National Policies, Strategies and Action Plans.
3. Increasing and designing new financing options and risk-reducing mechanisms for suppliers of clean fuels or technologies.
4. Mobilising funding in clean cooking fuels and technologies.
5. Allocating resources to civil society organisations, faith-based organisations, or community-based organisations and small-scale providers of clean fuel or technology.
6. Designing and implementing awareness-raising and capacity-building programmes for local communities.
7. Incentivising gas companies to supply cleaner fuels to rural and remote communities.
8. Collecting information and data on clean cooking demand in rural communities.
9. Designing and implementing a well-intended educational intervention programme for capacity and awareness raising
10. National energy policies should address lopsided subsidy intervention and competing demand for unproductive, and environment-degrading uses of agro-residues and wastes.

11. Designing policy that empowers government agency to develop quality assurance and quality control programmes.

To effectively increase the impact of the study, a policy brief and a page infographic summary that links stakeholders with opportunities and drivers are presented. In the same reasoning, a promotional video with infographics that resonate with the lay person to drive home the findings of the project is developed.

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1. INTRODUCTION

1.1. Background / Context

There is abundant evidence that there exists a gap in the socio-economic development in the world's richest and poorest countries ("Global North/South Divide"). Regrettably, faster economic growth in the Global North meant that it became responsible for 90%+ of excess global carbon emissions leading to the climate breakdown the world is experiencing today. However, it is the Global South that is most vulnerable to the repercussions of our changing environment (*e.g.* desertification, flooding, rise in temperatures, intensive tropical cyclones). It is now common ground that we need to change our patterns of living to protect vulnerable communities and preserve the planet for future generations. This includes a targeted approach to changing the way we generate and use energy to meet the varying needs of different communities while contributing to the achievement of the Sustainable Development Goals (SDGs).

Cooking is one of the principal energy demands for rural communities in the Global South. However, scientific research on the subject quasi-unanimously agrees on the detrimental consequences of current practices employed. More broadly, rural communities also have lower resilience to the detrimental consequences of climate change. Considering the foregoing, this research project focuses on proposing policy recommendations to drive a transition towards the reliance on clean fuels and technologies for cooking in rural communities in the Global South.

1.2. Need for Research-to-Action

Burdened by the need to close the socio-economic gap with the Global North (SDG.10), and despite abundant availability of renewable energy resources (solar, wind, biomass, hydro and geothermal, *etc.*), countries in the Global South have insufficient research & development, financial and technical capabilities to produce and utilise green energy in key sectors (including housing, agriculture, transport). This could be reflected in a flurry of incoherent policy documents and strategies in countries in the Global South that aim to outline sustainable plans to move away from the reliance on environmentally harmful fuels through acknowledging and attempting to address identified technical, financial, economic, and socio-cultural barriers. This not only drags the global effort to slow/stop climate change, but it also exposes the least resilient rural communities to health hazards (contravenes SDG.3 “Good health and wellbeing”), pollutes their environments (contravenes SDGs 6 “Clean water and sanitation” & SDG.11 “Sustainable cities and communities”) and imposes heavy financial burdens on Governments to recover from the repercussions of climate change which would lead to further poverty (contravenes SDG.1 “No poverty”). Therefore, there is an urgent need to develop adequate policy pathways that aim to present Governments in the Global South with options to be holistically weighed in order to effectively drive the clean energy cooking space in their respective countries (SDG.7).

1.3. Objective(s) of the R2A Project

This project sets out to achieve one broad objective, and a set of sub-objectives:

1.3.1. Broad objective

Developing policy pathways for overcoming barriers for the uptake of clean technologies for sustainable energy access in rural communities in the Global South.

1.3.2. Sub-objectives

1) Identifying existing clean energy technologies – solar, wind, biomass, small hydropower.

2) Mapping existing clean energy technologies with end-use energy demand for electricity, cooking, heating, cooling and productive uses.

3) Identifying barriers to clean energy uptake in rural communities in the Global South (including cost assessment and financial sustainability of the technology; policy; cultural; *etc.*).

4) Suggesting policy pathways to surmount the barriers to long-term sustainable energy access and uptake.

5) Engage in communication activities to widely disseminate the outputs of the project using face-to-face (in-person or virtual), social media campaigns, and podcasts.

2. METHODOLOGY / APPROACH

[How to collect evidence / conduct research on the issues stated above — literature review, case studies, surveys, interviews, stakeholder consultations, documentaries, etc. Also say why one or more methods are used, their strengths and complementarity, etc.]

The steps undertaken for this study are summarised below:

1. **Conducted a systematic literature review to gather evidence on access to clean energy technologies and barriers for their uptake in rural communities in selected countries (Nigeria, Ghana and Fiji) in the Global South** – this involved reviewing peer-reviewed articles and grey literature. The review focused on the publications targeting the Global South with an emphasis on rural communities. The team members also developed a specific literature review template that was used to collate data under the following headings: technologies and endues, health impacts, environmental impacts, socio-cultural impacts, enabling policies – drivers and barriers for clean energy access and business model review. Due to time constraints, primary collection of data was not possible, hence, the policy recommendations for this work were based on information gathered from literature review, stakeholder engagement and comparative study.
2. **Stakeholder mapping and analysis were conducted** - this activity involved critically and systematically identifying, assessing and linking all stakeholders (primary and secondary) that are involved in the energy access sector. The stakeholders were analysed against end-users, suppliers, and interest groups, which were then mapped in the importance-influence chart. This step was carried out as it was a key to identifying stakeholders in the 3 selected countries.
3. ***Developed stakeholder engagement modality framework –*** this step ensured seamless operation of the project. This activity matched the outputs from the stakeholder analysis with adequate engagement strategies and developed a workable framework to engage the identified stakeholders. The engagement framework was anchored on participatory approaches with a focus on telephone, email, and virtual meetings in the Global South nations, namely Fiji, Ghana and Nigeria. This activity benefitted from residue knowledge derived from existing research networks, institutional collaborations and community awareness (grassroots knowledge). The stakeholder engagement aimed to ensure that the project responds to tangible policy interests. To that end, early engagement with key stakeholders was favoured where possible to help shape the direction of the project.

4. ***Carried out a comparative study for the selected countries (Fiji, Ghana and Nigeria) based on the data gathered from the systematic literature review and stakeholder engagement -*** comparisons were done on the drivers and barriers for the rate of clean energy access and end-use, technologies adopted, economic implications, existing policies, socio-cultural characteristics, *etc.*

   To obtain an indication of cooking fuel and technology access in rural areas and communities in the three countries (Fiji, Ghana and Nigeria) online questionnaires (see annex 8.1) were designed. This data collection may be constrained by social science nuances, which are important in balancing the dichotomy of new entrant and traditional cooking services; however, the current approach is sufficient for a first approximation analysis. The stakeholders in each country were divided into three groups (i) End-users, (ii) Suppliers and (iii) Interest groups. The end-users are defined as the people in rural communities who are using fuels and technologies for cooking. Their interest in shifting towards clean cooking fuels and technologies is envisioned to improve health and living conditions, empower women, educate children, and provide reliable and safe energy access. The suppliers are the stakeholders who supply fuel and clean cooking technologies to the rural communities such as government departments/ministries, public authorities, energy service companies, financial institutions, clean fuel suppliers, etc. Finally, interest groups are defined as organisations (non-government organisations, community-based organisations, women groups, etc.) who have an interest in climate action, gender equality, reducing poverty, and health and safety. Based on these definitions, the stakeholders the team had identified as part of its stakeholder mapping and analysis exercise (Activity 2) were categorised into the three groups. The contact details of stakeholders were either known to the project team members and when not known, then common liaison persons were contacted to obtain contacts. In Fiji's case, some initial virtual meetings were done with the regional organisation where some key stakeholder names were given and who were later contacted.

   The questions for each stakeholder group were drafted and vetted in team meetings. It was later transferred to an online form for each of the three categories of stakeholders. Microsoft Forms was used to create the online versions of the questionnaires, which were shared electronically on 10 September 2021. The recipients were given two weeks to complete the online survey.

   One of the major challenges for the online questionnaire was getting responses from end-users in Fiji. Because the study focuses on rural communities, the internet availability in rural areas is very poor, people have limited internet data and rural communities do not have email addresses. In addition, with the COVID pandemic and time constraints for project output, the team could not conduct face-to-face interviews in households. In Fiji, two students who live in a rural community helped gather data and information on the online survey for end-users. Further, because there is not much published literature on cooking fuels in Fiji, zoom meetings on a one-to-one basis were carried out with key stakeholders.

5. ***Developed a business model*** – to ensure that rural communities are able to apply the model in their daily routines and ensure the longevity of the project. The business model took into account income generation options for the communities, ways to save money and allocate funds for the maintenance of the energy system.
6. ***Developed policy recommendations based on the comparative study, stakeholder engagement and literature review*** - to address barriers for the uptake of sustainable clean energy in rural communities in the Global South.
7. ***Prepared documents / outputs*** – the results from all the activities were adequately documented to produce the outputs detailed below:

- Developed a policy brief to engage key stakeholders on the issue of the uptake of clean energy technologies. The policy brief is tied to the nationally determined contributions (NDC) of countries in the Global South in order to gain attention for dialogue and possibly implementation
- Developed promotional video and a one-page summary with infographics that resonate with the lay person to drive home the findings of the project. This would be uploaded on YouTube and other social media platforms.
- Recorded a podcast with one or more key stakeholders to discuss the importance of the project's findings for their activities and raise awareness around the topic.
- Organised policy workshops in universities within the Global South to highlight the urgency of clean energy technologies for rural communities.[1]

8. ***Outputs were disseminated*** – The outputs were first disseminated through a virtual workshop where short presentations were delivered by the project members and keynote speakers followed by a roundtable discussion amongst various stakeholders. The outputs were also be disseminated via social medial channels, institutional websites and newsletters, presentations in public events with wider coverage of critical stakeholders, *e.g.* COP26, and face-to-face distribution of policy brief to policymakers at the local, national and international arena.
9. ***Continuous measurement of the R2A project's progress and impact was done*** - all the work was done, was actively monitored, in order to record potential challenges. Weekly virtual meetings were conducted amongst team members so discuss the progress done during the past week and the steps forward in the project. One drive folder was created where online documents were worked on simultaneously by team members. This analysis enabled the team and/or the responsible stakeholders to ensure the viability and sustainable delivery of the project's outcomes.
10. ***Drafted Final report –*** team had prepared reports for each of the activities mentioned in the previous steps. These reports were then collated in the final report template provided by ACU.

3. FINDINGS / UNDERSTANDING THE LANDSCAPE

[All data and information collected through different methods is summarised in this chapter]

3.1. Literature Review

This section presents works targeting technologies used to provide energy to remote rural settlements in order to meet their energy end-use, with clean cooking in focus, in the context of the Global South. In this context, clean fuel and technologies are defined as those that limit the emission of particulate matter (to below (PM 2.5) as 10 µg/m^3) and carbon monoxide (24-hour average carbon monoxide (CO) emission levels to be under 7 mg/m^3) (WHO, 2014). The final energy use derived from the presented technologies is connected with possible health impacts. In the same framework, the works related to environmental and socio-cultural impacts were systematically mapped. Policy issues related to drivers, barriers and opportunities are presented in the context of the Global South. Going forward, an attempt was made to present some pertinent business models existing in the public domain.

3.1.1. Technologies and Energy end-use

Several researchers focused on the provision of technologies that support energy cooking services in remote communities, which depend on biomass, coal, natural gas, LPG, biogas and electricity. There is a strong connection between available energy solutions in rural communities and cooking services. According to the International Energy Agency (IEA), 2.6 billion people worldwide do not have access to clean cooking with the majority of such people concentrated in rural and remote communities [1]. In most cases, energy for cooking comes from traditional biomass or kerosene or coals or other oil-based fuel [2,3]. However, there are existing clean technologies that are readily available to support modern clean cooking services in rural communities.

Huenteler *et al.* [4] focused on six renewable energy technologies to support Thailand's renewable energy target for 2021. The work shows, by technological learning, that the cost of electricity from renewable energy sources could be reduced to a competitive level with fossil fuels. It was stressed that local capacity and learning curve in renewable energy technologies has the potential of reducing the cost of energy from renewable energy technology. Zebra *et al.* [5] presented scientific data available in the open domain and suggested four essential steps needed to deploy sustainable energy – the first step focuses on setting up policy mechanisms and institutional arrangements; the second step entails interconnection of the main elements that ensure the feasibility of mini-grids; the third step focuses on economic viability and financial mechanisms and the final step is on the successful operation of mini-grids. Similarly, Chauhan and Saini [6] presented a methodological framework that supports the demand and resources assessment of renewable energy-driven energy systems in the remote area of Uttarakhand, India. The work also presented some barriers to the implementation of renewable energy technologies in remote communities, with potential solutions to eliminate the barriers. The solutions are anchored on discussion with the energy end-users, provision of institutional regulatory framework for financial management, creation of a database for resource assessment, provision of online subsidy disbursement mechanism, the development of an energy-efficient system by considering demand-side- management, the skilled workforce development, the development of standards for small scale renewable energy products and the system design considering future load growth.

Hansen *et al.* [7] studied the effects of local content requirements (LCRs) in localising the production of components of renewable energy systems (*e.g.,* wind and solar) in some nations in the Global South, namely South Africa, Brazil, India, and China. The study showed that the effectiveness of LCRs in promoting local industrial development differs across countries and technologies. The LCRs was also linked to the active local engagement and participation in renewable energy solutions as presented by Frame *et al.* [8], which focus on the deployment model (PV as a case study) for rural communities in sub-Saharan Africa. The deployment model highlights community ownership (involvement in the decision-making) of renewable energy solutions should be considered in the perspective of income generation to operate and maintain the system beyond the donor's supports.

Some researchers presented advanced renewable energy technology (hybrid energy system) to mitigate the unsteady supply of renewable energy sources (*e.g.*, solar and wind) by introducing energy storage in the form of battery [9], which, in some cases, attributed to high cost of energy [10]. The management of the use of batteries, their waste and their cost in hybrid systems are also discussed by Shezan [11]. Mohammed *et al.* [12] focuses on hybrid systems regarding the drivers and specific benefits of hybrid renewable energy systems (HRES); a back-up battery system for energy storage was essential for solar and wind. The diffusion of different non-hydro renewable energy (NHRE) technologies in developing countries is studied by Pfeiffer and Mulder [13]. It shows that NHRE diffusion accelerates with the implementation of economic and regulatory instruments, higher per capita income and schooling levels, and stable, democratic regimes.

Ockwell *et al.* [14] presented socio-technical innovation pathways for the transformation of clean energy access space by 2030 in the Global South and the strong connection between energy access and clean cooking services. It shows that gender, the scale of technologies, political and economic status are important in the intervention for electric cooking. The study discussed solar portable lantern and electric cookstoves, and how the transformative clean energy technology should be lensed with social justice especially in the area of gender factors in clean energy access, and how politics and political economy dynamics drive the success of interventions around new technologies at the rural community level. Diemuodeke *et al.* [10] focused on solar electric cooking technologies and presented technical and economic analyses of various electric cooking technologies in the context of rural communities. It established the possibility of solar PV induction cookstove technology to fill the gap of clean energy cooking services in the rural communities. The study showed that cooking at 2 kWh/day effective energy demand, is adequate for a household in a rural community (on average 2 tons of fuel wood is needed by a Fijian household to cook 3 meals [3]). Additionally, it was revealed that the Levelized Cost of Energy (LCOE) fluctuates between 0.120 - 0.390 $/kWh from without-battery to with-battery induction cookstoves, which is cheaper than LPG cookstove (0.500 $/kWh). It also identifies a study that shows that a solar PV cookstove could cost as low as 0.139 $/kWh.

The economic aspect of cooking was one of the main pillars of the study presented by Jewitt *et al.* [15]; that cooking technology is constrained by the interconnection of economic, access and spatio-temporal distribution of fuel cost, availability, service quality, socio-cultural aspect of cooking practices. It also shows that fuel staking is the ultimate to meet cooking demand because of the seasonality of some of the fuel sources. The implication is that change in seasonality caused by climate change will have a severe impact on cooking. The methodology was a field-based approach using a state located in the north-central of Nigeria as a case study. The choice of the state was informed by cooking data available in Nigerian Demographic Health Surveys. The research showed that the traditional cookstoves (biomass, coal and kerosene) are attributed to Household Air Pollution related health risks. It was also found that there is a huge opportunity to transform the cooking landscape of low-income biomass dependent rural communities to cleaner cookstoves once national energy policies steer the cause of cleaner cookstoves beyond the traditional cooking technologies. In the framework of clean cooking. Ozoh *et al.* [16] performed a cross-sectional and population-based survey, which focused on the choice of household cooking fuel and the attitudes towards the use of LPG in a densely populated town in the Global South. It shows over 90% of households were willing to accept LPG as cooking fuel in the absence of safety issues and high costs. The study showed that the link between national clean energy access policy and end-users seems to be inadequate. A study by Black *et al.* [17] showed that there is huge potential of biogas to meet the cooking energy needs of off-grid households and the added benefits of biogas generation in the context of a circular economy - effective management of waste (especially agro-residues and wastes) and nutrient recovery. It presented a novel biogas small-scale and low-cost generation technology, which could fit well as a clean cooking fuel, in the form of compressed biogas in bottles (cylinders). It was found that economies of scale and local cost of LPG have an important role to play in the economics of a biogas production system in the perspective of the payback period. Specifically, the large-scale (well-suited for a dense community) has better economic prosperity, while the small-scale (well suited for dispersed community) will struggle to break even. Several barriers and opportunities were also reported. At this point, it should be noted that the study focuses wholly on the techno-economic side of the biogas generation. However, enabling policy informed by the techno-economic evidence in the study needs to be done in the context of agro-residues and wastes management to support a circular economy. Buskirk *et al.* [18] study stressed that the continued use of firewood for cooking was directly connected to cost and, therefore, presents pathways to make solar PV electric cookstoves more economically competitive than firewood-based cookstoves.

3.1.2. Health impacts

Poor air quality is attributed to health problems in communities or societies [17][19,20] and many premature deaths [17][19,20]. In response to the adverse effects of the inefficient use of solid biomass for cooking on health, World Health Organisation (WHO) has set “Guidelines for indoor air quality: household fuel combustion” to help countries to identify key stakeholders and design and implement policies for household energy [21]. According to WHO Guidelines for indoor air quality – household fuel combustion 2012 – clean fuel and technologies should have annual average emission of fine particulate matter (PM2.5) as 10 µg/m3 and 24-hour average carbon monoxide (CO) level to be 7 mg/m^3 (WHO, 2014). Cooking fuels and technologies have been categorised into 3 levels by WHO – clean, transitional, and polluting; solar, electric, biogas, natural gas, liquefied petroleum gas (LPG), and alcohol fuels including ethanol are considered to be clean cooking fuels and technologies. Transitional fuels and technologies are those that provide some health benefit but do not achieve WHO emissions levels of PM2.5 and CO, *e.g.*, improved biomass cookstoves that have ISO Tier 3 PM2.5 and Tier 3 or Tier 4 CO emission levels (WHO, 2021). Coal and kerosene are considered to be polluting fuels and are strongly discouraged by the WHO Guidelines. Ozoh *et al.* [16] presented a study that focused on clean energy access with the policy aim of transforming the current household air pollution cooking space to cleaner LPG cookstoves and signals the policy to promote the transition from kerosene to LPG and scale up the deployment and adoption of LPG.

Tian *et al.* [22] have used the Chinese General Social Survey data to investigate the health effects of household cooking choices. They found that rural households are more dependent on solid fuels for cooking and thus bear a higher health risk. In Ghana, it is reported that more than 3,000 children die each year as a result of acute lower respiratory infections, including pneumonia, caused by the use of solid fuels [23]. Similarly, Ortega *et al.* [24] carried out a detailed study on the health impacts of replacing kerosene lighting with renewable electricity in 13 countries in East Africa. They used comparative risk assessment methods to quantify various health problems of individuals exposed to particulate matter emitted by kerosene lighting in 2015. They presented estimates of the number of deaths and disabilities due to exposure in three different scenarios of households replacing kerosene lights with renewable energy; (i) 33%, (ii) 66% and (iii) 100%, which give 6218, 10092, 12723 avoidable deaths. Importantly, women and children are the most affected by the *status quo* as more than half a million pre-mature deaths per year were reported in sub-Saharan Africa in 2015 [25]. [1][21] United Nations' Economic and Social Commission for Asia and the Pacific (ESCAP) [26] conducted a systematic review of 86 studies that used a quantitative evaluation method such as a Randomized Control Trial (RCT) or a quasi-experimental approach. Their systematic review found that 52 out of the 86 studies focussed on improved biomass cooking stoves and that there were reduced carbon monoxide levels but impacts on pneumonia, blood pressure and hypertension were not statistically significant. The implication is that further research work is needed to adequately address the impact of improved cookstove on health [24].

3.1.3. Environmental impacts

The environmental impact of clean cooking services is important to design an effective policy programme. It also provides the policymakers policy data and information to monitor emissions at the sectoral level for reporting at national and international levels. It is estimated that about a 2 tonne of fuelwood per year is needed by a Fijian household to cook 3 meals a day where feedstock is sourced from mangrove swamps or community forests [3]. This implies that the continuous trend of traditional cooking with fuelwood (firewood) would have a severe impact on climate change by raising the global temperature beyond the threshold because trees, which serve as natural carbon sequestration, are indiscriminately sourced for cooking energy.

It is estimated that inefficient traditional cooking fuel use in households causes around 25 per cent of global black carbon emissions, and their use contributes to forest degradation, loss of biodiversity, and localized deforestation [27]. Urmee and Harries [28] report that the use of solar home systems (SHS) by rural, remote, and maritime communities in Fiji have enabled households to live in a cleaner indoor environment. A 100 kW micro-hydro power plant installed in the highlands of Fiji has the potential to save 160 tCO_{2e} greenhouse gas emissions [29]. Similarly, mini biogas generators (each of 6 m^3 volume) installed in Bali, Indonesia, across 752 rural cattle farms with no electricity access, can potentially avoid 1.92 ± 0.96 Gg of CO_{2e} GHG emissions [30]. A study in Ethiopia found that a solar electrified rural household has the potential to save 43,68 litres of kerosene per annum and emission of 107 $kgCO_2$ and 2.72 kg of Black Carbon per year per household relative to a non-electrified home [31]. They employed a cross-sectional survey method involving 605 sample households along with a direct field investigation of 137 solar PVs and lanterns in four rural districts of Ethiopia. However, challenges include poor quality of solar PV in the market, high cost of verified solar products, lack of after-sales maintenance services, and limited access to credit financing sources [31]. Corfee-Morlot *et al.* [32] also found that most of those without clean cooking access in sub-Saharan Africa rely on traditional biomass causing deforestation and smoke and soot pollution, which in turn harms the local and global environment and human health.

3.1.4. Socio-cultural impacts

The political livelihood of rural communities which is shaped by socio-cultural stance, is expected to influence the adoption of cooking services. Shankar *et al.* [33] studied clean cooking solutions such as electric induction cooking, LPG, ethanol/methanol, biogas, compressed biomass pellets and briquettes. The study showed that in every programme, substantial stove stacking (concurrent use of multiple cookstoves) practised, which in some way negates the efforts to transition households to cleaner fuel options. It was reported that even with the clean cooking fuel/technology transferred to communities, they still use biomass burning stoves with reasons given as (i) for LPG – recurrent high fuel costs and long distance to travel to refill LPG, and (ii) biogas – not enough fuel to cook meals that take a long time to cook and also household prefer the flavour of foods cooked using wood or charcoal [33]. Corfee-Morlot *et al.* [32] noted that while women are a primary beneficiary of clean energy, they have been under-represented in energy policy leadership and in establishing and promoting related businesses. The authors highlighted the importance of placing women at the centre of decision-making around energy access for cooking (due to the fact that they collect fuel, make the household cooking decisions and have a close understanding of the family's cooking needs), and of proposing solutions that are tailor-made to the needs of the communities in question (*e.g.,* preferences for temperature levels, cooking pot size and shape, different types of cooking and usage habits).

Indeed, multiple studies highlighted that cooking programmes can fall short if they do not take account of social and cultural factors and do not involve women from the outset [25,34,35]. While both men and women are negatively impacted by a lack of access to clean and sustainable forms of energy, social inequalities, economic capability, and gender-defined roles ensure that women are often disproportionally affected by lack of energy access [25].

In parallel, work could be done with this specific section of the end-users (women) to raise awareness of the detrimental health risks caused by traditional cooking practices and the benefits and unfounded safety concerns around alternatives [27]. Issue of acceptance has also been highlighted in a study; unwillingness to take the risk of switching, particularly if there was previous bad experience with low-quality options [36]. This is consistent with the G20 Leaders' recommendation that the energy transition needs to span the power generation and the end-use sectors alike [37] [32] [25]. The billions of hours that continue to be spent each year in the collection of biomass could have been otherwise be spent more productively [25,27,38]. According to the World Bank, the estimated cumulative annual opportunity cost for continuing to use traditional fuels in sub-Saharan Africa is 3% of the region's $32 billion annual gross domestic product due to time lost to fuel collection and slow cooking, household expenditures on inefficient fuels and stoves, and increased health-related costs for households and health care systems [36]. As such and given that 62% of economically active women are working in agriculture (over 90% in countries such as Burkina Faso, Malawi, and Rwanda), improvements in the energy sector are predicted to benefit them the most [39]. Moreover, while clean cooking reduces the risk of illness or death from air pollution and saves time for women, research showed that electricity access also boosts female employment rates and improve education for children – most notably girls; since almost 60% of health facilities in sub-Saharan Africa have no electricity [39] while on average, just 34% of hospitals and 28% of health facilities in sub-Saharan Africa have reliable electricity access [36,40]. The mini-grids that support modern energy cooking services could also power the health sector thereby providing better maternal health services and conditions [25,32].

It is shown that improved biomass cookstoves could reduce cooking time by 34% and ability to reduce firewood usage by 54 % [3]; both the time and firewood use reduction imply saving time in cooking services which could be directed towards productive social-cultural activities for improved wellbeing; for example, freeing up time for women to take up community level or income-generating activities, which in turn can improve gender equality. On the other hand, access to clean energy (with clean cooking in focus) can help to raise millions from poverty and to improve the livelihoods of the rural poor [32] [41]. [41]The authors further report that children have better lights to study during nights and help women with their daily choices – an observation also supported by [42]. Households can also enjoy other benefits of electricity such as better entertainment and communication by using radios, TV, phone charging and computers. Also, Urmee and Harries [28], corroborated by [29], found that SHS help in the facilitation of social gatherings and the ability to undertake activities during evenings that were not possible when using kerosene or benzine supported lighting. It is shown for Asian-Pacific countries that access to electricity for cooking services could facilitate economic activity and provision of a range of essential services such as storage of food and vaccinations and access to information from the use of computers, televisions, radios, and mobile phones [43,44]. It was further highlighted that the use of electronic appliances led to greater access to formal financial services in rural areas [34]. On the other hand, research shows that women perform as well or better than men as entrepreneurs and agents in furthering renewable energy businesses designing and promoting access, such as in the marketing and provision of technical support for clean cookstoves [34,45]. Yet in terms of employment, female employees are a minority in most rural renewable energy enterprises, particularly in managerial and technical positions [46]. However, limited access to capital and limited mobility, as well as sociocultural restrictions, often preclude a larger role for women in many modern renewable energy enterprises [46]. A study shows that potential market and economic disruptions that might result from major shifts in energy policy requires "redeployed, re-trained or compensated, and not left stranded" [47]. [36][39] The OECD *et al.* [47] advanced that the introduction of carbon pricing can have positive socio-economic and cultural impacts on rural communities. Revenues generated from such a system can be used to invest in education, health, clean technology and also contribute to reducing taxes for poorer households. However, there are other complex socio-cultural challenges in transitioning the socio-cultural norms (e.g., gender and kitchen structure) of traditional biomass cooking to cleaner cooking space in order to balance the dichotomy between new entrant and traditional cooking services [48].

3.1.5. Enabling Policies – drivers and barriers to access to clean energy

There are several factors that can either enable or hamper policy development for the adoption and deployment of clean energy technology in rural communities. In this section, the literature reviewed were synthesised for drivers, barriers and opportunities that commonly influence the effectiveness of policy development on the subject of clean energy for cooking in rural communities; followed by a more targeted review of the relevant policy landscapes in Ghana, Nigeria and Fiji, which serve as the case study for the current work. The examined literature suggests that every region faces different challenges for the effective penetration of clean energy technology, especially in rural and remote communities, but there are fundamental challenges that seem to be universal in the Global South context. Therefore, there is a basic understanding of the efforts that would need to be exerted to enable the desired shift. Going forward, the following subsections highlight the synthesis of the literature from the perspective of drivers, barriers and opportunities.

3.1.5.1. Drivers

The examined literature highlighted areas where efforts could be exerted to drive a move towards the use of renewable energy fuels and technologies for clean cooking. These include:

1) **Developing policy frameworks to support the growth of alternative fuel markets and avoid barriers to new entrants** – this could be achieved through: carbon pricing to incentivise private investment in clean energy and streamlining relevant permitting and licensing requirements for mini-grids [25,27,32]; linking subsidies to outcomes; facilitating access to finance; policy advocacy by various stakeholders involved; generating knowledge about public goods by conducting market, business model, and impact research on clean biofuel cooking opportunities (many interventions are relevant to a variety of markets, mainly because most alternative cooking biofuel markets are nascent in Sub-Saharan Africa) [27].
2) An **explicit government endorsement of a shift towards alternative renewable sources as part of holistic energy access policies and targets which include productive uses**. This

should be long-term (to provide certainty to attract foreign investment) and country-specific (taking into account different national circumstances, needs, challenges and priorities, such as domestic energy resources, economic development, energy access and energy demand dynamics), and emphasise on the imperative of energy cost-efficiency and the importance of sustainability for economic growth, boosting human productivity and limiting and managing the economic risk of climate change. Moreover, **national policies** (cross-cutting policies) around energy access, climate, national growth strategies/rural development policies, investment and competition, education and training, anti-corruption, public financial management (including through state-owned enterprises that typically operate national electric utilities) **must be aligned**, alongside the development of shorter-term sector-specific policies that create enabling conditions and target specific outcomes (*e.g.* in relation to clean cooking: emphasis on LPG and the distribution and use of clean cookstoves and fuels) [25,27,32,37].

3) Focusing specifically on rural communities, Energy Access Outlook 2017 [25] highlighted the importance of facilitating rural electricity access by **creating suitable conditions for off-grid investment** and by making provision for subsequent connection of decentralised solutions to the grid, and of **putting women at the centre of the shift to clean cooking**.
4) developing policies to **raise public awareness and training** around the risks posed by current energy practices and the benefits of using clean energy for cooking / shifting public perceptions [25].
5) Support with **capacity building, training of local manufacturers and operators** of technologies that support clean cooking services [25].
6) Ensuring that the transition to clean energy is achieved while **relocating manpower** and preserving jobs and **engaging women and marginalised communities** [32].
7) Developing research and development policies to **provide research grants for international collaboration** to drive technological breakthrough for modern clean cooking services [10,39]. OECD, the World Bank and UN Environment highlighted the essential importance of public research through government research institutes and laboratories. In order to elaborate long-term inclusive and cross-sectoral policies, and in addition to targeting technological progress, public research should explore socio-economic and political aspects that could help deliver systemic changes in production and consumption practices, habits and behaviour or that could influence the acceptance and adoption of new technologies. The report also lays out an agenda to enable societies around the world to undertake the kind of systemic actions that the transformation towards a low-emission, resilient future will require [47].

3.1.5.2. Barriers

Key barriers that are recurring in the published literature on the topic of clean energy access (with special focus on cooking services) could be grouped under the following headings:

1) **Insufficiency of public and private investment in alternative fuels/clean technologies and enabling policies to support it**. This is due to several obstacles/uncertainties that are related to setting the appropriate policy and regulatory environment, technology development, dissemination and deployment, insufficient capacity building,

considerations of regional integration, and coordination and collaboration [49,50]**.** Seven areas of **uncertainties pervading investment decisions** have been identified by UNEP; these focus on the impacts of (a) climate change itself; (b) shifts in the economic and geopolitical features of globalization; (c) the technological intensification and digitization of infrastructure; (d) new economic, business and financing models such as the shared and circular economy and rentalisation; (e) new forms of citizen engagement; (f) changes to the financial system; and (g) economic downturns and external shocks [49]

2) **Barriers holding back the growth of alternative fuel markets**, including poorly calibrated tax and tariff regimes (that make it difficult to import fuel production equipment, biofuel stoves, and fuels) [27]

3) **Fragmented energy policy with no specific institutional arrangement for clean energy cooking services.** Existing energy policies are fragmented without centre coordination and responsibilities, especially for clean cooking services [51]

4) **Inefficient fossil fuel subsidies** (IFFS) that encourage wasteful consumption, distort energy markets, impede investment in clean energy sources, place a strain on public budgets, and incentivise unsustainable infrastructure investments [37]

5) Some **alternative fuels** (*e.g.,* alternative biomass fuels) and the equipment needed to utilise them (*e.g.* stoves) **are not affordable** for most rural communities. This is especially the case for the roughly 50 per cent of households that rely on the free collection of biomass to meet their cooking fuel needs—many are unwilling or unable to pay for clean fuels [27]

6) **Substandard/inferior materials (battery, solar panel etc) in the clean energy space of the Global South**. Substandard materials, induced by the upfront cost of clean energy systems, cause a frequent breakdown of appliances, which discourages potential end-users from adopting clean energy technologies for cooking services [18]. **Progress with respect to clean fuel and stove penetration has been slow** [27]

7) [25] **Cultural reasons** (taste preference, affordability, practices of women selling collected biomass as an additional family income) may entail that even when access to clean fuels/ energy technologies is afforded, many households would continue to use biomass alongside the alternative (referred to as “fuel stacking”)

8) Many sub-Saharan countries are rich in fossil fuels and thus a move to renewable energy presents **economic and political barriers** to action [32]

9) **Misinformation, safety and poor supply chain** are identified as barriers to the adoption of LPG as a transition fuel to support clean cooking services in the Global South Ozoh *et al.* [16]

10) **Lack of universally established feedstock to dispersed location management associated with biomass as a provider of clean energy**. This barrier is identified mainly with biogas cookstove when at the same time huge investment opportunities for small-scale applications like bottling, biogas cookstove and biogas lantern were also identified [17].

3.1.5.3. Opportunities

Developments in trends around energy access have also been identified to highlight potential strengths and weaknesses to which future enabling policies must be sensitive to. These include:

1) A nascent market for briquettes, pellets, and ethanol is quickly growing, with many new entrants and rising interest among donors and investors [27]; this is promising as the G20 Leaders had recommended in 2017 that **energy transitions should rely on a diversification of sustainable and clean energy technologies**, but in particular energy efficiency will play an important role in all our future energy systems. Flexibility options are important elements of delivering reliable, affordable and resilient energy [37]
2) This is reinforced by the fact that the **sub-Saharan region is rich in resources that could potentially be utilised to generate electricity** [49]
3) **The uncertainties surrounding investment decisions which the UNEP identified could be overcome by clustering them into possible futures which would in turn allow the determination of how best to achieve the specific objectives of the rural community in question**. These scenarios offer broad, framing insights that can support effective policymaking, market practice and citizens' action. They also demonstrate how financing climate-compatible infrastructure requires decision-making under conditions of growing complexity and uncertainty [50]
4) **The alternative biomass cooking fuel sector is young and dynamic**, including ambitious start-ups poised to move beyond their pilot phase. Over the next two to three years, some could reach 50,000–100,000 customers [27]
5) **Recent trends in Sub-Saharan Africa and across the world are positive for biofuels and reveal increasing interest from a variety of actors**, including larger enterprises and policymakers. This is supported by a number of developments [27]
6) **Leveraging partnerships and existing market infrastructure to significantly reduce operational costs for biofuels** [27]
7) **The development community has paid increasing attention and made significant investments in clean cooking over the past five years**, leading to growth in clean and efficient stoves sales from 2.6 million units in 2010 to 20.6 million units in 2015 and increase in manufacturers, technological improvements, etc [27]
8) **A number of multinational development banks, regional organisations and bilateral donors are now taking steps to mainstream gender in energy programmes and policy and methodologies and best practices are beginning to emerge.** Moreover, **several initiatives now bring together energy, gender, health and climate with women's empowerment, employment and representation in the energy sector**, including the Global Alliance for Clean Cookstoves, SEforALL, ECOWAS Energy-Gender Policy & Regulation, ENERGIA and the Clean Energy Ministerial. Moreover, good practice indicates that local women should be encouraged to lead initiatives to produce and/or distribute and maintain clean cooking devices and fuels, and to ensure the stoves and programmes are designed to better their conditions [25]; Hosier et al [27] noted that NGOs and women's groups contribute to distributing biofuels beyond middle-class, urban end user

9) **There are significant synergies between policies to address energy access, local air pollution, health and climate change, which underline *the importance of integrating policies and local initiatives* to reduce barriers to improving access to clean cooking** [52]
10) **A number of international development organisations have promoted improved cookstoves as a pathway to clean cooking**, including SEforAll and the Global Alliance for Clean Cookstoves. However, for many remote rural areas where other alternatives are unavailable or unaffordable, improved cookstoves are the only practicable option [25]
11) The G20 Energy Access Action Plan in Sub-Saharan Africa noted that, in many cases in sub-Saharan Africa, electricity tariffs are among the highest in the world and losses in poorly maintained transmission and distribution networks are double the world average. The report further noted that the poor reliability of grid supply has resulted in the **extensive use of costly back-up generators using oil products**. **In light of the inefficiency of the current energy system, this could present a golden opportunity to rely on clean renewable energy technologies instead.** This is further supported by the report stating that by 2040, around 90% of the population projected to be without electricity access in the region are in rural areas. As of 2018, 17% of the sub-Saharan African population had access to clean cooking [1], while in the low-income countries this number is even lower [38]
12) [32][27]**G20** members have also committed themselves to **support renewable energy access in sub-Saharan Africa** (where two thirds of the population live without electricity) **with the recognition that determination of the energy mix of a country is a sovereign decision of the respective governments**, including the usage of all available indigenous renewable and fossil energy resources (depending on the specific circumstances and resource endowment renewable sources of energy may prove to be particularly attractive) [49].

An attempt was made to analyse the current policy landscape in 3 selected countries in the Global South for a better understanding of the policy pathways that could be advanced by governments and international partnering organisations to shift the cooking services from "dirty" to clean energy services. Thus, the overview of the energy policy landscape in Ghana, Nigeria and Fiji is presented below [47].

3.1.5.4. Ghana

Key challenges identified by the Ghanaian Energy Commission [52] in its Strategic National Energy Plan (2006-2020) included the overreliance on wood fuels (creating a risk of deforestation due to projected increase in energy demands), and the lack of initiatives to exploit relatively abundant solar energy. The Ghanaian Ministry of Energy also published the Energy Sector Strategy and Development Plan in 2010 [53]. The Plan highlighted Ghana's development agenda and approached the challenge of increasing the supply of sustainable energy and building energy infrastructure as an integral part of its achievement. It set the target of achieving universal access to modern energy by 2020, while recognising the major challenges of attracting the necessary investment, building local capacities, and implementing policy and regulatory reforms to ensure the sustainable development of the energy sector.

The Ghanaian Government also published its Sustainable Energy For All Action Plan in 2012 [54]. In this document, the Government laid out the context within which Ghana is prioritising the acceleration of sustainable access to clean modern energy for households and productive uses. It recognises the importance of effective and sustained access to energy plays in the provision of services to meet basic human needs including heat, light, cooking and mechanical power. Moreover, the Ghana SE4ALL Country Action Plan [39], which recognises the need for collaboration across government, civil society, research community and the private sector, focuses on two main sources of clean energy/technology - LPG and Improved Cookstoves. It is noteworthy that in 2010, 40.2% of households in Ghana used fuelwood as the main fuel for cooking, 33.7% used charcoal, while only 18.2% used LPG [55] - creating a concern of deforestation for the Ghanaian Government (although the health and socio-cultural impacts are referred to in the SE4ALL Plan, the focus of the shift to LPG is mainly motivated by the concern of deforestation). In line with its National Energy Policy 2010, Ghana had set itself the target of achieving Universal Access to Electricity by the year 2020. It also set goals across various areas of the energy sector, including Renewable Energy, Energy and Gender. It highlighted that its implementation would require the entry into force of new legislation for renewable energy resources development, which has recently been passed. Moreover, the Ghana Renewable Energy Masterplan (REM) [56] took note of global trends and reiterated that the Government of Ghana has identified renewable energy as one of the options that could contribute to the overall energy supply mix and minimise adverse effects on the environment. It noted that renewable energy solutions have been decisive in the capacity of projects implemented in recent years to reduce poverty and improve socio-economic development, particularly, in rural communities. The broad strategic goals set out in the REM focus on building local capacity for the production and operation of renewable energies, as well as the imperative to invest in research and development. The MEP set out 12-year targets to be implemented in three cycles (subject to review): the first (transition phase) running from 2019 to 2020, and the subsequent cycles running from 2021 to 2025 and 2026 and 2030 respectively [39,55,56].

3.1.5.5. Nigeria

Precious Onuvae [51] reviewed the policy landscape around clean cooking in Nigeria and found that there is no standalone policy applicable to the subject. Rather, there are policy guidelines that affect clean cooking in several official documents. Onuvae highlighted the Nigerian Economic Sustainability Plan 2020 (hereinafter 'ESP'), which aims to mitigate the effects of a deep recession following the COVID-19 pandemic while addressing long-standing economic vulnerabilities as envisaged in the Economic Recovery and Growth Plan 2017–2020. Importantly, a cornerstone of the ESP is its focus on the gas (a transition fuel) sector to drive economic recovery and growth. It promotes domestic utilisation of gas by encouraging local manufacturing to support a transition towards LPG. More specifically, the ESP provided for an "LPG Expansion Programme" which was built on the National Gas Policy of 2017 and labelled as one of the "7 Big Wins" of the gas sector developed by the Ministry of Petroleum Resources and the Economic Recovery and Growth Plan. The Programme to "

Other relevant policy documents include (1) the National Energy Policy (2018), which focused on the efficient use of energy resources to ensure a sustainable national development engaging the private sector, and placed an emphasis on relying on efficient biomass cookstoves and other fuels and technologies for cooking, but failed to set clear targets or plans to achieve its aims; (2) the National Biofuel Policy (2007), which set a target for the Government to create an enabling environment for the achievement of 100% domestic production of biofuels consumed in Nigeria by 2020, and focused on expanding private-sector investments in the domestic production of biofuels to achieve this; (3) several policy documents aiming to encourage the use of renewable energy in cooking, including the Renewable Energy Master Plan (REMP) (2004 and 2012),which set targets for the use of renewables, especially clean biomass technologies for cooking, the national Sustainable Energy for All (SE4ALL) Action Agenda (2016),which pledges Nigeria's commitment to global sustainable development, the National Renewable Energy Action Plan (NREAP) (2016), the National Energy Efficiency Action Plan, *etc.* The NREAP aims to rely on providing improved cookstoves, efficient charcoal production and modern fuel alternatives for cooking including LPG and ethanol gel fuel to achieve its target of ensuring 100% clean-cooking-fuel coverage by 2030 without laying out concrete plans to achieve this.

In parallel, Onuvae [51] noted the ambitions of donors, seeking to pilot institutional cooking to drive policy development, raising doubts around the Nigerian Government's ownership of the issue and the sustainability and implementation of public-sector initiatives on clean cooking. She cited initiatives by USAID to build technical capacity and support the development of institutional-cooking policies in some states, the German GIZ/Nigerian Energy Support Programme's Clean Cooking Intervention 2015–2017 and the present Nigeria Institutional Cookstove Acceleration Scheme which attempted to raise awareness of the importance of productive uses of clean cooking, as examples. Nevertheless, she conceded that, in practice, the impacts of such initiatives have historically been disappointingly limited. Onuvae [51] also provided an insight into Nigeria's energy policies prior to the new emphasis on LPG. She advanced that since the 1970s, successive Nigerian Governments had centred much of the cooking-energy policies on the supply of kerosene, offering generous subsidies for it, alongside gasoline and diesel [51].

3.1.5.6. Fiji

The policy landscape of Fiji is supportive of the use of renewable energy use and the promotion of energy efficiency measures in different sectors of Fiji. Promotion of renewable energy or alternative fuels and efficiency in electricity generation and transport sector has been prioritized in national energy policies. For instance, the 2006 national energy policy (NEP) of Fiji aimed to (i) strengthen the capacity for energy planning through appropriate policy, regulatory and implementation frameworks and effective and efficient management; (ii) enhance energy security through greater participation and collaboration within the industry; (iii) increase access to affordable and reliable electricity services; and (iv) research, promote, and utilize renewable energy applications [81]. The policy landscape for cooking is not robust; only acknowledged 50% of households use wood fuels. The 2006 NEP strategy recognised the use of agricultural waste as feedstocks for bio-fuel production.

The 2006 NEP got reviewed in 2013 and a 2013 draft NEP was developed. The 2013 draft NEP of Fiji has its targets aligned with the Sustainable Energy for All (SE4ALL) initiative of the United Nations. It targets (i) 100% of the population have electricity access and 0% of the population relying primarily on wood fuels for cooking by 2030, (ii) improved energy efficiency by reducing the energy intensity to 0.077 litres of fuel consumption per unit of GDP and reducing energy consumption to 0.209 kWh per unit of GDP by 2030, (iii) 100% electricity generation using renewable energy sources and 23 % renewable energy share in total energy consumption by 2030 [82]. The draft 2013 NEP has been used by ministries for planning their activities and now Fiji's NEP is currently being reviewed and a new NEP is being drafted in 2021. The focus areas in the new 2021 NEP are (i) renewable energy and grid power supply, (ii) energy efficiency, (iii) energy access and (iv) transport, with due recognition of clean cooking fuel and technology access.

Apart from the NEP, there are other strategic planning documents that support the clean energy transition in Fiji. Fiji's Green Growth Framework (GGF) is a strategic planning document that provides plans for cooking fuels and technologies. It mentions that because of high dependence on open fire cook stoves in rural areas, women's health is adversely affected, and so modern energy sources for cooking should be introduced [57]. In its short-term action plan, the GGF plans to promote public education on energy-efficient technologies, especially in cooking. Fiji's Sustainable Energy for All (SE4All): Rapid Assessment and Gap Analysis report identifies rural areas using wood for cooking because of affordability issues and supply chain gaps for modern fuels [58]. It suggests exploring the use of biogas digestors as around 20 digestors have already been installed by Fiji Department of Energy. Also, it recommends introducing the use of improved cook stoves in a medium term timeline as there are no such programs exists currently. It further recommends the use of modern fuels such as LPG, kerosene and electricity [58]. However, it should be noted that kerosene is a polluting fuel and should not be encouraged to be used. Fiji's National Development Plan aims to provide electricity access to 100% of its population by 2021, generate 100% of electricity using renewable resources by 2036 and eliminate all wood consumption for cooking by 2036 [59]. The more recent Fiji's Low Emission Development Strategy is targeting net zero emissions by 2050 and phases out open fire stoves and wood stoves by 2030 that will be replaced by LPG and electric stoves [60]. In terms of fiscal incentives and policies, Fiji has zero import duty on the import of renewable energy and energy efficiency equipment and provides a 5-year tax holiday to investors who invest in clean energy projects.

3.1.6. Business model review

The development of a proper business model would be crucial in order to be able to propose solutions accessible and affordable for end-users. Additionally, it could create a market for suppliers/manufacturers, interested in the field.

There is a wide variation in the energy needs between the rich and the poor. However, both the rich and the poor primarily need energy for cooking and lighting. It is the more reason the SDG7 promotes universal access to affordable, reliable, and modern energy. Unfortunately, the poor who are often in rural communities are disadvantaged in energy access. IEA *et al.* [1]

observed that more than 73% of indigenous people in the rural African communities do not have access to electricity and the numbers are even higher in terms of clean energy access.

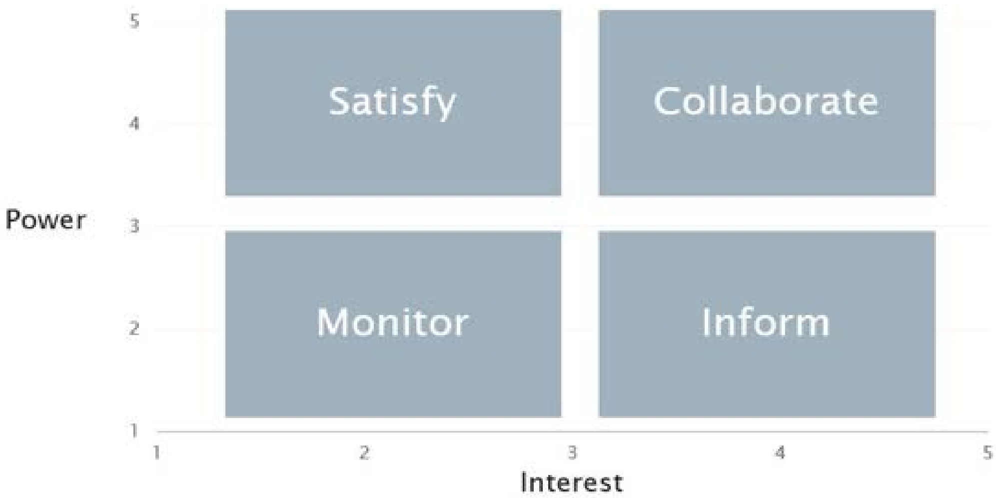
The lack of energy and most importantly clean energy technology access in rural communities has been attributed to several factors spanning from policy, development to financing. Yannick Glemarec [61] content that financing is a key challenge to the uptake of clean energy technologies in rural communities. In a related study, Bensch *et al.* [62] reviewed the supply chain for clean energy access in Kenya and report that inappropriate business models are hindering clean energy penetration in rural communities. In the view of Glemarec [61], the uptake and sustainability of clean energy technology by rural communities hinges on the economic viability of the business model. Hence, developing an appropriate business model for clean energy uptake is as important as developing the technology itself.

Currently, there is no universally accepted business model for clean energy technology uptake. A review of the literature in this field shows pockets of business models which are contented. This justifies the need for the present study to consolidate the findings in the existing literature and attempt to offer alternative business solutions to promote clean energy access in rural communities. The existing business models can be grouped into three main headlines: incentive-driven [63,64], government-driven [63,65] and private-sector-driven [61,62,66]. The proponents of the incentive-driven models are of the view that rural communities do not have the financial capacity to uptake clean energy; therefore, NGOs, international and local governments should offer incentives, grants, subsidies, tax-wavers, and other free packages to these vulnerable communities. This is a typical pro-poor policy and sustainability depends on how long the freebies will continue to be available. On the other, the government-driven business model places the responsibility of the clean energy uptake on both the central government and the rural communities. The government, however, is the main driver in this model. The central government provides the initial resources requirement, and the communities are made responsible for maintaining the technology. The government-driven model is the most used approach in rural communities in the global south [65]. The sustainability of this model is a challenge because the communities are often unable to maintain the technology due to the financial implications [61]. Moreover, the private-sector-driven is more profit-oriented. It involves private energy entrepreneurs developing clean technology and using various methods to sell the technology to rural communities. Although, this approach serves as a relief to the already financially constrained governments' budget; it is often expensive to the rural communities who live below the poverty line. To ensure the uptake and sustainability of clean energy technology by rural communities, this study analyses the clean energy value chain and recommend a blended approach of the three traditional business models suggested in the literature.

3.2. Stakeholder Analysis and Engagement Framework

The project team a six-step approach to stakeholder analysis, which was relied upon to determine the communication method and approach of engagement with different groups. The framework consisted of:

- Steps 1 and 2: Define the list of stakeholder groups and their potential stakes in the project (please refer to the Stakeholder engagement strategy table, paragraph 8.2 below). This step allowed the team to think of a logical and useful categorisation of potential stakeholders that would have differing interests in the project outcomes.
- Step 3: Identify specific individuals under each category and their specific interest in the project. In this step, the project team developed a table of individuals with their respective contact details, affiliations, specific interests in the project, and included sections to monitor the progress in our engagements with each. The list included 40+ names, but the table will not be shared for GDPR reasons.
- Step 4: Stakeholder assessment - employing a system for “rating”/ “ranking” (1 to 5) of stakeholders according to their relative importance to the project. This was performed in function of (1) Power - the influence which a stakeholder/group may have to implement the research outcomes; and (2) interest - a combination of (a) the level of importance which the specific stakeholder/group give to the work and its outcomes and of (b) how prepared they are to act to achieve them. This was performed in order to determine the appropriate communication method to be employed with different stakeholders as per this table:



Our assessment was transposed to a table for organisation purposes. For GDPR reasons, that table will not be shared.

- Step 5: Attribute communication method based on stakeholder ranking in accordance with the following figure:

- Step 6: Develop a communication management plan in accordance with the communication method adopted for respective stakeholders. Ultimately, the project team relied on the use of questionnaires, bilateral meetings, telephone conversations, and is planning to collaborate with a group of stakeholders during a workshop at the end of November 2021. Moreover, communication methods include the dissemination of a policy brief, a one-page summary with infographics, and a short promotional video. These will be used with respective stakeholder groups identified following the aforementioned steps.

3.3. Stakeholder Consultation Outcomes (if applicable)

In order to ensure that the solutions put forward by the SENSouth project are appropriate, desirable and viable, to a reasonable degree, the project team formulated three online questionnaires designed to capture insights from the three categories of key stakeholders: (i) End-users, (ii) Suppliers and (iii) Interest groups; given their distinctive and complementary interests in clean energy access for cooking in rural communities in Fiji, Ghana and Nigeria. This data collection may be constrained by social science nuances, which are important in balancing the dichotomy of new entrant and traditional cooking services; however, the current approach is sufficient for a first approximation analysis. The end-users are defined as the people in rural communities who are using fuels and technologies for cooking. Their interest in shifting towards clean cooking fuels and technologies is envisioned to improve health and living conditions, empower women, educate children, and provide reliable and safe energy access. The suppliers are the stakeholders who supply fuel and clean cooking technologies to the rural communities such as government departments/ministries, public authorities, energy service companies, financial institutions, clean fuel suppliers, etc. Finally, interest groups are defined as organisations (non-government organisations, community-based organisations, women groups, etc.) who have an interest in climate action, gender equality, reducing poverty, and health and safety. Based on these definitions, the stakeholders the team had identified as part of its stakeholder mapping and analysis exercise (Activity 2) were categorised into the three groups. The contact details of stakeholders were either known to the project team members and when not known, then common liaison persons were contacted to obtain contacts. In Fiji's case, some initial virtual meetings were done with the regional organisation where some key stakeholder names were given and who were later contacted.

The questions for each stakeholder group were drafted and vetted in team meetings. It was later transferred to an online form for each of the three categories of stakeholders. Microsoft Forms was used to create the online versions of the questionnaires, which were shared electronically on 10 September 2021. The recipients were given two weeks to complete the online survey.

One of the major challenges for the online questionnaire was getting responses from end-users in Fiji. Because the study focuses on rural communities, the internet availability in rural areas is very poor, people have limited internet data and rural communities do not have email addresses. In addition, with the COVID pandemic and time constraints for project output, the team could not conduct face-to-face interviews in households. In Fiji, two students who live in a rural community helped gather data and information on the online survey for end-users. Further, because there is not much published literature on cooking fuels in Fiji, zoom meetings on a one-to-one basis were carried out with key stakeholders.

The responses received allow the team to conduct a comparative study across the three countries examined, highlighting commonalities and differences in their respective landscapes, and to broadly identify alignments and/or potential conflicts of interest amongst the three categories which might drive and/or hinder attempts to elaborate or implement solutions around the issue of clean energy access for cooking. As of 27 September 2021, the team received 18 responses from energy suppliers, 23 responses from end-users, and 12 responses from interest groups. The following is a comparative presentation of those responses:

3.3.1. Energy suppliers

Out of the total of 18 responses received from stakeholders involved in the energy supply sector, 10 came from stakeholders based in Fiji, 6 from stakeholders based in Ghana, and 2 were received from individuals working in international/regional organisations.

- The respondents quasi-unanimously thought that a shift towards clean energy access for cooking in rural communities in their respective countries is of utmost importance. (14 out of 18 responses indicating the “highest” levels of importance, and the remaining 4 indicating “very high” levels) – Rating (4.8/5).

- In terms of which technologies/fuels could be more readily implemented to supply cooking energy for rural communities, improved cookstoves and solar/electricity power generation were perceived by 35% of the respondents as most readily available, whereas 23.5% of the respondents opted for biogas, and nearly 6% for LPG (see Fig. 1 below). On a more granular level, responses revealed a clear lack of homogeneity in what suppliers perceived as solutions that could be relied upon to afford clean energy access for cooking in rural communities in the near future: 3 respondents from Fiji indicated that improved cookstoves could be most readily implemented to, whereas 2 respondents from the same country considered this to be the least readily available technology; 3 other respondents from Fiji considered solar/electricity as most readily available, whereas 3 respondents from the same country considered this to be the least readily available; 3 other respondents from Fiji considered biogas as most readily available, whereas 2 respondents from the same country considered this to be the least readily available. Responses from Ghanaian stakeholders showed a similar lack of harmony across the sector. This is reflective of a lack of prioritisation and certainty due to the inexistence and/or inadequacy of current policies in the examined countries, and a reliance instead on open/unregulated markets for energy/technology production.

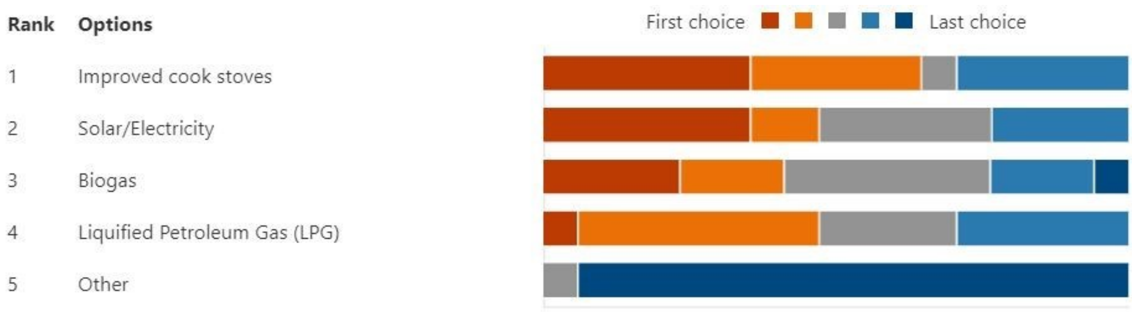


Fig. 1.

- In terms of key cost factors of shifting towards cleaner technologies/fuels for cooking in rural communities, the respondents' first choices were split as follow: production costs (39%); transport/distribution costs (17%); other costs, including capacity building and purchasing power/financing (17%); importation costs (11%); safety measures (11%) and marketing (5.5%). Examined individually, a lack of consistency similar to the one in relation to the most readily available technologies/fuels is noted in the responses provided with regards to each of the cost factors, as reflected in Fig. 2 below. Moreover, a more focused look at responses from each country reveals inconsistencies within them.

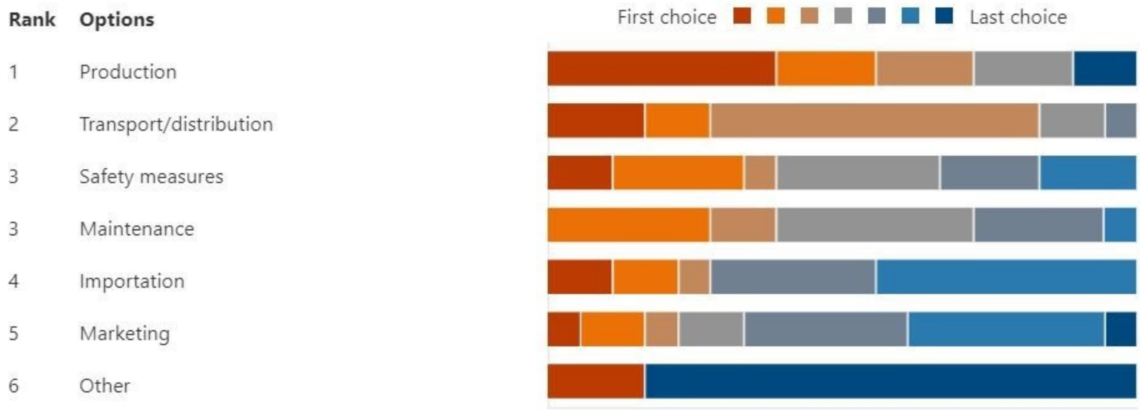


Fig. 2.

- Answering a question around the most important potential benefits for shifting towards cleaner fuels/technologies for cooking in rural communities, 47% of the respondents indicated improved health and conditions of rural communities; 47% indicated reduced costs for end-users, whereas 6% thought the most important benefit to consist of meeting energy and environmental policy targets (Fig. 3 below). Interestingly, 78% of respondents from Fiji indicated perceived reduced costs as the most important potential benefit, while 22% thought it would be the improved health and conditions of rural communities. On the other hand, 83% of respondents from Ghana thought the biggest benefit was the improved health conditions, while 17% thought it would be the meeting of set energy and environmental policy targets.

Fig. 3.

- Focusing on *technologies* for clean cooking, the suppliers also rated the readiness levels for their employment in rural communities, using a 1-5 rating system where 1 is the lowest and 5 is the highest levels of readiness. On average, a rating of 3.11 was given by the respondents. However, upon deeper examination, strong discrepancies are noted as 16.7% provided a rating of 5, 22.2% a rating of 4, 22.2% a rating of 3, 33.3% a rating of 2, and 5.6% a rating of 1. No notable patterns are detectable in the answers provided by stakeholders respectively based in Fiji and Ghana.

- Asked about whether the shift towards cleaner energy technologies for cooking in rural communities is supported by existing national/local policies in their respective countries, the majority of the respondents (61%) answered in the affirmative, only 5.5% answered “no”, while 33.3% of the respondents indicated that the existing policies somewhat support such transition (see Fig. 4).

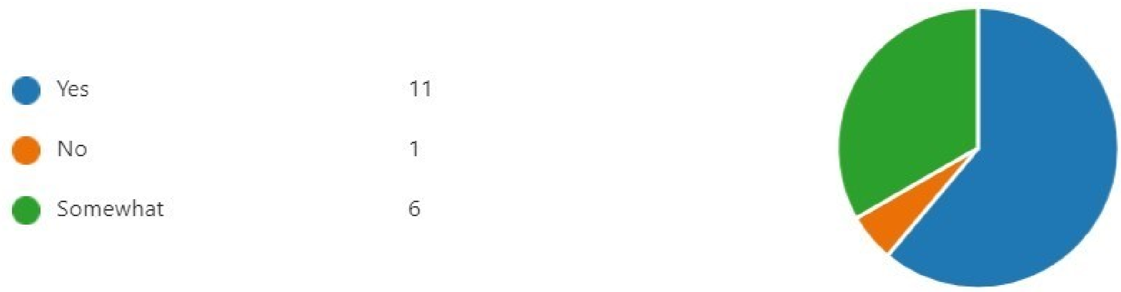


Fig. 4.

- Asked about how suppliers ensure the longevity of an implemented clean energy project/program, the respondents’ answers highlighted the importance of, *inter alia*, monitoring/maintenance, the regulation and enforcement of manufacturing standards, price reductions/accessibility for end-users, and a wider sustainability culture behind the sector.

- Asked about their perceptions of the current market for clean/alternative fuels for clean cooking in rural communities in their jurisdiction, 67% of the respondents described it as at an “infant stage”, 28% thought the market is at an “intermediate stage”, while only 5.5% thought the market is at an advanced stage (as per Fig. 5 below).

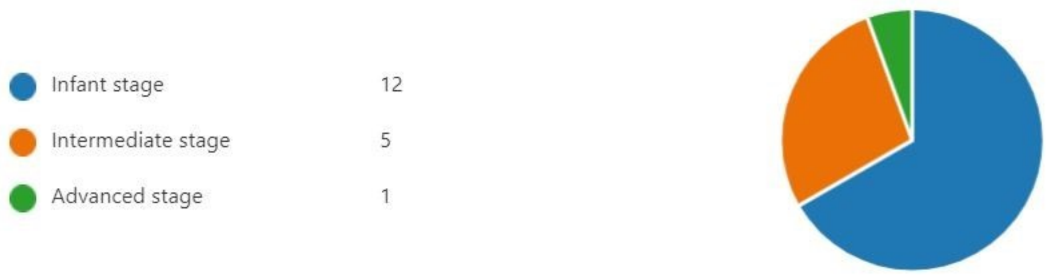


Fig. 5.

- In terms of the readiness levels of the current distribution/delivery infrastructure necessary for shifting towards such fuels, 50% of the respondents thought it is underdeveloped, 44.5% thought it is at an intermediate stage, and 5.5% thought it is at an advanced stage (Fig. 6).

Fig. 6.

- Asked about their perceptions of the demand for clean fuels/technologies in rural communities, the respondents provided an average rating of 2.94/5 (1 being the lowest and 5 being the highest). A country-specific examination reveals an average of 3.5 for Fiji and 2.2 for Ghana.

- Focusing on the differing needs of urban and rural communities, the respondents highlighted varying factors influencing end-user behaviours. These include lower income levels and less energy options for rural communities, a higher awareness in urban communities of the availability of alternative energy options, and lower accessibility to such options for rural communities.

- Asked about whether technologies/fuels supplied by them are locally sssmanufactured/produced or imported, 61% of the respondents indicated that these are imported, 16.7% indicated that they are locally manufactured, and 22.2% indicated that a combination of both approaches is applicable.

- In terms of what respondents perceived as their major concerns when making investment decisions to shift towards clean energy access for rural communities, answers included end-users' purchasing capacity, health and safety, the sustainability and longevity of the projects and building local capacities/transferring knowledge to local folks.

3.3.2. End-users

Out of the total of 23 responses received from stakeholders involved in the energy supply sector, 13 came from stakeholders based in Fiji, 6 from stakeholders based in Ghana, and 4 from stakeholders based in Nigeria.

- On average, the households of the respondents based on Fiji consisted of 5.3 members, compared to 7.1 for those based in Ghana and 5.5 for those based in Nigeria.

- In terms of hours spent per household/day, responses varied between 1h and 7h/day, without any clear distinctions between the countries examined. Some respondents in Fiji indicated their reliance on a combination of fuels/technologies for cooking.

- Asked about the fuels used for cooking in their households, LPG, biomass or wood, kerosene appeared to be overwhelmingly relied on, in comparison to electricity/solar. Two respondents from Fiji indicated that they rely on coal (see Fig. 7).

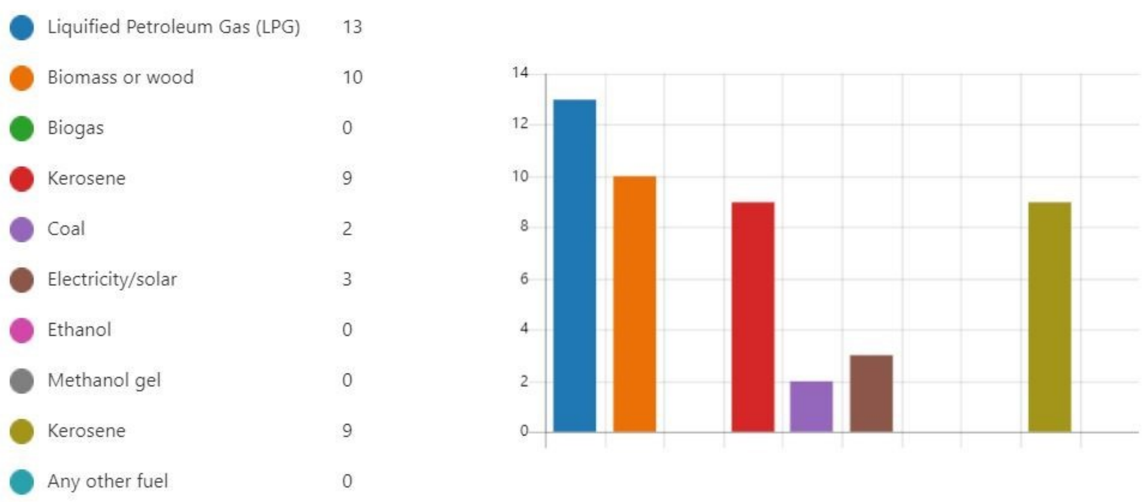


Fig. 7.

- Asked about the cooking appliances and/or technologies currently used for cooking in their households, respondents showed an overwhelming reliance on LPG cookstoves, closely followed by open fire cookstoves and kerosene cookstoves (Fig. 8).

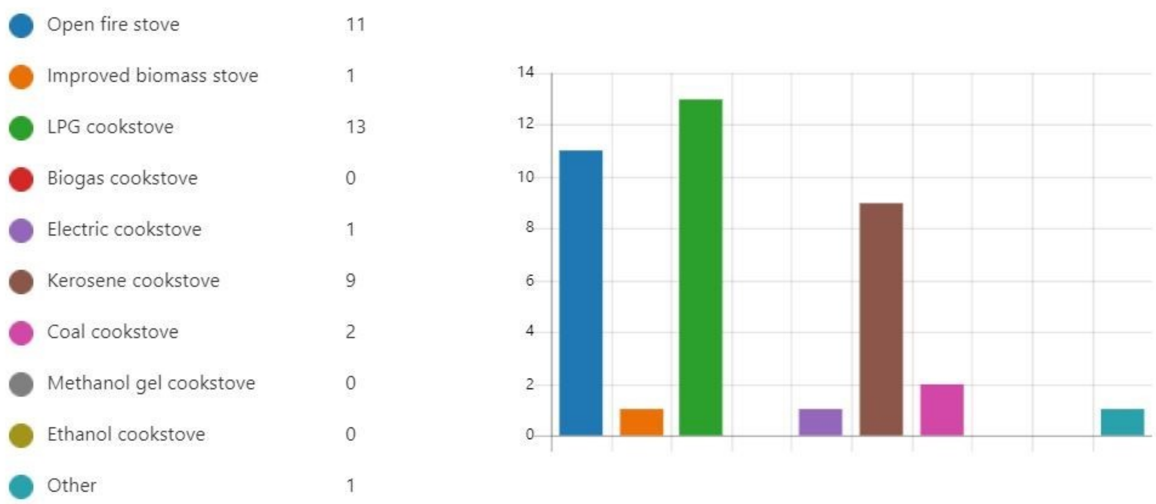


Fig. 8.

- Respondents also overwhelmingly (96%) indicated that they only rely on one cooking technology in a day. This could reflect preferred cooking preference techniques in their households.

- Asked about their perception of how important it would be to shift towards cleaner fuels for cooking, respondents provided an overall rating of 4.35/5 (1 being least important and 5 being most important). The average rating being 3.7 for respondents in Fiji, nearly 5 for those in Ghana and 5 for those in Nigeria.

- Asked about which alternative cookstove would receive the highest level of acceptance in their respective communities, respondents from Ghana and Nigeria split between biogas, LPG and electric cookstoves, while only 2 respondents based in Fiji indicated for electric and LPG cookstoves (Fig. 9). Respondents in Fiji mainly preferred using open wood fire and kerosene stoves, and their preference was mainly driven by its **affordability**. Cost effectiveness, ease of use/reliability and environmental friendliness were amongst the motives for the answers.

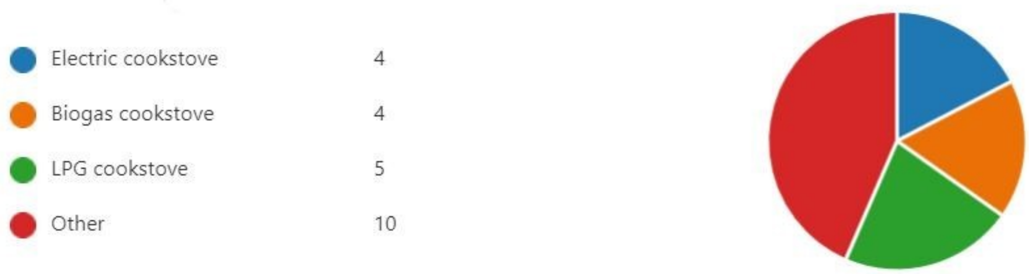


Fig. 9.

- In response to a question around how a shift towards cleaner technologies/fuels might disrupt daily routines and cooking patterns, answers varied but provided valuable insights. Most comments were positive as respondents saw a shift as presenting advantages including saving time from collecting wood, freeing up more time for other chores and studies. On the other hand, some answers highlighted that such a shift would lead to increasing costs for cooking and undesirable cooking outcomes.

- Asked more specifically about the time gained from using alternative fuels could benefit women and children in their community, 38% of the respondents thought a shift would free-up time for education, 27% thought it would support women empowerment, and 23% saw a value in increased social and community activities, while only 10% thought the time gained would be used for recreational activities (Fig. 10).

Fig. 10.

- Lastly, the participants were asked to share their thoughts on what they perceived to be the main barrier for shifting towards cleaner energy access for cooking in their community. 56.5% of the responses indicated maintenance costs as the main barrier, followed by set-up costs (17.5%) and refuelling costs and the underdevelopment or inadequacy of current energy markets (13% each). Nearly 74% of the respondents indicated refuelling costs as the second most important barrier for transitioning towards clean fuels (Fig. 11).

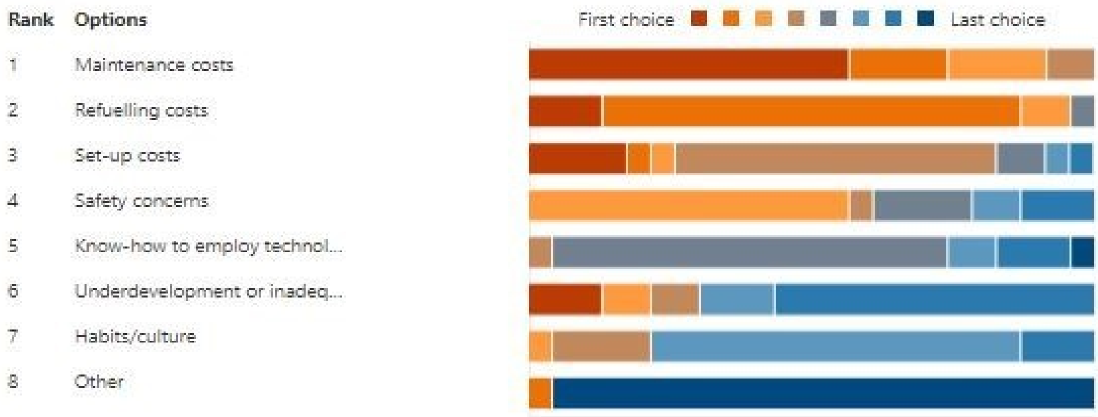


Fig. 11.

3.3.3. Interest groups

Out of the total of 12 responses received from stakeholders involved in the energy supply sector, 6 came from stakeholders based in Fiji and 6 from stakeholders based in Ghana. The stakeholders' affiliated organisations included research institutions, healthcare clinics, governmental departments, social groups/charities and NGOs.

- In response to a question around the main barriers impeding a shift towards cleaner energy access for cooking in rural communities, 33% of the respondents thought end-user behaviours/response to new fuels/technologies constitutes the biggest hurdle, followed by 25% that it is rather due to lack of investment and 25% considering that it is due to the unavailability of technologies/energy sources. Only 8.3% of the respondents considered the inadequacy of existing policy frameworks as the main barrier for such transition (Fig. 12)

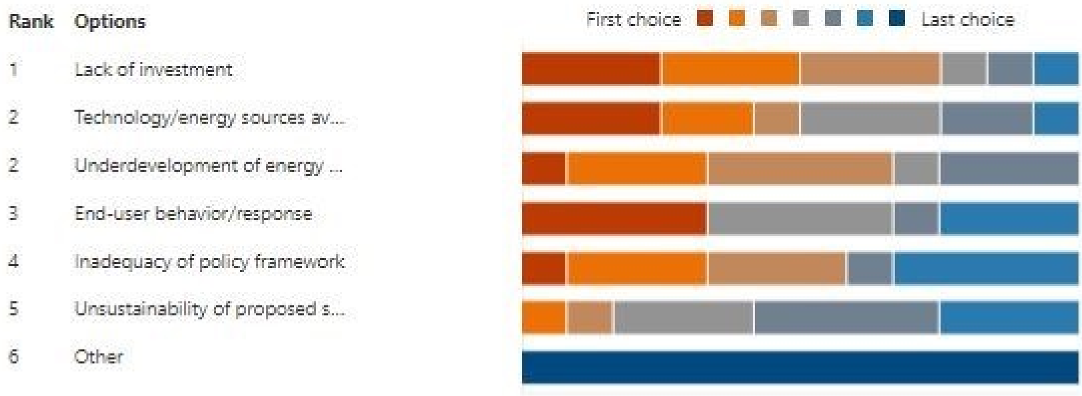


Fig. 12.

- Asked about initiatives they have been involved in to realise this energy transition, respondents' answers included efforts for educating rural folks, the planning for the construction of biogas plants (which was not implemented), and international collaborative projects to reduce carbon emissions.

- Unsurprisingly, when asked to rate the success levels of the aforesaid initiatives, the average rating was 2.73/5 (1 being the lowest, and 5 being the highest). The BMZ project which consisted of the construction of low carbon emission cooking stoves and solar cooker in Vanua Balavu and resulted from the collaboration of ADRA Germany and ADRA Fiji received the highest rating of 4/5.

- Asked about what they perceive the main reasons for the failures of these initiatives, answers included the lack of funding, lack of awareness of the effects of current/alternative cooking practices, lack of policy and market infrastructures, setting-up/maintenance costs, lack of education/knowledge from end-users in terms of employing new technologies, and the necessity to import materials.

- Asked about what they would perceive to be the main drivers for the prospective success of these initiatives, answers included foreign or local investment, political affiliations, the scarcity of current fuels (firewood), projects being led by international organisations (NGOs), and the availability of materials/technologies.

- Asked about their practices to ensure the longevity of projects, the respondents predominately answered that they do this by implementing monitoring/supervision and maintenance practices. Two respondents highlighted the importance of capacity building and training, and one respondent highlighted the value of partnerships for projects to have more influence.

- Asked about their perceptions of the level of awareness around the health and social impacts of current cooking practices in the countries examined, the respondents' average rating was 2.25/5 (1 being the lowest and 5 being the highest).

- Asked about how they would rate the level of awareness around the implications of current cooking practices on climate change, the respondents' average rating was 2.33 (1 being the lowest and 5 being the highest).

- Asked about how they would rate the level of awareness around the benefits of shifting towards cleaner fuels for cooking, the respondents' average rating was 2.75 (1 being the lowest and 5 being the highest). The average rating from respondents based in Fiji was 3, whereas that from respondents based in Ghana was 2.5.

- Asked to rank the main benefits of implementing this shift towards cleaner energy access, the responses were even as 25% of the respondents chose improved health for rural communities, more reliable energy access, climate change mitigation, and economic benefits as the most important benefits (Fig. 13.)

Fig. 13.

4. SYNTHESIS OF THE FINDINGS

4.1. Introduction

The International Energy Agency (IEA) is one of the leading agencies in assessing and analysing energy access data for individual countries, provides electricity and clean cooking access (SDG7.1) data for countries and provides progress of countries towards SDG target 7.2 (renewable energy) and SDG7.3 (energy efficiency). This current study adopts the definition of clean cooking fuel and technology advanced by the World Health Organization (WHO) as stated in the literature review. These are categorised into 3 levels – clean, transitional and polluting; solar, electric, biogas, natural gas, liquefied petroleum gas (LPG), and alcohol fuels including ethanol are considered to be clean cooking fuels and technologies. Accordingly, clean cooking technologies and fuels, such as solar, electric, biogas, liquified petroleum gas (LPG) and alcohol fuels, limit indoor household emission. This study focuses on clean cooking fuel and technology access in rural communities in three countries: Fiji, Ghana and Nigeria. The data on clean energy access is shown in Table 1. Fiji is an island nation in the South Pacific region with a population of less than a million while Nigeria and Ghana are developing nations in West Africa with respective populations of around 196 and 30 million. Land area and Current Gross Domestic Product (GDP) in the 3 countries varies starkly with Fiji having the least GDP and Nigeria the highest.

Table 1: Key characteristics of the 3 countries under study [1, 2, 67]

		Nigeria	Ghana	Fiji*
Population in 2018 (millions)		195.90	29.80	0.89
GDP in 2018 (billion USD)		397.19	65.32	5.58
Land area (km^2)		910,770	227,540	18,270
Population density (people/km^2)		215.00	131.00	48.40
Proportion of the population with access to clean cooking	2000	<5.00%	5.90%	n.a
	2005	<5.00%	9.40%	n.a
	2010	<5.00%	14.00%	38.00%
	2015	5.40%	20.40%	n.a
	2018	9.20%	24.90%	56.00%
Population without access (millions)	2018	177.90	22.10	0.39
Population relying on traditional use of biomass (millions)	2018	142.30	22.00	0.17

* Data for Fiji was not available at IEA, hence data was sought from (FBoS, 2018).

4.1.1. Current cooking fuels and Technologies

This section discusses the current cooking fuels and technologies used in Fiji, Nigeria and Ghana. The data were sought from the Bureau of Statistics of the respective countries. For Fiji's case, details of the different technologies and fuels used were obtained during stakeholder engagement as there is not much published literature.

4.1.1.1. Fiji

Fig. 14 shows that in the past decade, cooking fuel usage in households has changed significantly. Compared to 2007 census data, in 2017 LPG usage had increased from 28% to 38% of households while woodstoves and open fire stoves have reduced from 42% to 21%. In addition, it is seen more households are using electric stoves for cooking with the share increasing from 4% in 2007 to 15% in 2017.

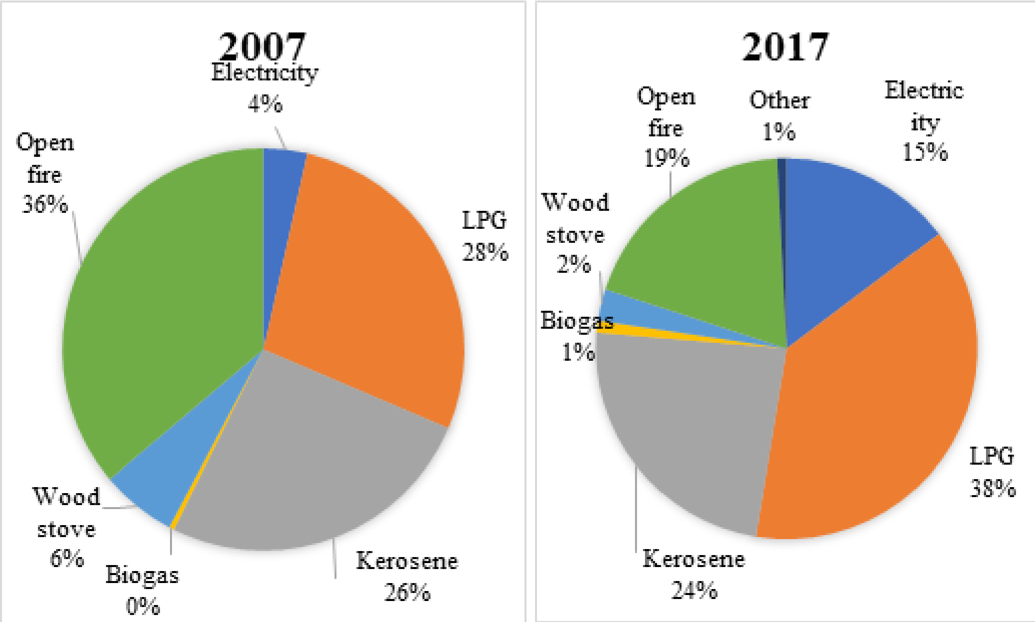


Fig. 14. Cooking fuels in total households in Fiji for 2007 and 2017 [2,68].

From 2017 census data, 57% of the total households in Fiji use clean cooking fuels while in 2007 it was just 38%. One of the reasons could be due to reduction in LPG prices and improvement in the social status of households there is increased use of LPG and electric stoves in 2017 compared to 2007.

However, there is a disparity between rural and urban households. In 2017, Fig. 15 clearly shows that 63% of rural households are using open firewood stoves and kerosene stoves while 28% of urban households use open firewood stoves and kerosene.

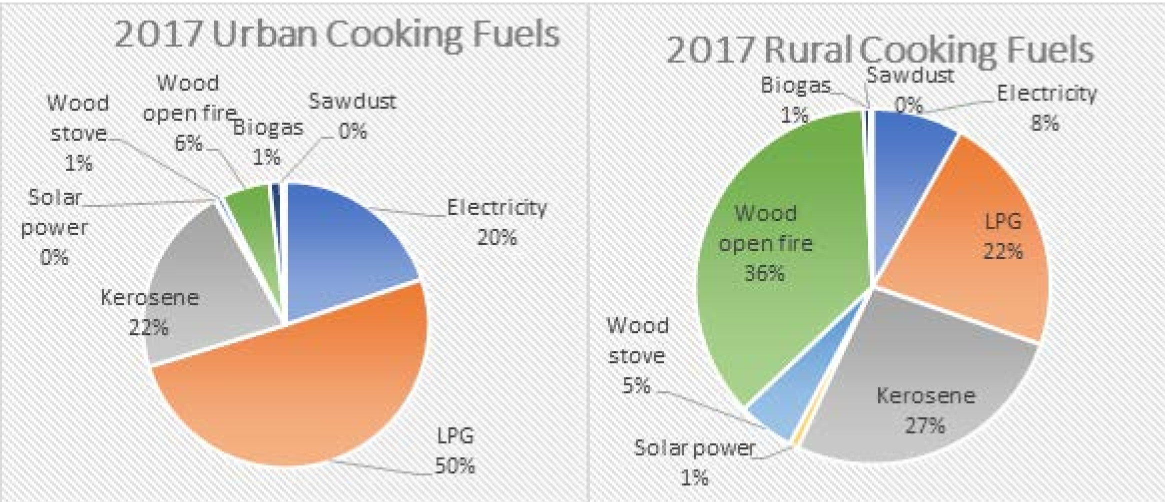


Fig. 15. Cooking fuels in rural and urban areas of Fiji in 2017 [2].

The SDG goal is to move away from kerosene stoves or the use of open fire. Hence, several measures are being undertaken by many organizations and institutions in Fiji. From the stakeholder engagement, the Fiji Department of Energy has been installing fixed dome concrete biogas digesters over the past decade, funded by the Government of Fiji. From 2009 to 2012, there was a total of 14 biogas digesters installed in Fiji. Out of this, 10 are operational, of size 111 m^3 to date. The main reason for biogas digesters not operating are discontinuous supply of feedstock or digesters were not maintained properly.

From the stakeholder engagement, the Ministry of Agriculture (MoA) has also rolled out a biogas project to control the waste from farms and the project has annual funding of FJ$100,000 to import biogas digestors from Israel and implement these on farms. In addition to this, the Government of Israel is giving extra 10 units free of charge (FoC). These systems have 10-15 years of warrantee given. The MoA staff are trained to install these digestors on farms. A total of around 34-35 digestors have been installed on farms around Fiji. It is a partnership work between the MoA and the households/farm. MoA supplies the main equipment and installs the system, and the role of the household is to clear the site for installation, build a base for the digestor to be placed upon and have a protective shelter around the digestor so that outsiders do not vandalise the system. There has been a lot of positive feedback from farmers that have already installed the digestors. Using biogas means that women and children do not have to go and cut trees and mangroves for firewood. Hence, the flora and fauna are protected. The slurry from the digestor is also used as manure that contributes to organic farming. The biogas produced on farms are used for cooking and some systems have lighting systems as well. In addition, MoA is receiving a lot of expression of interest from farmers – there are 4000 pig farms around the country and 300 dairy farms. These farms send EOI to the ministry but due to limited funding, only a few numbers of digestors are installed every year.

Similarly, from stakeholder engagement with suppliers in Fiji, a private company has started the home biogas business since 2017. Their main focus is on agriculture and organic practices, and this is where they found out about the biogas technology to be very beneficial from waste management, creating clean energy and liquid fertilizer which is an extra plus point that farmer can use in their crops. They are selling and installing inflatable biogas digestors to homes in Fiji and in the Pacific. To date, they have sold around 100 units in Fiji but installed only 60-70 installed because of COVID-19 restrictions and sold around 300 to the pacific island partners. They have partnered with a retail company in Fiji so that homes are able to purchase the system on hire purchase instead of buying cash. The private company also have inhouse lay-buy options for their customers.

Improved cook stoves (ICS) powered by biomass feedstock initiative was first started by Ministry of Women and Poverty Alleviation in 2014. They had run a pilot programme (Rocket stove) and then applied for India Brazil and South Africa (IBSA) funding. Funding was approved but it was disseminated through the UN office. So, the small grants programme at UNDP was approached to facilitate. UNDP's role was to make sure that funds get to those who were implementing. Four NGOs were selected by putting out a call. The NGOs were required to (i) carry out awareness with the communities they are going to work with – mitigation action and awareness on rocket stove (ii) increase efficacy of cooking with reduced cooking time and less firewood or fuelwood requirement – this translates to less trees being cut, improve livelihoods of women, (iii) replant woodlots in areas identified in communities – this because it was found from their background work that women have to now go further to get firewood for household cooking and (iv) fabricate and distribute the ICS and also train the communities on fabrication.

Some of the outputs of the "Rocket Stove" project are [69]:

- 56 communities in 10 provinces were assisted (traditional villages and informal settlements)
- 1,650 trained individuals (79 percent women) – knowledge and skill transfer
- 1,580 rocket stoves produced
- 1,331 woodlots seedlings raised and distributed for replanting
- At least two knowledge management products produced

Table 2 shows the number of communities and households reached out for Rocket stove project. These were implemented by the 4 NGOs.

Table 2: Number of communities reached by each of the 4 NGOs and Number of rocket stoves fabricated by the NGO in the identified communities [70]

	Communities reached (village/settlements)	Number of rocket stoves fabricated (1 stove/kitchen)
C3 Fiji	13	200
ADRA	15	400
GTM	16	630
GCCAF	12	350
Total	56	1580

From stakeholder engagement, to ensure sustainability of the rocket stove project, (i) communities were trained on how to fabricate the ICS so that ICS is accessible, (ii) woodlots were replanted with fuelwood that were previously cut and (iii) storage warehouses to be established so that communities can be trained in future and manufacture cookstoves can be stored. Phase 2 of the project is to work with a Women's Vocational Center to provide training on the fabrication of ICS and also provide storage space for storing ICS for future distribution.

In addition, stakeholder engagement with a private company involved in distribution revealed that they have distributed 55,000 ICS out of 60,000 to farming communities, informal settlements and remote villages. They are the country representative in the CDM project initiated by the Korean Carbon Management Ltd [71]. They are responsible for distributing clean cooking stoves to women who predominantly use outdoor open fire stoves or "choolha" in rural areas and does monitoring and valuation of the project. They are well placed to do this task as the company has 5 big warehouses around the country and have trucks to deliver the ICS.

4.1.1.2. Ghana

Households in Ghana mostly depend on charcoal, wood and gas as cooking main cooking fuels, as shown in Fig. 16. Other fuel sources used for cooking are crop residue, animal waste, sawdust, electricity and kerosene. 33 % of households use wood fuel while 34 % of households use charcoal fuel. For these fuels, traditional coal pot or 3 stone fire stoves are used by 62% of the households, Fig. 18. 12% of households use improved charcoal stoves while another 12 % of the households use improved mud stoves with or without a chimney. When comparing urban and rural households, shown in Fig. 17, again disparity is evidenced. 55 % of urban households use polluting fuels such as wood and charcoal for cooking while 85 % of rural households use wood and charcoal for cooking.

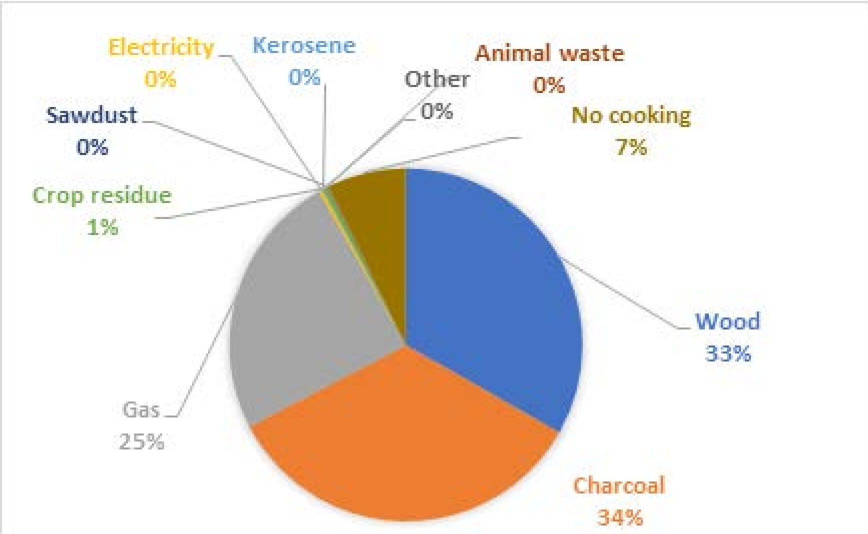


Fig. 16. Percentage of households in Ghana using fuels for cooking in 2017 [72].

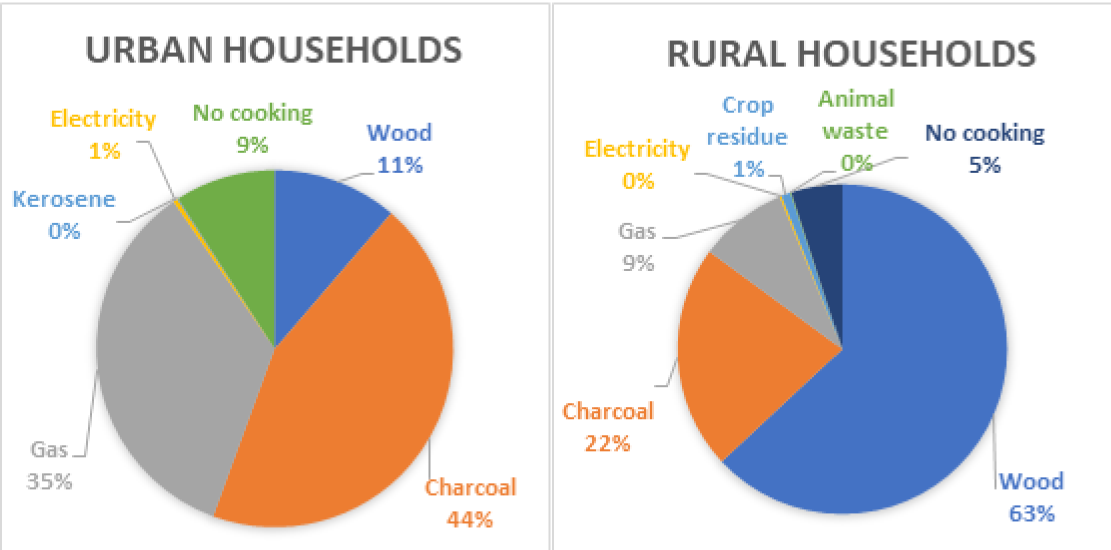


Fig. 17. Cooking fuels in rural and urban areas of Ghana in 2017 [72].

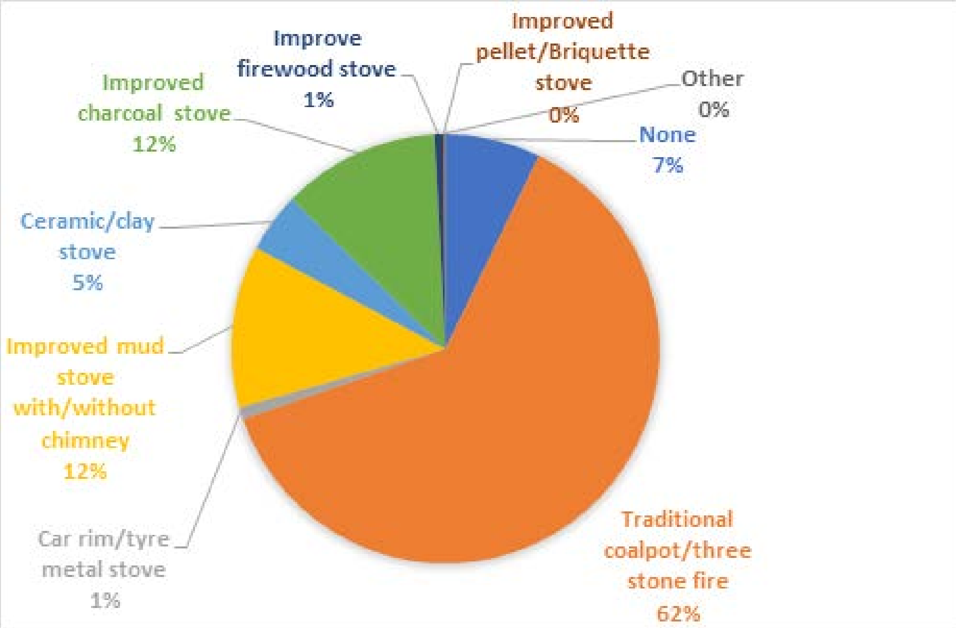


Fig. 18. Different types of biomass cook stoves used in Ghana in 2017 [72].

In Ghana, the 2010 National Energy Policy (NEP) and the 2010 Energy Sector Strategy and Development Plan (ESSDP) are the two documents that provides details on the country's specific goals and targets for cooking fuels and technologies [73]. According to the national energy policy 2010, the move towards clean cooking fuels and technologies, such as improved wood burning stoves, are driven by the need to reduce deforestation and negative health impacts of inferior cooking equipment [74]. With regards to LPG, the ESSDP planned to increase access from the current level of 6% of households to 50% by 2015 through the development of LPG infrastructure and pricing incentives to encourage distributors to expand their operations, especially to the rural and deprived areas [54]. However, as seen from the 2017 Ghana Living Standards Survey, this target was not reached where only 25% of the households were using LPG.

4.1.1.3. Nigeria

Almost all households in Nigeria cook at home. 51% of households use 3 stone or open fire stoves, 14 % use biomass stoves while 17 % use kerosene. Clean fuels only make up 18 % of the total households in Nigeria as seen in Fig. 19. Again, for Nigeria, there is a clear difference between urban and rural household cooking stove mix 36% of urban households use clean cooking fuel stoves such as LPG and electric while the rest kerosene, 3 stone or open fire stoves and biomass stoves while only 6 % of rural households use LPG or electric stove. 71% of rural households use open fire stoves and the rest kerosene and biomass stoves, as seen in Fig. 20.

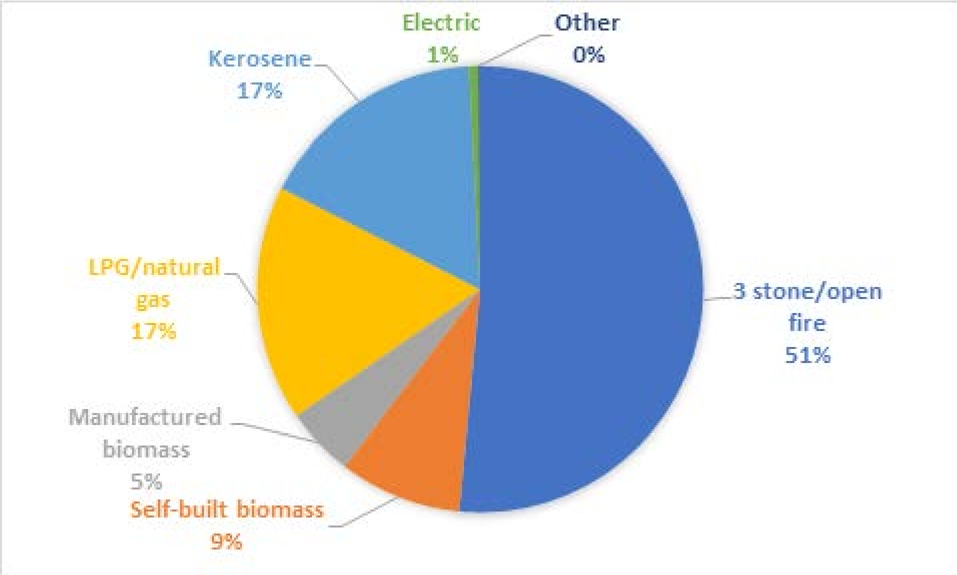


Fig. 19. Percentage of households in Nigeria using primary cookstoves in 2018-2019 [75].

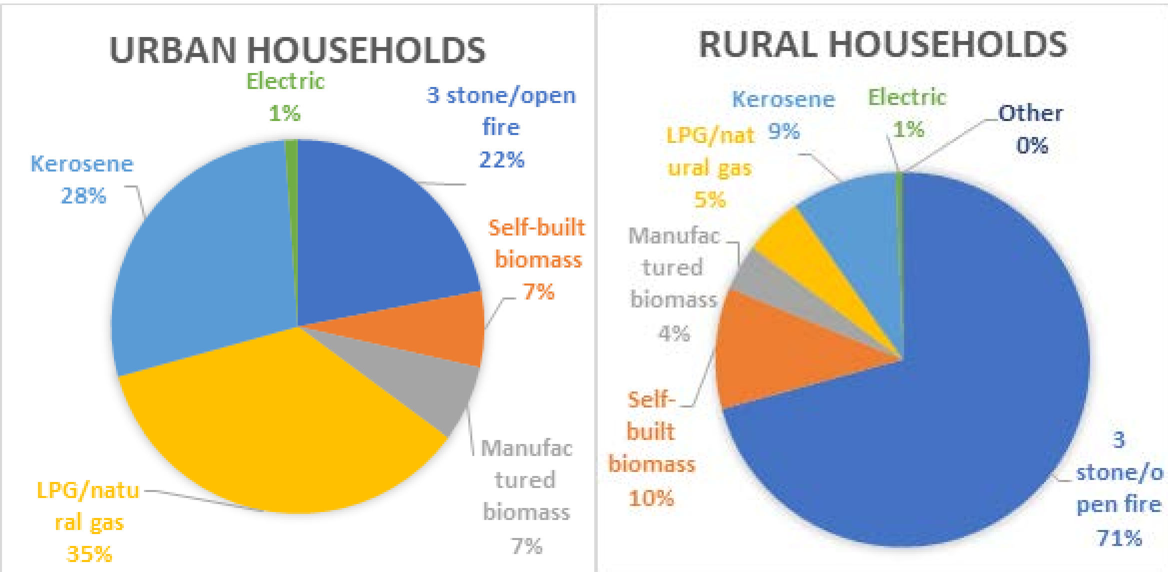


Fig. 20. Cooking fuels in rural and urban areas of Ghana in 2017 [75].

4.2. Discussion

4.2.1. Technology options

The data shows that a lot of people rely on the traditional use of biomass for the purposes of cooking. This is approximately the 20% of the population of Fiji, 70% of the population of Nigeria and 73% of the population of Ghana. Based on that, each country worked on different projects in order to be able to provide different solutions. Studies have also shown the different characteristics as well as the different positive and negative characteristics of the several types of energy used for heating and cooling. Aramesh *et al.* and Vianello [76, 77] have formed a relevant table, presented below:

Table 3: Different Energy characteristics

Technology	Pros	Cons
Firewood	Often widely available, particularly in rural areas; Can be produced locally and is conditionally renewable; Production costs can be very low; Can be smoke-free if dried and efficiently burned; Familiar and easy to use	Needs to be dried and processed into small pieces for low emissions and high efficiency; If not, burns inefficiently and produces high emissions; Fuelwood plantations rarely the most economically attractive option for landowners; Costly to transport due to relatively low energy density
Charcoal	Potentially renewable if sources are sustainably managed; Local cash benefits and employment Relatively low emissions; Can be burned efficiently and safely with right stove; Popular and convenient for users; Lower transport costs than firewood per unit of energy	High energy losses from raw wood to final product; May be associated with environmental degradation at large commercial scale
Briquettes	Potentially renewable using biomass residues; Homogeneous and standardized	Tends to be costly per unit of energy; Unfamiliar to users; Inferior burning qualities; May require special stoves; Can be hard to source bulk supplies
Coal	Cheap in some countries Relatively high heat value	High emissions (greenhouse gases and black carbon); Dirty to transport and handle
Kerosene	Often available through existing distribution systems, even in remote areas, due to popularity for lighting; Can be burned cleanly and efficiently in pressurized stove; Convenient and quick to use	Non-renewable; Often imported, depleting foreign exchange and reducing energy security; Needs special stove; Dirty and unhealthy in wick stoves; Potentially lethal in wick stoves (heats to flash point, explodes on spillage); Risky to transport, distribute and store; Users may sell and revert to woodfuel
Ethanol	Clean cooking with low emissions; Production can contribute to local economy and jobs; Relatively easy to use; Heats up quickly	Low heating value, especially with gel additives; Needs special stove; Costly to produce and distribute

Other biofuels	Relatively clean-burning; Lower lifecycle greenhouse gas emissions; Can be produced locally, supporting rural development	Usually costlier than fossil fuels; Potential conflict with food production; Infrastructure costly for large-scale production
LPG	Clean, fast and safe to use; No smoke or soot; Heats instantly and easily adjusted; Can be transported in bulk and stored in small units	Safety concerns; Significant outlay to refill cylinder; Usually imported, depleting foreign exchange and reducing energy security; Needs special stove; Potential for leakage from old and poorly maintained cylinders; Distribution infrastructure expensive and difficult to manage; Supply chain unreliable
Biogas	Clean-burning; no smoke; Easy to use and control; Flexible sizing to fit demand; Can be integrated with sanitation management;	High capital cost; High water and feedstock requirements; Potentially high maintenance needs
Electricity	No emissions at point of use; Low greenhouse gas emissions if generated from renewable sources; Easy to manage heat; Relatively safe;	More expensive than other fuels, especially if sourced from generator; Absent or unreliable in rural areas, where displaced people are often located; Needs special stoves
Solar (thermal) – solar boxer; concentrating cooker	Renewable and clean; Fuel is free; Minimal maintenance of cooker;	High socio-cultural barriers, including need to cook outside during middle of day; Requires continual realignment, especially for high-performance model; Cannot fry or roast; Cannot be used all day long; Needs extensive awareness-raising and training;
Solar (electric) – resistive burner	Renewable and clean; Fuel is free; Minimal maintenance of cooker; Readily available in the local markets; The burner is relative cheap;	High socio-cultural barriers; High inefficiency; Needs for energy storage; High overall system cost with energy storage;
Solar (electric) – induction burner	Renewable and clean; Fuel is free; Better efficiency relative to resistive burner;	High socio-cultural barriers; Needs for energy storage; High overall system cost with energy storage; Expensive burner and growing technology; Scarce in the local market;
Solar box cookers	Small size; Socially acceptable design; Light weight; Affordability;	Cannot sustain its heat compared to usual stoves due to weather conditions

	Can be modified to operate in poor irradiance with low energy consumption rate of 210W	
Solar concentrating cookers	High efficiency (direct type)	Not as popular as the box type; Not as cheap; Not as easy to construct like the box type;
Solar panel cookers	Ease of construction; Low cost	Less efficient than other designs;

4.2.1.1. Fiji

Fiji amongst others promoted a public-private partnership, with the government owning the solar home system (SHS) while private energy service companies provide servicing, maintenance works and the households. Using the same method, they've engaged micro-hydro power stations, while they've set a goal to set up 24 new biogas plants set up in rural communities for clean cooking by 2022.

4.2.1.2. Ghana

Ghana recognized their overreliance on biofuels and especially wood, thus creating a risk of deforestation. It also reported the lack of initiatives to exploit solar energy and focused on several energy development plans, which are aiming to increase the proportion of renewable energy in the total energy mix and to ensure its efficient production and use. They additionally aim to achieve universal access to electricity, which is still underway. They have also explored the use of as much "clean modern energy" as possible, in the form of Liquefied Petroleum Gas and Improved Cookstoves.

4.2.1.3. Nigeria

Nigeria does not have a standalone policy applicable to the clean cooking subject. Although, there are several development plans which propose several solutions. Specifically, there is a focus on the gas sector to drive economic recovery and growth, by promoting domestic utilisation of gas and by encouraging local manufacturing efforts to support a transition towards LPG. Additionally, there are plans for efficient utilisation of energy resources for sustainable national development; for example, the promotion of efficient biomass cookstoves and other fuels and technologies for cooking. A set of targets is also set, for 100% clean-cooking-fuel coverage by 2030 by providing improved cookstoves (59%), efficient charcoal production (7%) and modern fuel alternatives for cooking including LPG and ethanol gel fuel (34%). Finally, a target for 80% of the population to be using modern cooking fuel (LPG, ethanol, gel fuel, etc.) by 2030 is also set.

4.2.2. Energy demand for clean cooking in the three countries

4.2.2.1. Ghana. It is noteworthy that in 2010, 40.2% of households used fuelwood as the main fuel for cooking, 33.7% used charcoal, and only 18.2% used LPG. Based on Bisu *et al.* [78], the national electricity access is 344 kWh/person. It should also be noted that in 2016, just 21% of the total population had access to clean fuels for cooking [79].

4.2.2.2. Nigeria. The national electricity access is 149 kWh/person. About 65 % of the total energy consumption is taken by the household while cooking accounts for about 91% of the total domestic energy consumption [78] which sums to about 88 kWh/person. The access to clean cooking although is very limited, since 2016, just 4% of the total population had access to clean fuels for cooking [79]. This number is extremely low if you consider that at the same time 55% of the total population had access to electricity [79].

4.2.2.3. Fiji. In 2016, 39.56% of the total population had access to clean fuels for cooking [79]. This number can be considered relatively low, given that at the same time, almost 100% of the total population had access to electricity.

4.2.3. Drivers for clean cooking fuel and technology transition

The drivers discussed in this section is from the literature review and the stakeholder survey responses. The choice of fuel used depends on the convenience and affordability of the households. It was noted from the questionnaire survey responses of end-users that the choice of fuel used in homes depended on the accessibility and affordability of fuels and technologies. For instance, many respondents of the end-user category reported that they used firewood for cooking because it was free and readily available. According to the literature review, in Nigeria cooking technology is restricted by the fuel cost, ease of fueling, accessibility, availability and service quality [15]. In addition, the literature review re-iterates that firewood cooking in sub-Saharan Africa is directly connected to cost and the recurrent high cost of LPG, long-distance travel to refill LPG and not enough fuel from biogas for cooking. Similarly, it also noted from the Secretariat of the Pacific Community (SPC) [80] survey that households in Fiji prefer to use open fire stoves for cooking because fuel is free. Also, some respondents from the questionnaire survey informed that because of their age, they could not go out and collect firewood and with no one else helping out to collect firewood, they just used kerosene for cooking. In addition, from the questionnaire survey, some end-users responded that they could afford to buy gas and kerosene as their family members overseas are sending them money. Hence, if clean cooking fuel and technology transition happens, the fuel and technology need to be accessible and affordable to the end-users. To drive this transition, below are some drivers that were revealed from the literature review and during stakeholder engagement.

4.2.3.1. Women empowerment and promoting women as agents of change

According to the literature review, success stories of Nigerian women have been shared in [31]. These success stories of women in leadership roles provide evidence that women are able to better engage with their peers and help build trust that enables successful uptake of clean energy technologies and maintenance over time. In addition, women's engagement in the clean energy business is an encouragement to young girls who can aspire to be like these powerful successful women. In addition, the literature review highlights that women should be placed at the centre of decision making for clean cooking and should be included in projects from the very beginning as women are the main actors involvement in fuel collection, household cooking decision and understanding their family's cooking needs. From the questionnaire survey, approximately 57% of the end-user respondents (13/23) indicated women empowerment as one of the drivers for clean cooking fuel and technology transition. In addition, 35% of "Supplier" respondents have women empowerment as the second choice to the benefit of transitioning towards cleaner cooking fuels and technologies. Women spend a considerable amount of time cooking using inefficient cooking technologies and fuels. Transitioning to clean cooking fuels and technologies would mean less time for cooking as efficient stoves will be used, and women will get more time to spend with their family, children and friends. In Fiji, one of the clean cooking technologies (biogas) suppliers, explained that the slurry from the inflatable biogas digesters installed is used by women in their farms and flower gardens. The women in the villages are amazed at the freshness of the vegetables, and they are able to earn money by selling them in their villages and the neighbouring villages. Moreover, women are getting orders on flowers and vegetables, which is a confidence booster for women and encourages them to be creative.

4.2.3.2. Education

From the questionnaire survey, approximately 74 % of the end-user respondents indicated children's education as one of the drivers for clean cooking transition. Using solid biomass would mean more time spent collecting fuel and commuting long distances to find fuel. Virtual meeting with UNDP officers in Fiji revealed that women and children are going farther into the bushes to find firewood to cook. In addition, end-user respondents of the questionnaire survey informed that children or grandchildren are the ones usually going to collect firewood. Mothers, grandmothers, and sisters revealed that tasks are distributed with some collecting firewood while the other is responsible for cooking. A few respondents were students and they informed that their studies do get disturbed from collecting firewood. Hence, transitioning to clean cooking fuel and technologies would mean more quality time for students to concentrate on their studies and less time on household chores such as collecting firewood for cooking. This is also supported by the literature review that reports that billions of hours are spent each year on collecting biomass and transitioning to clean cooking fuel and technology would save time that could be used for other productive activities and improving education in children, especially girls.

4.2.3.3. Health

Another key driver to clean cooking fuel and technology transition is the impact of cooking fuels and technology on the health of household members, especially women and children involved in cooking. From the literature review, the Nigerian Demographic Health survey showed that traditional cookstoves (biomass, coal and kerosene) contribute to health problems due to household air pollution. Similarly, speaking with suppliers of home biogas units in Fiji during stakeholder engagement, they informed that people get eye itchiness when using kerosene cookstoves – from their households visits rural communities either to install the unit or to assess their demand. From the questionnaire survey, 83% of the respondents of the "supplier" category from Ghana reported improved health conditions as the biggest benefit to shifting towards cleaner cooking fuels and technologies. In Ghana, it is reported that more than 3,000 children die each as a result of acute lower respiratory infections, including pneumonias, caused by the use of solid fuels [81]. In addition, 13,000 death occur each year in Ghana as a result of smoke from cookstoves and literature review reports more than half a million premature death occurs annually in sub-Saharan Africa.

4.2.3.4. Clean Environment

Environmental impact from cooking fuels and technologies is another driver to transition towards clean fuels and technologies. From the questionnaire responses, many end-user respondents indicated that they prefer LPG or electric cookstoves because they are clean for the environment, safe and have no adverse health impacts. According to the literature review, inefficient traditional cooking fuel use in sub-Saharan Africa causes 25% of global black carbon emissions and contributes to forest degradation, loss of biodiversity and localized deforestation. Similarly, collecting firewood can lead to deforestation as evidenced by the UNDP project in Fiji and the SPC report that women and children have to go farther into the bushes to collect firewood. Global Alliance for Clean Cookstoves [81] reports that in Ghana, because of high reliance on solid fuels for cooking, women and children spend many hours each week collecting wood that contributes to deforestation and desertification. According to the literature review, the Ghanian government is concerned about the deforestation from the use of fuel wood by households for cooking and so are strategizing to move towards LPG. For the improved cookstove (ICS) programme in Fiji facilitated by UNDP and implemented by four NGOs to 1,580 households around Fiji, part of the implementation programme was the distribution and replanting of woodlot seedlings in communities where the ICS were distributed. This ensures reforestation of communities and sustainability of feedstock supply to ICS. From the literature review [17], it is seen that there is a huge potential of biogas to meet the cooking energy needs for rural communities in Ghana as it promotes circular economy – waste management, nutrient recovery, and energy production that leads to environment protection. Similarly, during stakeholder engagement, it has been reported that the slurry from the biogas digestor can be used in farms and gardens to produce cash crops as well as beautify the environment apart from earning money. The gas used for cooking is non-polluting and healthy for the environment as well as the end-users. Similarly for Ghana, because of high reliance on solid fuels for cooking, women and children spend many hours each week collecting wood that contributes to deforestation and desertification [81].

4.2.3.5. Success stories, educational programs and awareness raising

To drive a change to clean cooking fuel and technology access, the awareness of people on the success of existing projects is important. During the stakeholder engagement process, a home biogas supplier in Fiji reported that once a household installs a home biogas unit, other surrounding families would see or hear its success and ease of operation and would be interested in getting a unit for their households. Similarly, hearing the benefits of inflation biogas digestors, farmers in Fiji have expressed their interest to the Ministry of Agriculture to have one unit installed on their premises. In addition, according to a literature review from a Nigerian study [16], well-designed and well-intended awareness and educational programmes for rural communities could promote the cost-effectiveness of LPG and clear misconceptions on safety issues of LPG and other technology use.

However, as reflected in the challenges subsection below, the unaffordability of fuels/technologies is problematic for end users. In response to the incapacity of some households to purchase in cash, Pacific Grow has partnered with a local retail shop to offer hire purchase of the system and additionally adopted an in-house "lay-buy" option. In parallel, the Ministry of Agriculture in Fiji distributes free inflatable home biogas units to households in farming communities. However, due to budget restraints, they are only able to supply the unit to 35 households so far. At the same time, there are many (4000 pig farms and 300 dairy farms) expressions of interest from pig and cattle farmers with the Ministry.

4.2.3.6. Existing policies and plans

From the questionnaire survey, 61% of the "supplier" respondents indicated that the shift towards cleaner energy technologies for cooking in rural communities is supported by existing national/local policies in their respective countries. For instance, Fiji, has zero import duty on the importation of renewable energy and energy-efficient technologies and equipment. The literature review also emphasizes subsidies and import tariffs in sub-Saharan Africa to increase the economic competitiveness of solar electric cook stoves. In addition, according to the literature review, Fiji, Ghana and Nigeria have national energy policy documents and other strategic planning documents such as Ghana Renewable Energy Master Plan, Fiji's National Development Plan and Nigeria Sustainable Development for All action agenda, to drive clean cooking fuel and technology transitions. Further, literature review reports, Nigeria and Ghana have clean cooking action plans and strategies that promote switching from dirty fuels to LPG.

4.2.3.7. NGOs, CBOs, FBOs, and donor agencies

The strong connection of non-government, community-based, and faith-based organisations with the local community in Fiji, Nigeria and Ghana is also a key driver of the transition towards clean cooking fuels and technologies. With donor funding to reach remote rural communities, communicate with them and train them, it is vital to have a strong connection with the end-users so that the technology or fuel is accepted by the community.

4.2.3.8. Research and Innovation

As reflected from the literature review, research and development in clean energy technologies are driving the move towards clean energy transition.

4.2.4. Challenges for Clean cooking fuel and technology transition

As reflected in the literature review, there are apparent developments in trends around energy access in rural communities which highlight potential strengths and weaknesses that must be considered when enabling policies are developed in the future. Underlying these trends is a recognition from the three categories of stakeholders of the importance of a shift towards cleaner fuels/technologies to address the negative impacts from current practices (see literature review, sections 3.1.2, 3.1.3, and 3.1.4). Markets for new fuels/technologies are emerging thanks to start-ups, investments from the development community and initiatives driven by female entrepreneurs; whilst good practice to overcome inherent uncertainties hampering policy development to support and incentivise a shift towards cleaner practices are crystallising, and clean cooking action plans and strategies are seeing the light in some countries (see literature review, section 3.1.5.3). Responses to the surveys from suppliers and end-users confirm this as when asked to rate the importance of implementing a shift in cooking practices, suppliers provided a rating of 4.8/5 and users a rating of 4.35/5. Equally, the SEA4ALL initiative has led to the development of Action Plans/Agendas in Ghana and Nigeria to implement a shift towards renewable/sustainable energies for cooking, with an emphasis on Liquefied Petroleum Gas and improved cookstoves (see literature review, sections 3.1.5.4. and 3.1.5.5.).

Nevertheless, significant challenges facing suppliers and end-users must be recognised and addressed to inform the development of targeted policies to achieve the transition in specific rural communities. These challenges have been identified and compiled in the literature review – they include the insufficiency of public and private investment in cleaner fuels/technologies, the lack of adequate policy incentives and disincentives to affect behavioural and [consequently] market change, the unaffordability and lack of awareness around the benefits of cleaner fuels/technologies, the slow-paced development of local technologies, and capabilities and the slow penetration of imported fuels/technologies in local markets, *etc*.

Despite noticeable developments in Fiji, Ghana and Nigeria, policies and action plans fail to afford long-term and comprehensive strategies that would prescribe a coherent and localised approach to tackling existing barriers. For example, Ghana's SE4ALL Country action plan identified a number of challenges including access to credit, inadequate infrastructure, the need for basic skills and training, limited access to markets, technology gaps, supply-side problems of production, insufficient information, and insufficient institutional capacity. It had also identified challenges specific to the shift towards improved cookstoves. The Plan merely recognised that these challenges require coordination across numerous policy areas and collaboration between various stakeholders (as opposed to being addressed within the specific provisions of targeted programmes and projects) and failed to elaborate on how such efforts would be mutually coherent. Given the overlapping policy documents in Ghana on the subject of clean energy access for cooking (Strategic National Energy Plan, National Energy Strategy, SEA4ALL Action Plan, Renewable Energy Masterplan, *etc.*), and taking account of best practices identified in the literature review (literature review, section A – drivers, point 2), future efforts should focus on acquiring explicit government endorsement of a shift towards alternative renewable sources through the development and adoption of holistic energy access policies in Ghana. Similarly, the fragmented nature and inherent inconsistencies of existing policies addressing clean cooking in Nigeria have been identified as one of the key barriers for implementing the transition. This is confirmed in the survey responses that were received as 61% of the suppliers thought that the transition is supported by existing national/local policies in their respective countries, while 33.3% thought it is "somewhat" supported, and only 5.5% thought it is not supported. In short, the problem seems to lie in the effort exerted to harmonise existing [more specific] policies and develop forward-looking overarching strategies highlighting synergies between them, rather than the absence of policies *per se*. This would afford the certainty required for the sustainability and longevity of projects, for the stability of clean energy markets, but more widely, for the adoption of sector-specific policies and initiatives to tackle the main challenges consistently facing suppliers and end-users.

For example, developing well-framed and research and development (R&D) policies to drive technological breakthroughs and reduce costs would be an efficient approach to address one of the main challenges faced by the end-users - the unaffordability of clean fuels/technologies (their purchasing capacity). In order to ensure the suitability of this solution, this should be underlined by an understanding of the specific requirements of the community that is being considered. To illustrate, end-user respondents from Fiji indicated that ease of use/affordability is the main driver for their choice to rely on the open wood fire and kerosene stoves while 0% of the respondents thought that habits/culture is the main barrier for the shift. A focus on policies to reduce costs would thus be a more appropriate solution than attempting to address cultural habits.

Following on from our example, R&D policies would then need to be complemented by and harmonised with policies aiming to build local capacities through training and relocating manpower and engaging women and marginalised communities. Equally, [private and public] investment policies, one of the main barriers identified in the reviewed literature and confirmed by responses to the surveys by interest groups and suppliers, would need to be harmonised with the business models developed to ensure the longevity of solutions adopted; whereas campaigns to raise awareness about the harmful effects of current practices and the benefits of cleaner fuels/technologies would become useful tools to create market demand and reduce the risks (and therefore costs) borne by suppliers.

4.3 Business model for clean cooking services

The existence of an appropriate business model is the bedrock of successful clean energy uptake. One key factor hindering the penetration of clean cooking energy to rural communities is the high cost of energy from both the investors and end-users' perspectives [10]. There is a disequilibrium between the investors' desired profit and the end-user's affordability. This disequilibrium can largely be attributed to the business model surrounding clean cooking energy technology. To ensure the uptake of clean cooking energy by rural communities; it is crucial to develop appropriate business models that address profitability and affordability. The existing literature shows three distinct business models for clean energy uptake to rural communities. These include the incentive-driven models [59,60], government-driven models [59,61] and private-sector-driven models [57,58,62]. None of the three models is exhaustive in ensuring clean energy access to rural communities due to their inherent problems. To offer alternative business models, the study examines the value chain of the various clean cooking energy technologies. The value chain describes all the activities that firms undertake to translate a business idea into a good or service and deliver it to the end-user and sometimes provide after-sales services (Gereffi & Fernandez-Stark, 2011). The activities within a value chain can either be confined within a single firm or networked of firms. Most value chain activities are built across a range of firms that focus on a different aspect of the value addition processes. The value additions within the value chain underpin the type of business model that can deliver value to the investors of the firms. There is a strong relationship between a value chain and business models. Whereas the value chain defines the activities that deliver value to the customer, the business model ensures the economic viability of the goods and services to the owners of the business (Apte & Davis, 2019). Strakova *et al.* (2021) studied the relationship between the value chain and business models of some 354 firms. Their findings suggest that the value chain forms the basis for the development of the business models. It is on this basis the study explores the clean energy value chain and integrates a business model that delivers value to end-users and profit to investors.

The business models focus on the three clean cooking energy technologies advanced in this study. These include LPG, improved biomass cookstoves, and electric cookstoves. Although these cooking energy solutions are distinct in their generation (manufacturing) and deployment (instalment), their value addition processes are related in many ways. Fig. 21 demonstrates the value chain of typical clean cooking energy (thus, LPG, improve biomass cookstoves and electric cookstoves). The first stage is clean energy planning where the choice of clean energy is determined. Data gathering, stakeholder consultation, prototype developments, and testing are critical at this stage. These activities require substantial investment in research and development (R&D). Households in rural communities do not have the financial capacity to commit to R&D. Consequently, the financial burden falls on local governments, private investors, NGOs, and international communities to initiate the process towards the development of clean cooking energy technology. It is worthy of note that the type of investor involved in the clean cooking energy development influences the business model adoption and determines whether the end-user can afford it. Private investors are highly profit-oriented and will sell clean energy at the highest possible price. The central government's funding can sell clean energy at a reasonable price. But government budgets for clean cooking energy technologies in developing countries like Ghana, Nigeria, and Fiji are scanty and often misapplied. Again, the administrative bureaucracies in these countries make it difficult to execute government-led rural developmental projects even in cases where international funding has been secured. A case in point is the rural electrification project in Ghana. Despite the many financial commitments to this project, the Ghana Energy Commission (2019) reports that more than 30% of rural communities are without electricity. A separate study in Nigeria reports that only 39% of rural households have electricity (African Development Bank, 2018). The study attributed the slow pace of rural electrification in Nigeria to various factors of which corruption is leading. The developmental deficit in rural Fiji keeps deepening as rural communities are still struggling to access freshwater (Naca & Ferreira, 2016). Due to these challenges, governments in developing countries could provide enabling policy environments to lure clean energy investors to compensate for their financial deficiencies.

The second segment of the clean energy value chain involves the actual implementation of the clean cooking energy solutions conceived in segment one. Investment in technology is a key driver here. The improved biomass cookstoves and electric cookstoves are developed to ensure optimum energy savings. The LPG energy will also require the building of reservoirs at vantage points within the rural communities. Again, the capital outlay at segment is purely the responsibility of the investor.

Segment three and four directly involves the end-users. The main question on the mind of investors is how to recover their investments and the sustainability of clean energy technology. Two separate business models namely the LPG Business Model and the Improved Cookstoves Business Model are discussed in this study. In each of the two models, we introduce the ***"mobile phones for clean energy concept"*** as an auxiliary business model which can be integrated into any business model. Moreover, the facility user fee which refers to how much the end-user pays to obtain the energy is relaxed. This is because, it has been established in the literature that LPG, improved biomass cookstoves, and electric cookstoves are relatively cheaper than the widely used biomass fuel and kerosine cookstoves [10, 16, 17, 18]. Particularly, Ozoh *et al.* [16] report that as high as 90% of users of hazardous cooking energies are willing to transition to the use of LPG energy. The debate on clean cooking energy is the upfront cost of the transition.

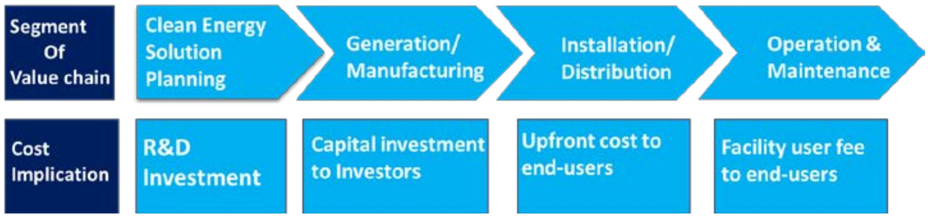


Fig. 21. Clean Energy Value Chain and Cost Implication Model

4.3.1. Mobile phones for the clean cooking energy concept

One major challenge hindering the uptake of clean cooking energy by rural communities is the upfront cost [10]. The ability to pay for the upfront cost of the burner, cylinder or the improved cookstoves set the barrier to the number of rural households that can uptake the clean cooking energy solutions. Also, in every business model, the number of users is critical. An increase in the number of users influences economies of scale and reduces the average cost of production. If the upfront cost can be made affordable through an innovative business model, the rural household demand for the LPG, improved biomass cookstoves and electric cookstoves will increase and make clean cooking energy economically viable to investors as well. Mobile telephony presents a unique business opportunity for clean cooking energy solutions. Several businesses such as agribusiness, transportation, hotel and restaurant services, retailing, banking, and other financial services have leveraged mobile telephony to thrive. For instance, Issahaku, Abu & Nkegbe (2018) examined the effect of mobile phone usage on smallholder maize farmers' productivity and reported that integrating mobile phone usage into farming activities improves productivity through information sharing and extension services. A similar study was carried out among informal micro traders in Ghana (Boateng, 2011). The findings suggest that mobile phone usage boosts profitability among traders since it offers micro traders the opportunity to monitor goods and pricing strategies, deliveries, and address inquiries and complaints. Loaba (2021) posits that the introduction of mobile banking into the traditional banking sector has improved formal and informal saving by 2.4% 0.83% respectively.

Clean cooking energy can also do the same by capitalizing on the high mobile phone penetration of about 70% in developing countries (World Bank Group, 2016). Glemarec (2012) contends that no matter the cost involved in any value proposition; with innovative business models “the poor have the capacity and the willingness to fully or partially pay for services that provide clear, immediate and substantial benefits”. There is a misconception that the poor or rural communities cannot afford essential services. But Glemarec (2012) is of the view that if businesses can readjust their cost and pricing strategies and use innovative distribution channels; the poor can afford to pay for goods and services that add value to their lives. For instance, about two decades ago owning a mobile telephony device was the prerogative of the rich and the poor did not stand the slightest chance of affording a telephone device. However, with the right business model, many poor communities can now own mobile telephone devices. In the same way, clean energy is centred in urban communities and can spread into rural areas only if there are appropriate business models.

At least 7 out of 10 people in rural communities own a mobile phone (World Bank Group, 2016). The rapid growth in the mobile telephony industry can revolutionize clean cooking energy adoption by facilitating the payment of the upfront cost associated with the burners, cylinders, and improved cookstoves. Energy entrepreneurs can link Mobile phone ownership to the acquisition of these cooking devices. The upfront cost is spread over a reasonable period and the buyer pays for the cost either through prepaid airtime purchase or mobile money repayment system. In Ghana, Nigeria, and Fiji, mobile phone sim cards users are registered and linked to national identification numbers. The mobile phone identification systems in these countries minimize the chances of credit default. Energy entrepreneurs can leverage this system to sell clean cooking devices. Lessons from other businesses like savings and loan companies are commendable and can be emulated by clean cooking energy investors. For instance, in Ghana savings and loan companies offer loans to users of mobile phones without prior provision of any collateral (Amoah, 2021). The identification system alone provides enough assurance that the borrower will repay the loan. The mobile phone for loan scheme is not constrained by geography and rural communities are benefiting from this model. Linking mobile phones to clean cooking energy solutions lowers the upfront cost barrier and increases the uptake of clean energy in rural areas. It is also economically viable since investors are presented with a business model to recover their investment.

4.3.2. LPG Business Model

There are two upfront costs the end-user has to bear: the cost of the cylinder and the cost of the burner.

There are two existing business models concerning cylinder acquisition in Ghana, Nigeria, and Fiji. These include the end-user outright purchase model and the cylinder recirculation model [73]. In The end-user outright purchase model, the end-user purchases the burner and cylinder outright. However, in the cylinder recirculation model, the LPG distribution company owns the cylinders and offers them to be used by the end-user. The end-user only pays for the LPG content in the cylinder. The LPG sold in this business model is slightly higher than the market price for the other models where the customer owns their cylinders. The premium on the price enables investors to recover, maintain and replace the cylinders. The cylinder recirculation model frees the end-user from the immediate capital cost of the cylinder. Since the cylinders are owned by a few distribution companies rather than dispersed individual users, the model can facilitate inspection, maintenance, and adherence of LPG cylinders to safety protocols. The use of this business model is largely found in urban centres and can be replicated in rural communities.

In Ghana, the introduction of cylinder recirculation in the LPG Promotion Program has contributed to a significant increase the access to LPG (Asante *et al.*, 2018). The government aims to use the cylinder circulation model to achieve 50% access to LPG. However, the cylinder recirculation model is bedevilled with some challenges. There are complaints of substandard cylinders, delivery delays, and measurement errors that need to be addressed to increase public confidence in the cylinder recirculation model (PWC, 2019).

The cylinder recirculation business model can be ideal for the rural communities if the following support services are put in place:

1. The building of LPG reservoirs at strategic centres to cut down the cost of transporting LPG from the manufacturing hubs to rural communities.
2. The business model to pay off the cost of the burners to rural households. the two cost the end-user bears to transition to LPG is the cost of the burner and the cylinder. The recirculation model takes care of the latter but the end-user still needs to pay for the upfront cost of the burner. A business model can also be built around the supply of the burners. The government in developing countries need to create enabling environment to attract investors within the LPG value chain who could offer the burner for sale on a credit basis. Rural households may not be able to afford the outright purchases but spreading the cost of the burner over a reasonable time frame will increase their ability to pay. In this case, the *Mobile phones for the clean cooking energy concept* can be integrated into the credit arrangement to facilitate the payment and collection of the periodic instalments.

4.4.4. Improved Cookstoves Business Model

Improved cookstoves are energy efficient, reduce cooking time and minimize health complications associated with traditional biomass. Just like all other clean cooking technologies, the upfront cost is challenging the uptake of improved cookstoves by rural communities. Entrepreneurs can adopt the *"mobile phones for clean cooking energy concept"* to facilitate the selling of cookstoves. In this model, the improved cookstoves are sold on a credit basis and the full cost is spread over a period. The instalment payments can be paid either through mobile money or the prepaid airtime payment system.

5. RECOMMENDATIONS

Clean cooking fuels and technologies used in rural areas is still at the infancy stage in the 3 countries studied; Fiji – 68% of rural households use wood and kerosene fuels, Ghana – 85% of rural households use wood and charcoal fuels, and Nigeria – 80% of rural households use wood for open fire stoves and kerosene while 14 % use self-built or manufactured biomass stoves.

Despite efforts in all three countries to align with the SDG7 and United Nations' Sustainable Energy for All (SE4ALL) initiative's common target of achieving universal access to affordable, reliable, sustainable, and modern energy for all by 2030, energy policies are set out in multiple strategy documents and plans which are marked with inconsistencies, ambiguities, and pose various challenges. Responses to the online survey shared with energy suppliers in the three countries confirm this reality: only 1 respondent out of 18 thought that the shift towards cleaner energy technologies for cooking in rural communities is not supported by existing national and/or local policies in their respective country, while 95% of the same respondents viewed the market for clean/alternative fuels for cooking in rural communities and the current infrastructure enabling a transition towards them at either infant or intermediate stage. This shows the imperative for developing pathways to drive an accelerated transition to clean/cleaner cooking in rural areas through tackling key barriers that are frequently highlighted by the literature on the subject and benefiting from existing strengths in the three countries examined.

The challenges identified in the study could be broadly summarized into four:

(i) the supply chain of cleaner fuels to rural areas, that is, the access of cleaner fuels in rural communities.
(ii) affordability of cooking fuels and technologies in rural areas.
(iii) lack of awareness of clean cooking technologies and their benefits.
(iv) lack of gender mainstreaming in energy access.

To address the challenges the policy pathways below are proposed to present individual governments and partnering international development organisations with options to be holistically weighed in order to effectively drive the clean energy cooking space in individual countries in the Global South. This is done with an awareness of the concurrent imperatives of improved economic empowerment and the general wellbeing of rural communities, especially women and children.

1. Integrating gender considerations into clean cooking policies and initiatives – Governments should recognise women's important role in clean cooking fuel and technologies uptake by rural communities. Policies must put women at the centre of clean cooking technologies uptake and strategise ways to increase participation in clean cooking initiatives, especially in leadership and technical roles.
2. Prioritising clean cooking fuels and technologies in National Policies, Strategies and Action Plans. Governments must explicitly state their position on clean fuels and

technology access and ensure that this position inconsistently supported in cross-cutting sectoral policies (*e.g.,* growth strategies, investment strategies, education strategies, *etc.*). A *clear direction* in national energy policy documents and related plans will provide certainty for suppliers and end-users and promote activities, programs, and projects undertaken by local governments, departments, and ministries.

3. Increasing and designing new financing options and risk-reducing mechanisms for suppliers of clean fuels or technologies. Governments, financial institutions, and the private sector need to collaborate to discuss strategies to support the private sector in reaching remote rural communities. Governments must investigate financing options such as concessional loans, subsidies, tax holidays, and others for applicability.
4. Establish a public body/Governmental agency to regulate, provide guidance, and support with tapping into existing international funds for clean energy projects in rural communities in the Global South and ensuring their adequate employment through defined monitoring and auditing practices.
5. Mobilise funding in clean cooking fuels and technologies for (i) uptake by end-users, (ii) research and development to reduce the costs of clean cooking technologies, (iii) programs and projects to be delivered by public bodies and institutions. This will make fuel and technologies for cooking affordable to end-users.
6. Allocate resources to civil society organisations (CSOs), faith-based organisations (FBOs), community-based organisations (CBOs), and small-scale providers of clean fuel or technology. Governments or local governments should collaborate with CSOs, CBOs and FBOs to encourage clean cooking initiatives These organisations can promote improved biomass cookstoves, provide training, support with the storage of cookstoves, and raise public awareness of the risks posed by current cooking practices and the benefits of a transition towards cleaner fuels/technologies. As part of their training programs, communities should be encouraged to replant trees and woodlots to ensure sustainable use of resources.
7. Governments should financially incentivise energy suppliers to supply clean energy to rural and remote communities – this can be done through tax rebates and government subsidies and other financial mechanisms.
8. Collect information and data on clean cooking demand in rural communities. Government departments can collaborate with academic institutions and Bureaus of Statistics to collect household fuel and energy demand, income levels, and other relevant data that can inform more targeted enabling policy for clean cooking fuel and technology access in rural communities.
9. Design and implement a well-intended and well-designed educational intervention programme aimed at postgraduate studies targeting clean energy access for cooking services in the rural and semi-rural communities to promote the aggressive adoption.
10. National energy policies should address lopsided subsidy intervention and competing demand for unproductive, and environment-degrading uses of agro-residues and wastes. In this effort, Governments should for example ensure consistency in supporting a biomass to biogas cookstove intervention and programmes.

11. Governments should elaborate and adopt policies that empower government agencies and public bodies to develop quality assurance and quality control programmes to ensure the compliance of all components of clean energy systems with internationally acclaimed standards to boost their durability and preserve their functionality.

6. CONCLUSION

While some of the cooking practices are known to induce climate change, the consequence of climate change has been shown to have a strong impact on the livelihood of the rural communities; flooding and desertification have increased the hours the women/girls used to collect fuelwood (firewood). Therefore, this study (research-to-action) presents the mapping of policies with clean technologies for the cooking space of rural communities in the Global South for sustainable development.

The study presents the barriers, opportunities, and drivers associated with clean cooking space in rural communities located in the Global South. The connection between clean energy and cooking services was identified with possible health impacts. The policy issues related to drivers, barriers, and opportunities are presented in the general context of rural communities in the Global South. The distribution of cooking technologies established from a literature review was presented and validated by engaging with stakeholders associated with the cooking space in Fiji, Ghana, and Nigeria. The study shows that there is huge potential for clean cooking technologies in rural communities. However, conscious intervention to link end-users and clean cooking technologies lies in the policy and business domains. To this end, an attempt was made to present a holistic business model and broad base policy pathways for the adoption of clean cooking services in the rural community for sustainable development. The policy pathways harmonise the major stakeholders in the cooking space; namely, government, NGO, clean energy developer, business services and end-user.

To effectively increase the impact of the study, a policy brief and a one-page infographic summary that links stakeholders with opportunities and drivers are presented. In the same reasoning, a promotional video with infographics that resonate with the layperson to drive home the findings of the project is developed. There are complex socio-cultural challenges surrounding the transitioning of traditional biomass cooking space to cleaner cooking space that need to be resolved to balance the dichotomy between new entrants and traditional cooking services. Therefore, it is expected that the effort made in this research could be advanced by decoupling the socio-cultural parameters using advanced social science data gathering approaches to obtain the detailed techno-economic parameters of clean cooking technologies that could be influenced by the policy pathways here established in connection with the socio-cultural factors associated with energy services.

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8. ANNEXES

8.1. Questions from questionnaires

Questionnaire for suppliers

Questionnaire for end-users

Questionnaire for interest groups

8.2. Stakeholder engagement strategy table

Category	Interest	Potential Relevance for SENSouth	Potential Stakeholders
Supply	Making profit; providing public services (education access, improved health and hospitalisation, infrastructure for rural activities including agriculture and household activities); attracting foreign and local investment; Research & Development; awareness-raising (risks of current energy patterns and benefits of alternatives); developing business models to make alternative technologies a viable and long-term approach; capacity building; women-empowerment	Stakeholders in this category would need to be convinced of the suitability of a shift towards cleaner enenegy access in rural communities for them invest effort and money into this transition. This would most likely involve a cost-benefit analysis for each respective stakeholder (both long-term and short-term). Given that a cross-sectoral policy alignment would be needed to implement a transition towards cleaner energy access for cooking in rural communities, interrelationships between stakeholders within this category must be attributed special attention.	Public authorities/Governments; women entrepreneur groups; women empowering groups; clean fuel suppliers; off-grid energy suppliers; financial institutions; contractors; energy service companies; etc.
Demand	Improving health and living conditions of rural communities; empowering-women; having reliable and safe energy access to satisfy rural communities' needs and specific requirements	Any recommendation made would need to reflect that the solutions advanced have been centred around the end-users. In our project, the focus should be on identifying what women in rural communities consider as suitable solutions as this would indicate the demand which would in turn influence supply decisions (investment in building the infrastructure, R&D, etc.). Distributors of cooking equipment could also be considered in this category, as they would determine the demand for imported equipment if local manufacturing is not possible.	End-users (women and children); community leaders; local equipment distributors; focus groups; etc.

Interest Groups	Climate action; gender equality; reducing poverty; health and safety	This stakeholder group would highlight the specific and wider policy relevance of the project. These should be stakeholders that are interested in lobbying for the solutions which SENSouth puts forward.	NGOs; UNDP, UNEP, Global Green Growth Institute (GGGI); Regulators; Environmental Protection Agencies;