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Prospects of Clean Cooking Energy in Africa - Transition Pathways and Implications

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ABSTRACT

Despite abundant renewable energy resources, African countries still suffer from energy poverty, particularly in cooking. Up to 2022, about 74% of the African population had no access to clean cooking energy. With focus to Sub-Saharan African population, 90% has no access to clean cooking energy which decrease by 7% when kerosene is included. Traditional cooking, which involves the use of charcoal and firewood, is associated with health problems, environmental degradation, socioeconomic issues, and gender inequality. Transitioning to clean cooking energy not only promises significant health benefits but also offers opportunities for sustainable economic development and environmental preservation. In this study, the desk research method was used, which involved compiling raw published data such as research articles, government reports, implemented project reports, and published statistics. The following are the findings of this study: Firstly, for the improvement of health, environment, and social economic issues, the community must transition from traditional cooking to clean cooking. Secondly, despite the promises posed by energy transition, upfront cost and technological challenges remain to be a challenge that need action. Thirdly, the government should weigh up on clean cooking technologies investment, program sustainability, and engaging the community. Lastly, the government should structure the clean cooking agenda based on the resource's proportionality in the region. Generally, to improve the welfare of the community, energy transition from traditional to clean cooking stands as the main piece, however, the government should intentionally intervene for the transition to be realized.

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INTRODUCTION

Clean cooking refers to cooking with a combination of stove and fuel with emissions below the limit set by WHO guidelines for indoor air quality (Khavari et al., 2023). Clean cooking is predominantly on Sustainable Development Goals (SDG) 7 with direct and indirect implications to other SDGs, such as poverty SDG 1, hunger SDG 2, good health and well-being SDG 3, gender equality SDG 5, economic growth SDG 8, and climatic goals SDG 13 (Dagnachew et al., 2020; Onah et al., 2021). Figure 1 shows the connection between SDG7 with other SDGs.

Figure 1: Connection between SDG7 with other SDGs.

Africa continent consumes less than 4% of the global energy consumption (Statista, 2024) which does not correspond to the population residing in the region, which is 13% of the global population (Roopnarain & Adeleke, 2017) and about 50% of it comes from fuel wood (Demirbas & Demirbas, 2007). By 2022, approximately 36% of the African population had access to clean cooking energy, and only 10% of the Sub-Saharan African population (Armah et al., 2019) which rises to 17% with the inclusion of kerosene (Armah et al., 2019; Khavari et al., 2023). This results in a low energy index despite that it leads to the most competitive renewable energy sources (Simkovich et al., 2019) with 60% of global solar sources, according to the International Energy Agency (IEA). Gabon is the top-performing country in Africa, with 60% of the population having access to clean cooking energy, while Liberia is the least performing, with only 0.07% of the population having access to clean cooking energy (Armah et al., 2019). Figure 2 shows the division of global primary energy use by region.

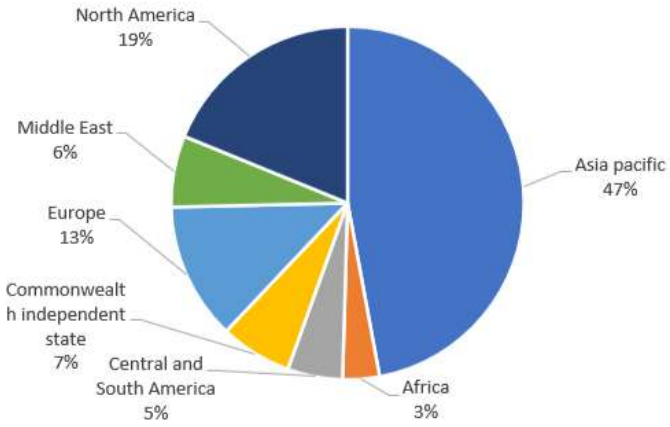

Figure 2: Global primary energy consumption by regions (Statista, 2024).

Africa has put effort into facilitating the move to cleaner cooking, however, the lack of bankable projects and the high capital cost of renewable energy projects in Africa, which is two to three times the price in developed countries, pose a barrier to energy investment agendas (IEA, 2024). In 2022, the World Bank allocated $ 9.204 billion of the African loan to the energy sector alone to facilitate the move towards clean cooking energy (The World Bank, 2022; World Bank, 2023), which shows a fall of the budget by 34% since its peak in 2014. Although there have been

advancements in the choice of cooking energy in the last two decades from firewood and charcoal to kerosene to LPG and natural gas then to the cleanest energy source, electricity (Dagnachew et al., 2020).

Africa is endowed with multiple energy sources which can be utilized to offset dependance on biomass, for instance, solar, hydropower, natural gas and geothermal energy. This poses an opportunity not only for the private sector but also for the government to enhance the health and well-being of the people as well as environmental protection (Simkovich et al., 2019).

This article targets to provide insights into the potential impacts of clean cooking on health, environmental sustainability, and poverty alleviation. Secondly, identify and analyze various clean cooking technologies used in Africa, including LPG, electric stoves, improved biomass stoves, and bioethanol. Thirdly, investigate the socioeconomic, cultural, and infrastructural barriers and enablers for implementing clean cooking solutions. Lastly, explore transitional pathways and policy frameworks facilitating clean cooking adoption in different African regions. Figure 3 shows how the article was structured.

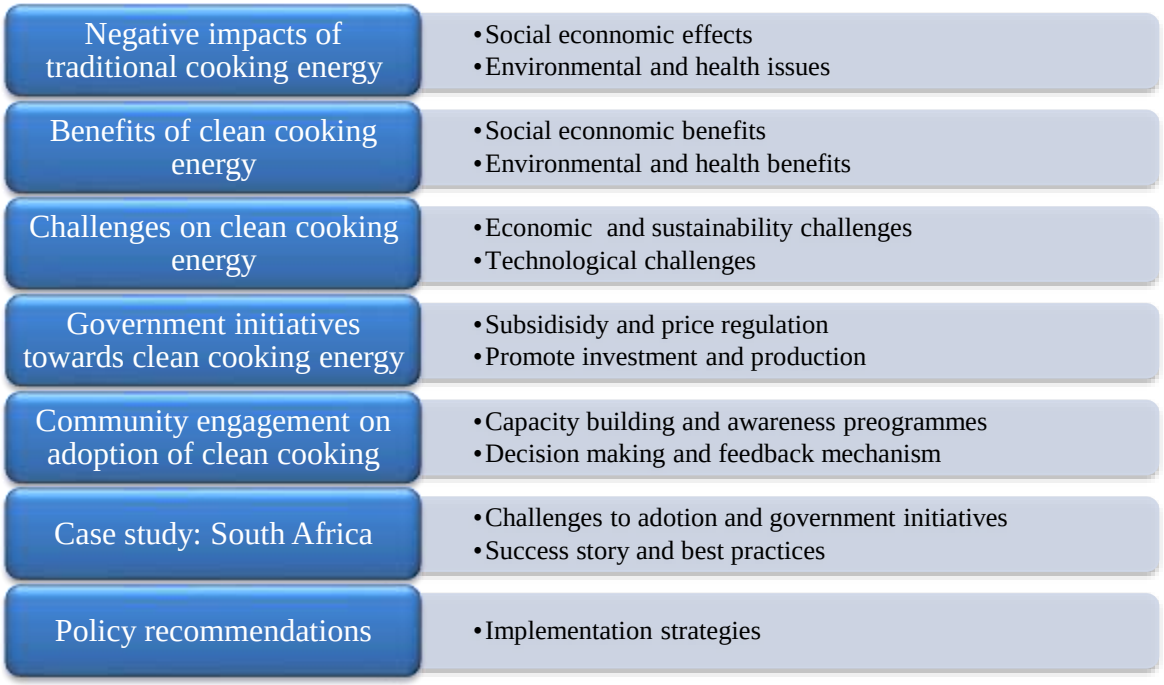

Figure 3: Structure of the article

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METHODS AND MATERIALS

This study conducts a comprehensive literature review to explore the current state, transitional pathways, and implementation strategies towards clean cooking in Africa. The methodology followed involves a systematic search, selection, and analysis of relevant literature and reports.

Literature sources and screening

Literature search: Relevant articles and reports were selected using electronic databases. The search focused on articles published between 2010 and 2024 to capture recent developments and innovations in clean cooking solutions across Africa. The following keywords were employed to ensure a comprehensive search of the literature:

i. Clean Cooking Africa,
ii. Clean Energy Transition,
iii. Biomass Stoves Africa,

iv. LPG Adoption Africa,
v. Energy Poverty Africa,
vi. Cooking Energy Policy,
vii. Health Impacts of Cooking.

Literature screening: Literature addressing traditional cooking, clean cooking, policy interventions, implementation strategies, and barriers to clean cooking adoption in African countries were included. Articles that provide data on adoption rates, health impacts, economic considerations, or environmental effects were also considered. Studies not connected to Africa, clean cooking, or those with insufficient data on implementation or transitional pathways were excluded.

Data extraction and analysis

A thematic analysis was conducted to identify recurring themes, such as the health impacts of traditional cooking methods, economic and infrastructure-related barriers, and success stories of policy interventions. Data was also extracted on the types of financial support, awareness programs, and government-driven initiatives that have facilitated clean cooking transitions.

Mapping and synthesis of literature

The literature findings were mapped to understand regional trends, identify common challenges, and highlight successful interventions. A literature synthesis was conducted to identify gaps in current knowledge and potential areas for future research. This included analyzing the role of the government in the adoption of clean cooking in African countries. Figure 4 shows the methodology summary of the study.

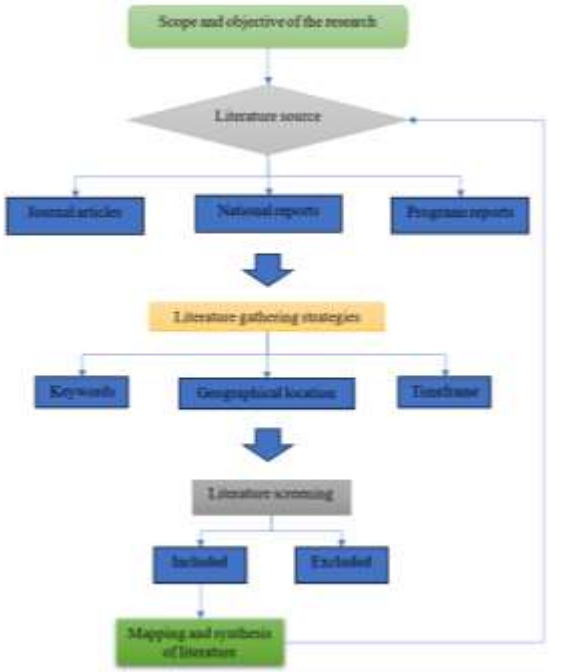

Figure 4: Summary of the study methodology

RESULT AND DISCUSSION

The negative effect of traditional clean cooking energy

Health effects of traditional cooking energy: Household air pollution (HAP) is generated by the use of traditional cooking technologies that involve firewood, charcoal, and inefficient stoves (Simkovich et al., 2019). Traditional cooking is associated with incomplete combustion of the fuel, which results in the emission of harmful gasses such as CO and NO_x, as well as particulate matter (Mitchell et al., 2020; Urmee & Gyamfi, 2014). The main health outcomes associated with HAP are cardiopulmonary, respiratory, neurologic, eye health, and burns (Das et al., 2017). According to the International Energy Association, 22% of respiratory chronic diseases and 36% of lower respiratory infections are caused by HAP, while WHO reported that among the top five leading causes of death disease are noncommunicable diseases such as Ischemic heart disease, lung cancer, chronic obstructive pulmonary disease (COPD), and stroke which are associated

by HAP exposure (WHO, 2024). Exposure to HAP above threshold limits causes respiratory diseases and infections such as pneumonia in children, cardiovascular and pulmonary diseases, and lung cancer in adults (Afrane & Ntiamoah, 2012; Urmee & Gyamfi, 2014). However, the mechanism by which HAP affects the respiratory system is uncertain (Tzanakis et al., 2001).

Millions of annual premature deaths in low and lower-middle-income countries are the result of charcoal and firewood application as cooking energy (LaFave et al., 2021; Stanistreet et al., 2019), and nearly 4 million are reported from Africa (Batchelor et al., 2018). Moreover, in Africa, major share of premature death occurs in sub-Saharan African countries (Mitchell et al., 2020). It has been reported that 2.9% of the total death globally are reported from pneumonia, chronic respiratory disease, and lung cancer, which are attributed by HAP from charcoal and wood use (Roberts et al., 2015).

Environmental effect of traditional cooking energy

Deforestation refers to the overharvesting of the forest, this is mainly influenced by the reliance on firewood and charcoal. According to the International Energy Association, about 74% of the African population still uses traditional fuel, which is associated with unsustainable forest harvesting (Simkovich et al., 2019). Unsustainable harvesting of the forest is the issue, the community should set a sustainable plan to facilitate afforestation and reforestation to neutralize the effect (Afrane & Ntiamoah, 2012; Zidago & Wang, 2016).

Land degradation refers to a decrease in land value in terms of how much it can produce and how hard it can sustain. The unsustainable extraction of wood for firewood and charcoal results in the deterioration of land productivity and quality. This not only diminishes soil fertility and agricultural productivity but also poses a threat to soil erosion, food insecurity, and economic challenges (Ajibola et al., 2020).

Greenhouse gas emissions refer to the release of harmful gasses into the atmosphere that contribute to global warming, such gasses are CO, NO_x, and CO_2. Black carbon is the particulate matter component that not only reduces air quality but also has a warming effect on the atmosphere (Urmee & Gyamfi, 2014). The use of traditional fuel is associated with the emission of these gases due to the low efficiency of the stoves, moreover, the production of charcoal is by the pyrolysis process that involves limiting of oxygen in the combustion process, which produces CO (Afrane & Ntiamoah, 2012). Based on World Bank data, firewood and charcoal account for 58% of the black carbon emissions and gigatons of CO_2 every year, which is about 2% of the total global pollution.

The social and economic effect of traditional cooking energy

Traditional cooking practices often exacerbate gender inequalities, particularly in regions where women and girls are primarily responsible for fuel collection and cooking. For many, the task of gathering firewood or purchasing charcoal is both time-consuming and financially burdensome, especially for women and children who are actively engaged in cooking and fuel collection activities more than others (Stanistreet et al., 2019). This responsibility can limit their opportunities for education and income-generating activities, reinforcing existing social and economic disparities (Longe, 2021). The time spent on these tasks is time not spent in formal education or paid work, which perpetuates the cycle of poverty and limits socio-economic advancement for women and girls.

The cost and effort involved in acquiring traditional cooking fuels can place a

significant economic strain on households as reliance on traditional cooking energy saw more time spent on the collection of the fuels. This situation means that families must allocate a substantial portion of their income to fuel, which could otherwise be used for other essential needs such as education or healthcare (Tamire et al., 2018). Traditional cooking is very cheap when it comes to initial investment, unlike clean cooking technology, however, it is costly, considering the cost of prepared traditional fuel and relative longer time taken for the process. Figure 5 shows the average time spent on fuel collection per day per household for some African countries.

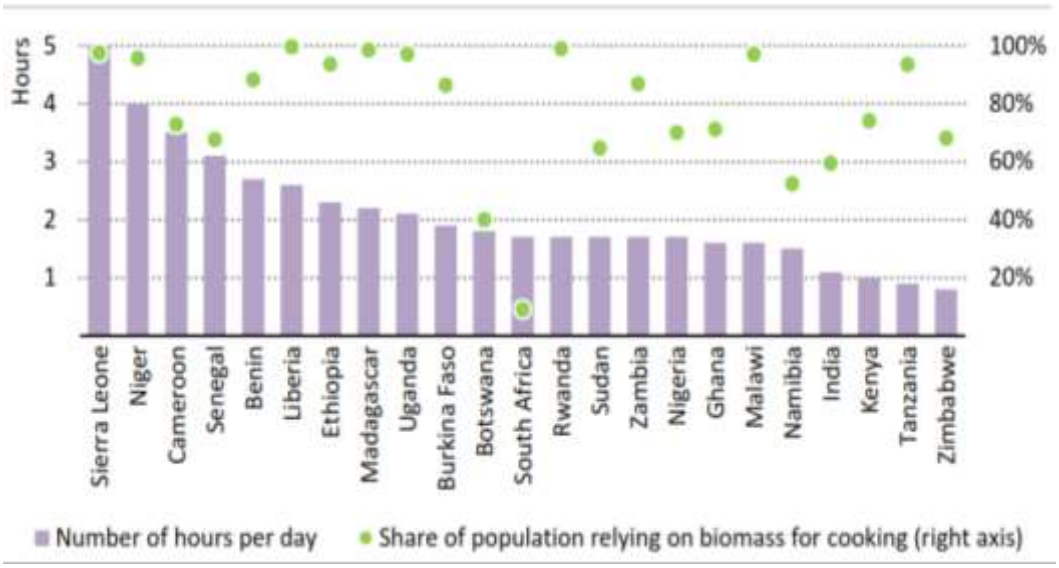

Figure 5: Average hours spent on fuel collection per day per household (IEA, 2023).

The transition from traditional cooking energy sources to cleaner alternatives involves several challenges. Technological advancement that changes the cooking methods, which involves changes in cooking practices and fuel use, requires education and behavior modification, which can be slow and difficult to implement (Armah et al., 2019). Some communities believe that smoke from firewood and charcoal is beneficial to newborns and postpartum mothers, which increases the bonding between the community and traditional cooking energy (Tamire et al., 2018). Despite these challenges, the long-term benefits of adopting cleaner cooking technologies include improved economic efficiency and opportunities for sustainable development. Figure 6 shows summary of the negative effects of traditional cooking.

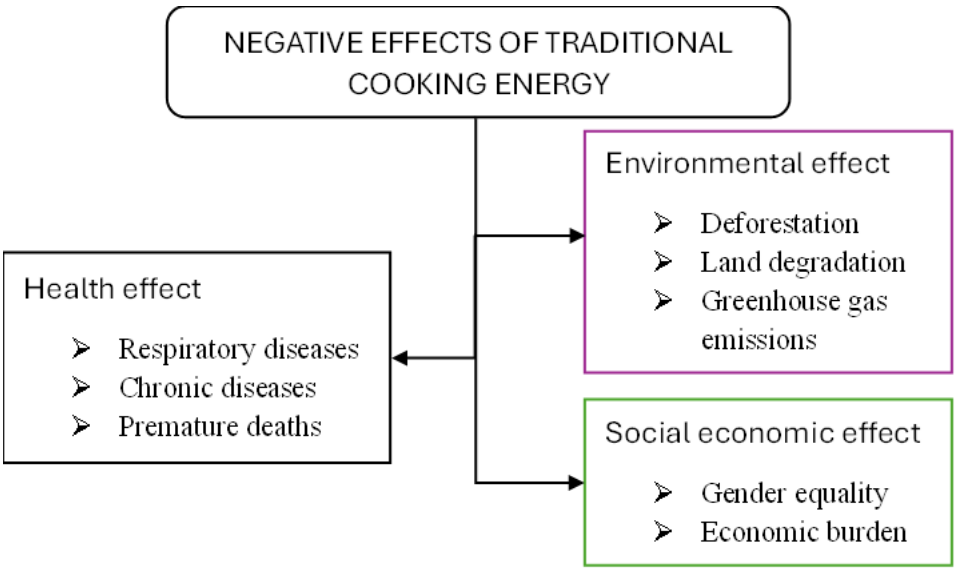

Figure 6: Negative effects of traditional cooking

Categories of clean cooking energy

Clean cooking energy such as electricity, LPG, natural gas, biogas, and solar offer alternatives to firewood and charcoal as they not only provide better efficiency but also human-friendly improvements in terms of the health and well-being of the community due to significant reduction of indoor air pollution (Simkovich et al., 2019). It has been challenging for low and middle-income countries to adopt clean energy for cooking, however, various measures such as improved biomass cookstoves and LPG promotion have been underway to combat the challenge (Debbi et al., 2014). The adoption of clean cooking energy relies on consumer acceptance, which is dictated by affordability in terms of initial investment, safety issues, infrastructure, and awareness of the technology (Simkovich et al., 2019; Wentzel & Pouris, 2007). Moreover, the solution to clean cooking energy should involve multiple options rather than a complete replacement of traditional cooking with a single cooking method to provide the consumer with the flexibility of the cooking method energy options (Wentzel & Pouris, 2007).

Electric cooking (e-cooking), such as pressure cookers, rice cookers, and induction stoves, is a clean cooking technology that uses electricity as an energy source. This cooking method can be the cleanest technology for adoption, depending on the electricity generation method. Furthermore, the technology can be incorporated with solar PV panels to function off-grid or in an attempt to diversify energy sources (Kizilcec et al., 2022). However, some are energy intensive, such as induction stoves, while others are energy savers like pressure cookers. The upfront payment for installation and equipment is high, but with proper energy management, the technology is cheaper compared to traditional fuel (Kizilcec et al., 2022). Figure 7 shows a schematic configuration of the electrical cooking.

LPG is the mixture of propane and butane in liquid form that is used for heating applications, while Compressed Natural Gas (CNG) is mainly composed of methane gas in liquid form. In cooking applications, these gasses are stored in a cylinder and controlled through pipes and valves that regulate the flow as per user flame intensity requirements. They are deemed as a more efficient and yet cleaner fuel in comparison to traditional fuel (Kimemia & Annegarn, 2016). Many countries in Africa have set goals to expand and facilitate the range of utilization of LPG and natural gas as

cooking energy due to the proven reserves in different African countries (Stanistreet et al., 2019). Shut-off valves and pressure regulators, among other safety features, are incorporated to maximize the safety of the user. Governments should protect the stability of LPG and natural gas policies to ensure no threat is posed upon them as the infrastructure is expensive and yet vulnerable (Stanistreet et al., 2019).

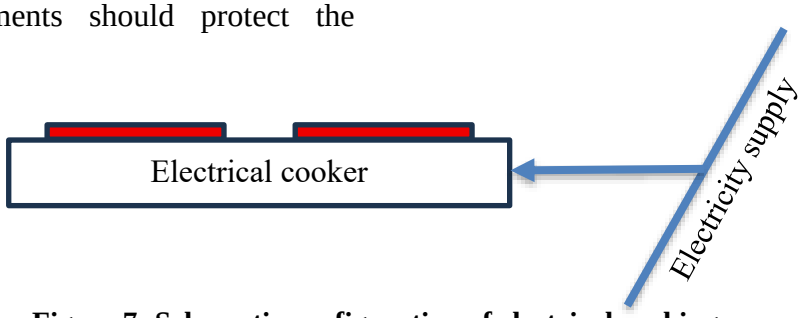

Figure 7: Schematic configuration of electrical cooking.

Biogas cookers utilize the biogas produced through the anaerobic digestion of organic waste. Biogas is clean energy but also renewable energy source, and therefore sustainable source of energy (Simkovich et al., 2019). With the increasing energy demand, biogas stands as a potential alternative source of cooking energy to traditional fuel due to its environmental and human-friendly nature (Roopnarain & Adeleke, 2017). Combining clean cooking and waste management, studies have been done to investigate the mixing of LPG and biogas from municipal waste as a fuel source (Chen et al., 2021). In terms of technical, economic, policy, and physical, the LPG-biogas mixture is promising as both an alternative energy source and waste management method. However, further improvement is necessary in an attempt to de-risk LPG-biogas utilization (Chen et al., 2021; Roopnarain & Adeleke, 2017). Figure 8 shows a schematic configuration of LPG, biogas or natural gas cooker.

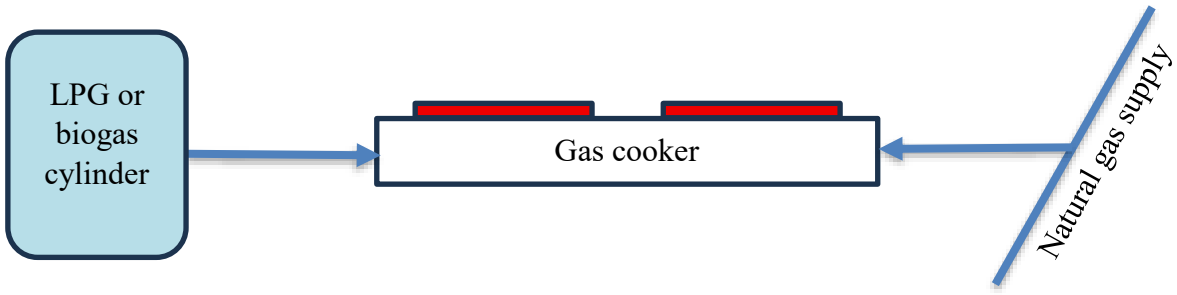

Figure 8: Schematical configuration of cookers (a) LPG or biogas (b) natural gas

Renewable energy stands as a potential solution to clean cooking, this saw the development of technologies to replace traditional cooking, particularly in off-grid areas. Solar energy is one of the numerous and excellent renewable energy sources in terms of both quantity and quality (Kalogirou, 2009; Panchal et al., 2017). Depending on the application and geographical location, solar cookers can be grouped as solar electric cookers (Batchelor et al., 2018) and solar thermal cookers (Wentzel & Pouris, 2007). Unlike solar electric cookers, solar cookers come in different designs such as box cookers, panel cookers, and parabolic cookers depending on consumer preferences and applications (Batchelor et al., 2018). Due to the intermittent nature of solar energy, solar electric cooker uses batteries for storage while solar thermal energy storage can be latent heat storage (Zhao et al., 2020) or sensible heat storage (Gautam & Saini,

2020) for cooking during off-sun hours. Integration of energy storage with solar cookers allows cooking with minimum sun exposure in the household (Bhave & Kale, 2020). Different type of cooking processes occurs at different levels of temperatures but frying and baking occur at the highest temperature above 220 ^{0}C, this temperature is attainable by solar cookers (Bhave & Kale, 2020). However, it costs more in traditional cooking as a significant amount of firewood and charcoal will be needed, and time to cook at this temperature. Figure 9 shows a schematic configuration of a solar cooker with and without storage.

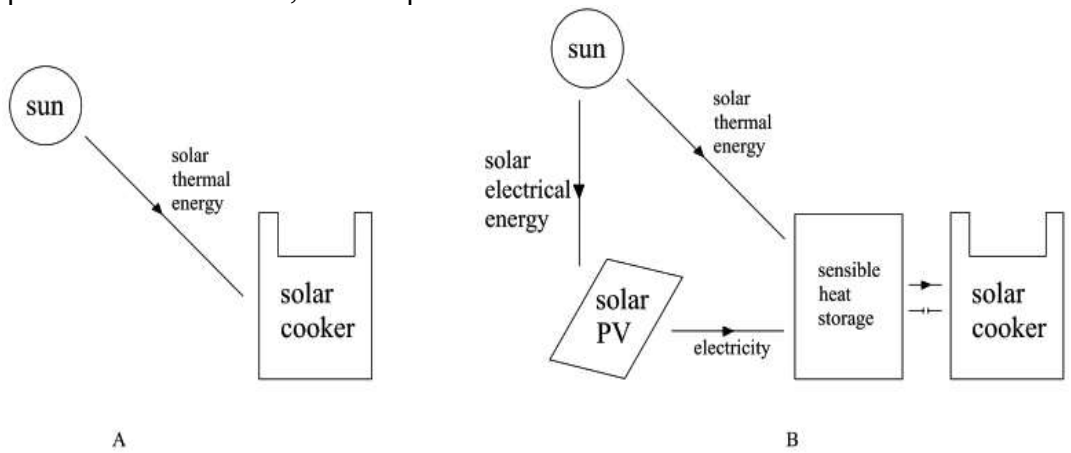

Figure 9: Schematic configuration of the solar cooker (a) without storage (b) with storage.

Improved biomass cookstoves are designed to ensure minimal biomass consumption and emissions associated with cooking by maximizing the efficiency (Urmee & Gyamfi, 2014). The improved cookstove is designed to enhance airflow as well as prevent heat losses (Khavari et al., 2022; Mitchell et al., 2020). These cookstoves reduce the negative health effects associated with biomass on the user and fuel wood and charcoal consumption as well (LaFave et al., 2021). This results in significant emission reduction of harmful gasses and particulate matter; however, technological advancement is necessary to further reduce the impact (LaFave et al., 2021; Pope et al., 2017). In addition to cookstove improvement, the type of wood used as its physical and chemical properties contribute to the emission reduction as well (Mitchell et al., 2020). Table 1 shows a comparison of clean cooking technologies in different categories.

Table 1: Clean cooking technologies comparison

SN	Fuel type	Efficiency	Emission	Initial / Running Cost	Health impact	Heat transfer mode
1	Firewood or charcoal	Low	High	Low/Medium	Very high	Combustion
2	LPG and CNG	High	Low	High/low	Low	Combustion
3	Biogas	High	Very low	High/low	Low (renewable)	Combustion
4	Biogas-LPG	High	Low	High/low	Low	Combustion
5	Solar	Medium	None	High/none	None (renewable)	Contact
6	Improved cookstove	Medium	Medium	Medium/medium	Medium	Combustion

Benefits of clean cooking energy

Clean cooking involves the use of sustainable and low-to-no-effect fuels for cooking, which is associated with high-efficiency cookers and low-carbon fuels. Clean cooking does not end in improving the health and well-being of the people (Roopnarain & Adeleke, 2017) but also promoting environmental protection, economic saving, and energy security (Dagnachew et al., 2020; Wentzel & Pouris, 2007).

Health benefits of clean cooking energy

Clean cooking technologies, such as electric stoves, LPG, and advanced biomass stoves, significantly reduce indoor air pollution. Traditional cooking methods using charcoal and firewood produce harmful emissions like carbon monoxide and particulate matter, which are linked to respiratory diseases, eye infections, and cardiovascular problems (Afrane & Ntiamoah, 2012; Das et al., 2017; Mitchell et al., 2020; Urmee & Gyamfi, 2014). In the model developed by Dagnachew *et al.* (2020) it was observed that eliminating the use of traditional cookstoves could reduce the child mortality rate resulting from pneumonia by 50%. Investment in awareness of the negative effects of firewood and charcoal will reduce respiratory and other health-associated issues by a significant amount (Batchelor et al., 2018; Kimemia & Annegarn, 2016) Unlike traditional cooking, clean cooking is not associated with energy-related incidents such as burns and poisoning due to the increased control of the flame and reduced risk of ingestion (Kimemia & Annegarn, 2016). Clean cooking is associated with high indoor air quality, which reduces health risks associated with HAP (Kimemia & Annegarn, 2016).

Environmental benefits of clean cooking energy

The widespread use of firewood and charcoal contributes to forest degradation, leading to biodiversity loss and climate change. Cleaner alternatives, such as biogas and solar cookers, provide sustainable solutions by utilizing renewable energy sources and reducing carbon footprints (Afrane & Ntiamoah, 2012; Ajibola et al., 2020; Simkovich et al., 2019; Zidago & Wang, 2016). Land degradation refers to the decrease in land quality and productivity, while greenhouse gasses are associated with the destruction of the ozone layer. Reliance on charcoal and firewood is associated with unsustainable tree harvest and incomplete combustion, which releases greenhouse gasses such as CO and NO_x (Armah et al., 2019; Stanistreet et al., 2019). Dagnachew et al. 2020 developed models that predict the result of biomass substitution such as a reduction of emission by 225 Mt of CO_2, and 335 million tons of firewood from harvest in 2030. Clean cooking solutions such as biogas digesters, ethanol stoves, and solar cookers offer renewable and eco-friendly options that reduce deforestation and emissions.

Social and economic benefits of clean cooking energy

Clean cooking reduces reliance on biomasses and lowers the costs associated with cooking fuel (Batchelor et al., 2018; Wentzel & Pouris, 2007). Moreover, the transition to clean cooking will create opportunities for businesses such as manufacturing, installation, and maintenance (Simkovich et al., 2019). Although clean cooking is capital-intensive in the initial investment, the ongoing cost is minimal compared to traditional cooking. Clean cooking technologies are more energy-efficient such that households spend less money on fuel over time. For instance, electric induction stoves consume less energy compared to traditional charcoal stoves, making them cost-effective.

It is approximated that people who use traditional sources of energy use at least 1.3 hours collecting biomass (Batchelor et al., 2018). The majority of women and children

are the ones directly involved with the human-induced impact associated with cooking energy choices due to time spent on fuel collection (LaFave et al., 2021; Onah et al., 2021). Moreover, families that adopt clean cooking methods face fewer health issues, reducing their medical bills and increasing productivity. The transition to cleaner energy will allow women and children to participate in other activities such as education and employment to promote community development and gender equality (Batchelor et al., 2018) which certainly improves the livelihood of women and children (Armah et al., 2019).

Challenges Towrds Adoption of Clean Cooking Energy

Economic challenges of clean cooking energy

Costs and challenges associated with the transition to clean cooking energy pose a barrier that, unless it's solved, will cause biomass to continue to have a significant share in cooking energy in Africa (Dagnachew et al., 2020). Traditional cooking consumes more time in fuel collection, which is mostly done by women and children and reduces their chances of economic activity participation. This results in the economic struggle of many families that use traditional biomass (Batchelor et al., 2018).

Moving to low carbon emission technologies such as LPG is the intermediate stage toward clean cooking energy. Lower and Middle-Income Countries (LMICs) have been promoting the use of LPG, but the main challenges remain the initial and refilling cost of the LPG cylinder (Troncoso et al., 2019). This can be faced by supporting innovative ideas for clean cooking technology as well as scaling up microfinance that targets low-income populations to emphasize clean cooking (Dagnachew et al., 2020; Wentzel & Pouris, 2007).

With affordability being a crucial factor, safety and awareness of health issues play key roles in determining the cooking energy source in society (Kimemia & Annegarn, 2016). The study shows that using LPG and natural gas is relatively cheaper compared to wood and charcoal in the longer term unless they can be collected for free (Stanistreet et al., 2019). However, the natural gas network is not yet complete enough to serve the communities in most African countries, and the market does not have enough retailers for LPG cylinders, which makes the switch challenging, particularly in a rural area that has a high reliance on natural resources to meet their basic needs (Onah et al., 2021). Furthermore, the upfront cost of acquiring LPG and the inability to be purchased in smaller quantities remain a challenge (Kizilcec et al., 2022).

Technological Challenges of Clean Cooking Energy

In Africa, cooking pots vary from small to large, with the fixed size of the cooking stand making it difficult for one to use the same stove to cook with the small pot and large pot. This enforces the use of alternatives to accommodate the pots in which biomass is involved in this case (Stanistreet et al., 2019).

Despite the ability to facilitate cooking at all temperatures, solar cookers are characterized by dependence on weather conditions as well as low efficiency during off-sun periods (Batchelor et al., 2018; Bhave & Kale, 2020). Solar cookers have the potential to reduce significant amounts of carbon emission, However, the equivalent amount of potential carbon emission to be reduced remains to be a question (Bhave & Kale, 2020; Wentzel & Pouris, 2007).

Safety concerns about the use of LPG and natural gas and the negative image of the technology pose a barrier to the adoption (Roopnarain & Adeleke, 2017). Incidents of leaks and explosions create fear, which necessitates community education programs to facilitate safe usage of LPG

and natural gas utilization (Kimemia & Annegarn, 2016; Stanistreet et al., 2019).

Government initiatives toward the adoption of clean cooking energy

Governments and NGOs have been implementing policies and interventions to promote clean cooking energies, aiming to improve the health and sustainability of the community in Africa (Simkovich et al., 2019). Coordination of a clean cooking agenda with wide development policies is necessary to facilitate the effectiveness and sustainability of the clean cooking program (Dagnachew et al., 2020). In 2024, The United Republic of Tanzania developed a ten-year national clean cooking strategy from 2024 to 2034 (Ministry of Energy, 2024). The strategy pointed out several initiatives to facilitate the clean cooking energy transition.

Clean cooking energy price control

The clean cooking energy supply chain, including the importation, transportation, and distribution of natural gas and LPG, is associated with price fluctuations. This price fluctuation is mainly due to currency value variation as well as the importation-exportation ratio, which always necessitates government intervention in terms of subsidies and other solutions to facilitate the transition. The government should ensure that the initial and usage costs of these clean cooking technologies are reduced to facilitate affordability (Ministry of Energy, 2024). These interventions increased the adoption of clean cooking in countries like Gabon (60%), Namibia (42%), and Angola (40%) (Armah et al., 2019). The countries with excess reserves of natural gas or LPG set aside an adequate amount for local consumption before exportation to ensure domestic demand is met before exportation such as Angola, and Algeria (Worldometer, 2024). On the other hand, countries with a deficit to no reserve of natural gas or LPG rely on imports to supplement the demand, which requires government concerns due to market instability, such as Malawi, Cameroon (Stanistreet et al., 2019), and Ethiopia (LaFave et al., 2021).

Conducive environment in clean cooking energy investment

Conducive environments have been created to facilitate cleaner cooking, for instance, reduction of taxes associated with equipment and refilling processes, and improved energy budget to specifically support the transition (Stanistreet et al., 2019). This set environment aims not only to attract investors in clean cooking but also to motivate users to transition. The government should be at the forefront of the promotion of cleaner cooking energy, including the improvement of financial benefits to motivate the users as well as investors (Afrane & Ntiamoah, 2012). Tanzania intends to develop, update, and harmonize enabling policies, laws, regulations, and guidelines to facilitate the adoption of clean cooking solutions (Ministry of Energy, 2024).

Financial aid for clean cooking adoption

Financial difficulties in switching to LPG and natural gas remain challenging in LMICs, particularly in Africa. Governments and private institutions have engaged to facilitate the switch by providing low-interest loans for people to acquire clean cooking equipment that has high upfront payment (Ministry of Energy, 2024; Stanistreet et al., 2019). Tanzania is planning to introduce a clean cooking project for each region as well as establish a database of statistics and information on clean cooking solutions by June 2025 (Ministry of Energy, 2024). Nigeria, between 2014 and 2018, decided to distribute 1000 improved cook stoves to reduce the amount of firewood and charcoal-induced carbon emission as well as forest degradation. (Onah et al., 2021).. Table 2 shows financial aid source, type, and beneficiaries.

Table 2: Financial aid source, type, and beneficiaries

SN	Financial Aid Source	Type of Aid	Target Beneficiaries
1	Government Loans	Low-interest loans	Low-income households
2	Private Sector Investments	Equity investment	Clean cooking technology firms
3	NGO Grants	Grants	Community programs and NGOs
4	Subsidies	Price subsidies	Users of clean cooking energy

Partnership with NGOs

In the move to clean cooking energy, African governments, in cooperation with NGOs, have started several initiatives such as Sustainable Energy for All (SEforALL) and Africa Renewable Energy Initiative (AREI), which promote the increase in access to clean cooking energy (Simkovich et al., 2019). NGOs have been involved in the promotion of clean cooking by introducing programs in Uganda and Ethiopia, among others (Roopnarain & Adeleke, 2017). For instance, through the Energia program between 2018 and 2022, 11700 renewable energy businesses run by women were supported, and more than 4.5 million consumers were reached with energy-enabled services and products in Kenya, Nigeria, Senegal, and Tanzania (Hivos, 2024).

Investment in clean cooking

In an attempt to promote investments in clean cooking, Tanzania aimed to encourage private sectors to seize business opportunities within the clean cooking value chain. Moreover, Tanzania aims to promote the use of national and international funds and programs to foster and enhance clean cooking investment (Ministry of Energy, 2024). This aims to see the decrease in the cost of permits, inclusion of clean cooking projects in investment guidelines, and award provision for clean cooking innovations.

Community involvement toward the adoption of clean cooking energy

Community engagement is a crucial aspect of promoting and implementing clean cooking energy in Africa (Wentzel & Pouris, 2007). To give the community ownership and sustainability in clean cooking to facilitate acceptance and empowerment, the community must be involved in the planning and implementation of the projects associated with clean cooking. Community empowerment, capacity, awareness building, and respect for cultural values and beliefs are essential in driving socioeconomic and environmental outcomes from the Clean Cooking project (Ministry of Energy, 2024; Simkovich et al., 2019).

In decision-making, the community should be involved as stakeholders or consultants (Wentzel & Pouris, 2007). The transition to clean energy involves changes in cooking habits, as well as technology, traditions, norms, and practices, which should be known to help tailor the clean cooking technology based on the values and beliefs of the community (Batchelor et al., 2018; Simkovich et al., 2019). This involvement helps in determining community preferences, needs, and concerns to be considered in the implementation of the clean cooking program. It's also necessary to create local economic opportunities from the clean cooking project, these opportunities include jobs, entrepreneurship, and other income generators that will directly engage community members in the project, which will accelerate the transition (Simkovich et al., 2019).

Energy transition comes with advancements in both designs and technologies for cooking applications. Through capacity-building and awareness programs such as workshops, training, outreach campaigns, and other education initiatives, the community will be aware of the economic, health, and environmental benefits that come with the technologies (Batchelor et al., 2018). These awareness

programs aim to equip the community with the knowledge and technical backup to facilitate the acceptance, operation, and maintenance of the deployed clean cooking technology (Wentzel & Pouris, 2007)
The feedback mechanism is necessary to ensure a long-term partnership, this will not only monitor but also evaluate the project implemented. Community feedback will create an impact beyond the project, such as trust and mutual understanding of the project. This can be established by the defined feedback channels, community meetings, and regular communications (Simkovich et al., 2019; Wentzel & Pouris, 2007). Table 3 shows community involvement, a description of the strategy, and the expected outcome.

Table 3: Community involvement strategy, description, and expected outcome

SN	Strategy	Description	Expected Outcomes
1	Stakeholder Involvement	Involve community members in decision-making	Increased project ownership and relevance
2	Capacity Building	Conduct workshops and training programs	Enhanced technical knowledge and skills
3	Awareness Programs	Run outreach campaigns to educate on the benefits	Improved understanding and acceptance
4	Feedback Mechanisms	Establish channels for community feedback	Continuous improvement and trust-building

Case Study: South Africa

Background

Same as other African countries, rural areas in South Africa consume relatively high traditional fuel with 41.2% of while only 6.9% of the urban population using traditional fuel (Accenture, 2011). Among other clean cooking options, E-cooking is the largest portion of clean cooking in South Africa, with 77% of the cooking energy being electricity (MECS, 2023). E-cooking potential was identified based on the government plan of 2030 that 100% of all citizens have access to electricity (Accenture, 2011). Unlike other technologies, the cost of e-cooking depends mostly on the efficiency of the appliance, as shown by the bar chart below. Figure 10 shows a cost comparison of different cooking energy sources in South Africa

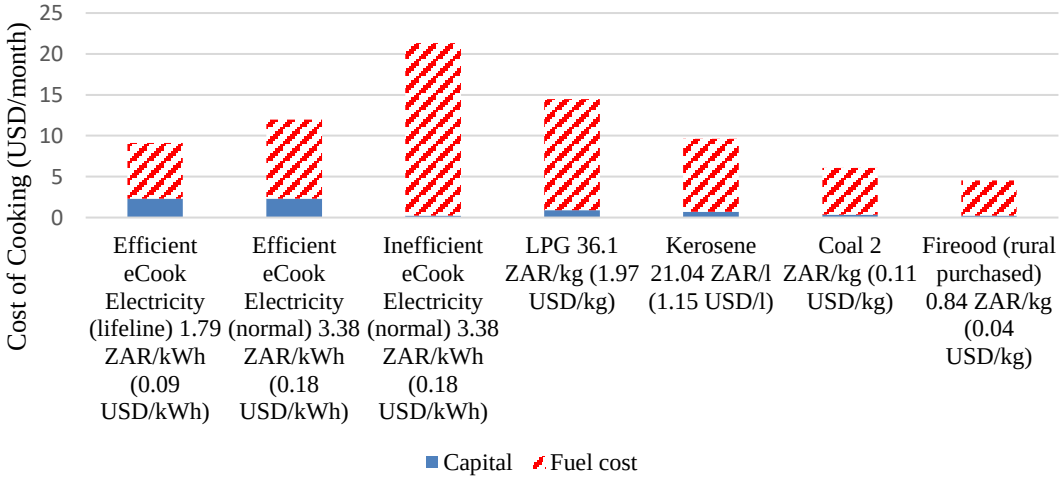

Figure 10: Monthly cost of different cooking energy in South Africa (MECS, 2023).

Government initiatives towards adoption of clean cooking energy in South Africa

Renewable Energy Independent Power Producer Procurement Program (REIPPPP) is the South African government initiative introduced in 2011 aiming to diversify the energy mix while bolstering national electricity generation capacity. Under the program, 123 projects were awarded to the private sector for power production and procurement (IPP Office, 2015). The diversification of the energy mix includes clean cooking energy alternatives (NPC, 2018).

Free basic alternative energy (FBAE) is a program that aims to provide alternative sources of energy such as LPG, solar energy, and bio-ethanol gel to poor households that are not connected to the grid. It was launched in 2003, and with modification, relaunched in 2007, the main objective being minimizing health risks, maximizing energy efficiency, as well as increasing electricity access to households (IEA, 2017). This program targeted to aid rural municipalities that struggled to provide free basic electricity (FBE), which improved clean cooking options for many households (Republic of South Africa, 2024).

Several types of subsidies have been implemented by the South African government, aiming to facilitate the affordability of clean cooking energy and technologies to alleviate energy poverty (Longe, 2021). These subsidies include low-interest financial loans, tax incentives, and grants for community projects. This aims to lower the financial barrier and make the adoption financially feasible for all households. Table 4 shows different government initiatives, their goal, and the results of their implementation.

Table 4: Government initiatives, goals, and results of implementation.

SN	Program	Goal	Actions Taken
1	Renewable Energy Independent Power Producer Procurement Program (REIPPPP)	Diversify energy mix, boost generation capacity	Awarded 123 projects, focusing on clean energy alternatives
2	Free Basic Alternative Energy (FBAE)	Provide alternative energy sources to poor households	Introduced LPG, solar energy, and bio-ethanol gel
3	Subsidies	Facilitate the affordability of clean cooking technologies	Low-interest loans, tax incentives, and grants

Challenges to the adoption of clean cooking energy in South Africa

Lack of comprehensive policy for clean cooking energy compared to other sectors. This lowered the contribution to clean cooking energy agendas, which left other issues unaddressed, leading to a lack of targeted support for clean cooking energy. Bureaucratic complexity due to multiple regulatory authorities contributes to delays in the introduction of clean cooking energy in terms of products and technology (Aliyu et al., 2018).

Reliance on biomass fuel by a significant portion of the South African population (Matinga et al., 2011), particularly in the rural areas, which is due to energy poverty where more than 10% of income is spent on energy (Longe, 2021). Traditional cooking energy is attached to the culture and norms of society, and changing it to clean cooking energy can be challenging.

Financial constraints have been a problem for many households in acquiring clean cooking technology. The high upfront costs are prohibitive for low-income families, provided that financing options are often

lacking (Matinga et al., 2011). Furthermore, the long-term sustainability of the funding remains a concern as most of them are limited or subjected to changes in political moves.

Geographical barriers in terms of the remoteness of the rural areas and difficult-to-reach areas make it challenging for clean cooking energy program implementation. Poor logistics due to rough terrain, dispersed population, and lack of roads affect the time and cost of project implementation. (Longe, 2021). This affects transportation as well as the supply chain, which may lead to the deterioration of the project. Table 5 shows challenges faced in the attempt at clean cooking adoption, the resulting impact, and potential solutions in South Africa

Table 5: Clean cooking adoption challenges faced in South Africa, impact, and potential solution.

SN	Challenge	Impact	Potential Solutions
1	Lack of Comprehensive Policy	Limited support and targeted interventions	Develop and implement clear policies for clean cooking
2	Reliance on Biomass Fuels	Cultural attachment and energy poverty	Increase awareness, provide alternatives
3	Financial Constraints	High upfront costs and limited funding	Expand financing options, support low-income households
4	Geographical Barriers	Difficult logistics and supply chain issues	Improve infrastructure and logistics for remote areas

The success of the implemented clean cooking energy effort in South Africa

South Africa has made notable strides in implementing clean cooking energy initiatives, aiming to address the challenges associated with traditional cooking fuels and improve overall energy access and sustainability. The success of these initiatives can be evaluated through various dimensions, including adoption rates, health benefits, environmental impact, and socioeconomic improvements.

South Africa has seen significant progress in increasing the adoption of clean cooking technologies. Government and non-governmental organizations have introduced various programs to promote the use of cleaner stoves and fuels, such as liquefied petroleum gas (LPG) and electricity. These initiatives have successfully reached a broad segment of the population, with increased numbers of households transitioning to cleaner energy sources. by 2023, more than 80% of the population had access to electricity, with 77% using it for cooking applications (MECS, 2023). Efforts such as subsidies, educational campaigns, and partnerships with local businesses have played a key role in scaling these technologies.

The shift to cleaner cooking technologies has led to measurable improvements in public health. By reducing reliance on traditional biomass fuels, which contribute to indoor air pollution, cleaner stoves and fuels have lessened respiratory and cardiovascular issues associated with smoke inhalation (Tamire et al., 2018). With the success of universal access to clean cooking energy by 2030, almost 4% of the population's health can be improved, particularly for women (Aktas et al., 2022). The adoption of clean cooking technologies has contributed to environmental conservation efforts in South Africa. Cleaner stoves and fuels generate fewer emissions and reduce the demand for biomass fuels, which helps mitigate deforestation and degradation (Aktas et al., 2022; Marebane, 2021). Government policies and incentives aimed at supporting renewable energy sources further enhance

the environmental benefits of these initiatives.

In terms of social-economic development, the transition to cleaner technologies has reduced the time and cost associated with fuel collection and purchase, allowing households to allocate resources more effectively (Longe, 2021). Additionally, the growth of the clean cooking sector has created job opportunities in the manufacturing, distribution, and maintenance of these technologies (Tamire et al., 2018). Programs that focus on supporting local entrepreneurs and businesses involved in the clean energy sector have further contributed to economic development.

CONCLUSION AND RECOMMENDATION

Policy recommendation and implementation strategy

Policy Recommendations:

Policy interventions are necessary for the transition to clean cooking as they are responsible for solving educational, financial, infrastructural, and regulation dilemmas facing the clean cooking transition (Armah et al., 2019). Collaboration of government, private sector, research institutions, and international partners is essential in the realization of the energy transition to clean cooking energy.

A policy that aims to facilitate the reliability of clean cooking alternatives should be set in place to attract users. Such facilitation includes the development of supply chains such as LPG and natural gas infrastructures as well as increased electricity networks would help to ensure the reliability of the clean cooking option to households (Kizilcec et al., 2022). Furthermore, the government should establish a regulatory framework for clean cooking that will create a conducive environment for the transition to clean cooking. The framework may include regulations that encourage the use of clean cooking technology, set standards for the cooking technology (Kimemia & Annegarn, 2016) as well as safety procedures for the use of clean cooking technology (Kizilcec et al., 2022). To allow improvement of the policy, a monitoring mechanism should be designated to evaluate the strengths and weaknesses of the implemented policy. This will facilitate decision-making and ensure the policy interventions effectively address the challenges and barriers associated with clean cooking adoption (Kizilcec et al., 2022).

Advancement of clean cooking technology requires innovation to maximize human interaction safety with the technology and promote renewable energy, which will accelerate both the transition and economic growth (Simkovich et al., 2019). The government should invest in research and innovation of new clean cooking technology to promote the development of new technologies, improving efficiency as well as tailoring the technologies to customer satisfaction (Dagnachew et al., 2020).

Different development goals merge with clean cooking when it comes to clean cooking targets, such as health improvement, hunger elimination, gender equality promotion, and environmental preservation. To make a clean cooking agenda sound, it's necessary to integrate it with broader development goals to produce a multiplier effect on the community (Afrane & Ntiamoah, 2012). Moreover, urbanization refers to the upgrading of rural areas to urban status by facilitating infrastructure and public services, among others. In sub-Saharan Africa, about 26% of the urban households while only 2% of the rural households which shows that the urban population has higher access compared to the rural population, which implies that urbanization may play an important role in the facilitation of access to clean cooking (Armah et al., 2019).

Implementation Strategies

Provision of education programs to provide knowledge to the community regarding health, environmental, and economic benefits that come with clean cooking

options (Afrane & Ntiamoah, 2012). This requires funding and sustenance to bolster community attention to the transition for a longer period to acceptance. Study shows that education level and wealth have joint and magnified effects on choice and access to clean cooking energy (Armah et al., 2019; Kizilcec et al., 2022).

To facilitate the adoption of clean cooking, the government and NGOs should provide subsidies to clean cooking technology to lower the cost of both acquiring the system (Batchelor et al., 2018) as well as running the system (Kimemia & Annegarn, 2016). In parallel to subsidies, the government should also build infrastructure such as LPG or natural gas networks and electricity grids to increase the reliability of clean cooking energy (Dagnachew et al., 2020). Moreover, it's necessary to promote an environmental agenda such as forest conservation by forestation to mitigate climatic changes and land management to increase water retention ability as well as productivity. The government should strengthen climatic and environmental frameworks such as careful budgeting, planning, and implementation, for instance, integration of the SDGs in the long-term national development plan to promote food and energy security (Onah et al., 2021) moreover, to prevent mistreatment but also to promote their importance (Afrane & Ntiamoah, 2012).

Pay-As-You-Go is the feature that is currently used in solar home systems, this allows households to pay a lump sum upfront payment in small and regular payments for a specified time. The incorporation of the technology in LPG and natural gas adoption will allow the acquisition of equipment and facilitate the adoption of clean cooking (Kizilcec et al., 2022).

In clean cooking utilization, it is important to consider the safety of the user against the clean cooking technology. This includes proper regulation on the exchange and refilling of LPG cylinders and set guidelines on natural gas equipment and other technologies to avoid risks associated with all technologies (Stanistreet et al., 2019). For instance, LPG cylinders are supplied with gas outlets that only have control over the amount of gas released, which controls the flame requirement (Kumar et al., 2016). However, the level of consumption still can't be monitored, which makes it unreliable. Incorporation of the device that measures the gas level will increase the cost in terms of the cost of maintenance and calibration but make the LPG cylinders more reliable for arranging saving plans and even alternating the source.

Conclusion

Generally, the use of traditional cooking energy sources, such as firewood and charcoal, has profound health, environmental, and socio-economic impacts, particularly in low and lower-middle-income countries. For instance, traditional cooking practices disproportionately burden women and girls, limiting their opportunities for education and economic advancement. Transitioning to cleaner cooking technologies not only promises significant health benefits but also offers opportunities for sustainable economic development and environmental preservation, which can be realized through technological innovation, community education, and involvement.

Clean cooking technologies offer significant advantages, including higher efficiency, reduced indoor air pollution, and enhanced well-being for communities. The adoption of clean cooking technologies is not just a matter of improving cooking practices; it is a crucial step toward a healthier, more sustainable, and equitable future for all. However, the transition to clean cooking energy posed challenges such as affordability, infrastructure, safety concerns, and community awareness. Moreover, the upfront costs associated with clean technologies like LPG, alongside the ongoing expenses for refills, remain prohibitive for many households, particularly in LMICs.

The transition to clean cooking energy in Africa requires initiation from the government, such as effective government policies, targeted financial support, and active participation from NGOs and the

private sector. Furthermore, the government should weigh the effort to address economic and infrastructural challenges and foster a supportive investment climate for private sectors. These efforts will significantly ease the transition to clean cooking energy, which will improve public health, environmental sustainability, and energy security across the continent. On the other hand, meaningful community engagement will facilitate the adoption of clean cooking energy as well as strengthen the long-term success and impact of government initiatives. By respecting local cultures, empowering community members, and fostering continuous dialogue, clean cooking projects can achieve their intended health, environmental, and economic outcomes more effectively.

The focus on investment such as infrastructure expansion, subsidies, and low-interest loans provision have been vital in ensuring the accessibility, affordability, and reliability of clean cooking technologies. Moreover, awareness campaigns addressing cultural and behavioral barriers highlight the need for culturally sensitive approaches in promoting clean cooking technologies. Partnerships between the government, private sector, NGOs, and international partners have been instrumental in scaling clean cooking initiatives and ensuring their sustainability. Furthermore, continuous monitoring and evaluation of clean cooking initiatives in South Africa have allowed for timely adjustments, ensuring program effectiveness. Other African nations should foster a similar environment towards transition pull resources and develop an appropriate plan towards clean cooking.

Generally, to improve the welfare of the community, energy transition from traditional to clean cooking stands as the main chess piece, however, the government remains a fundamental part of the energy transition. The government should intentionally intervene by providing deliberate efforts for the transition to be realized.

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