Bioethanol for Cooking

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Bioethanol has been identified by the academic literature and in the development community as a promising clean fuel to replace charcoal. Bioethanol is one of the cooking fuels considered to be clean based on the 2014 WHO guidelines, which aim to reduce the health risks associated with exposure to indoor air pollution from household fuel combustion.

bioethanol clean cooking

1. Introduction

Bioethanol is among the few fuels used for cooking that have the potential for positive health [1], climate and environmental benefits [2], gender equality [3], increased employment opportunity, earnings, time, and fuel saving impacts [4], alongside other wider economic and welfare implications. However, despite this wide range of known benefits, until recently, bioethanol has remained relatively unexplored by researchers and policymakers. According to [5], writing before the launch of KOKO in Kenya in late 2019, bioethanol is the least appreciated clean fuel today in most developing countries. It has received the least amount of attention, despite its performance attributes compared to LPG. There have been few comprehensive impact analyses of bioethanol alongside other fuels and stove technologies for cooking. This is explained by the limited number of studies that have taken place and a lack of consensus on the approach. The absence of a rigorous analysis of the benefits, as well as of the historical barriers to scalability, currently limit the understanding of the potential contribution of bioethanol fuels and stove technologies for cooking.

Globally recognized approaches to estimating the impacts of fuel and stove technologies are lacking and largely segregated, focusing on one or two specific impacts (i.e., health, environment, or wider economic impacts). A detailed review of the approaches used to estimate the impacts of cooking more generally are outside the scope of the current discussion. The focus here is on the available empirical evidence and the outcomes of a related benefits analysis.

The most extensive evidence on improved and/or clean fuels and stove technologies for cooking is in household transitions from using solid biomass (including firewood and charcoal) in traditional stoves to improved fuels and stove technologies [1][6][7][8]. More recent studies have focused on transitions to modern/clean cooking fuels such as LPG, biogas, and electricity [3][9]. Bioethanol is one of the cooking fuels considered to be clean based on the 2014 WHO guidelines, which aim to reduce the health risks associated with exposure to indoor air pollution from household fuel combustion. According to the World Bank’s Multi-Tier Framework for cooking [10], in which improving performance attributes across local emissions, efficiency, convenience, safety, affordability, quality, and fuel availability leads to higher tiers, bioethanol qualifies as a tier 5 (i.e., top) clean fuel and technology.

The following sections discuss the evidence around bioethanol cooking organized based on three impact categories: health, climate and environment, and economic and opportunity costs. It also provides a summary of how bioethanol supports the achievement of a range of SDGs.

2. Health Impacts

This section explores the evidence on the health benefits of using bioethanol for cooking. The discussion highlights the illnesses/diseases that may emanate from using unclean fuels and stoves and the possible health improvements of switching to clean fuels and stoves for cooking, such as bioethanol.

Cooking with open fires has harmful effects on health due to both household air pollution (HAP) and the physical effects of fuel collection. HAP causes or exacerbates a wide range of conditions, including ischemic heart disease (IHD), stroke, lung cancer, chronic obstructive pulmonary disease (COPD) in adults, and acute lower respiratory infection (ALRI) in children [1][6][11], with greater risks among poor populations [12]. Additionally, because of women's role in cooking and caring for children in Sub-Saharan Africa, they are highly exposed to the pollutants/particles produced from incomplete combustion, leading to respiratory and eye disorders and a high incidence of death, approximated at 1.6 million/year [13].

There is a growing consensus that use of improved stoves with the same solid biomass fuel does not significantly reduce the negative health effects associated with open-fire cooking. For example, ref. [7] provided evidence of this, while showing that the use of other cleaner fuels (i.e., LPG, bioethanol, and biogas) offers greater health benefits.

Due to the few studies that have been carried out and the time it takes for studies to obtain funding, since bioethanol has been commercialized at scale, empirical evidence for the health benefits of bioethanol-fueled cookstoves specifically is still relatively scarce. However, refs. [14][15] both show that cooking with bioethanol is a cleaner and healthier alternative, and ref. [13] includes it as one of the options for improved health conditions delivered from cooking with a clean smokeless fuel.

In Ethiopia, ref. [16] investigated the impact of using a bioethanol stove on indoor pollutants instead of inefficient cooking with wood. In their study, wood was associated with two major pollutants: soot/particulate matter (PM2.5) and carbon monoxide (CO), which are responsible for the bulk of the negative health impacts of indoor smoke. Ref. [16] and others showed that the use of bioethanol stoves resulted in average reductions of 84% and 76% for PM2.5 and CO, respectively.

Other health impacts have been studied, demonstrating the implications of bioethanol for cooking and pregnancy. Recent evidence from Nigeria shows that switching to bioethanol-fueled stoves has the potential to provide needed protection for women and their developing fetuses [17].

Ref. [5] reported on their own literature review of the emissions caused by different cooking fuels (firewood, charcoal, kerosene, LPG, and bioethanol) and concluded that bioethanol and LPG offer the greatest and most broadly comparable health benefits.

A separate type of health benefit arises from a switch away from firewood, which is a reduction in the need for carrying wood long distances [18]. The health effects of wood collection include long-term physical damage to the backbone, head, hands, and legs from the strenuous work [19], as well as encounters with wild animals and snakes.

3. Environmental Impacts

The environmental impacts of cooking discussed in this section include greenhouse gases and carbon neutrality, indoor and outdoor air pollution, biodegradability, deforestation, and the provision of warmth. At the end of this section, the health and climate impacts of cooking with different fuels and stoves is briefly summarized.

Burning bioethanol is widely assessed to be a carbon neutral activity, in the sense that the amount of carbon dioxide that is emitted during combustion is the same amount emitted by plants during photosynthesis [11]. Ref. [7] shows that the use of other cleaner fuels (i.e., LPG and biogas) offers lower greenhouse gas (GHG) emission reductions. Bioethanol emissions with sugarcane bagasse as a feedstock can meet the European Union Renewable Energy Directive of a 60% reduction in GHG emissions relative to petrol and other agricultural and forest sources [8]. In terms of air pollution, beyond being associated with a reduction in indoor air pollution, bioethanol is also associated with improved outdoor air quality [11]. In terms of its impacts on other media, bioethanol is considered to be biodegradable; therefore, its use reduces the toxic impacts of potential fuel spillage on land and in aquatic environments [20].

Empirical evidence shows that charcoal sold in urban areas and rural wood gathering contribute significantly to deforestation [21]. Deforestation in turn can lead to deforestation and aridification [22]. According to ref. [13], using a carbon-neutral source such as bioethanol and/or a more efficient combustion process means that forest degradation can be halted and reversed, and the tree cover has a chance to regenerate. There are significant emission reductions associated with a household switching from burning charcoal for cooking to bioethanol.

Finally, bioethanol burns cleanly enough that a chimney is not needed to remove air pollutants from an indoor kitchen. As such, the heat generated is retained in the room, which is a benefit in regions or at times of the year in which space heating is wanted.

The interlinkages between the act of cooking using fuels and stove technologies and the consequences it has on health and climate are evident. **Figure 1** presents an overview of the health and climate impacts of a wide range of fuel and stove combinations; however, these are averages, and their actual performance varies widely. However, bioethanol is included in region 4, with the least health and climate implications, which is a cluster of modern renewable fuels including bioethanol and biogas [1].

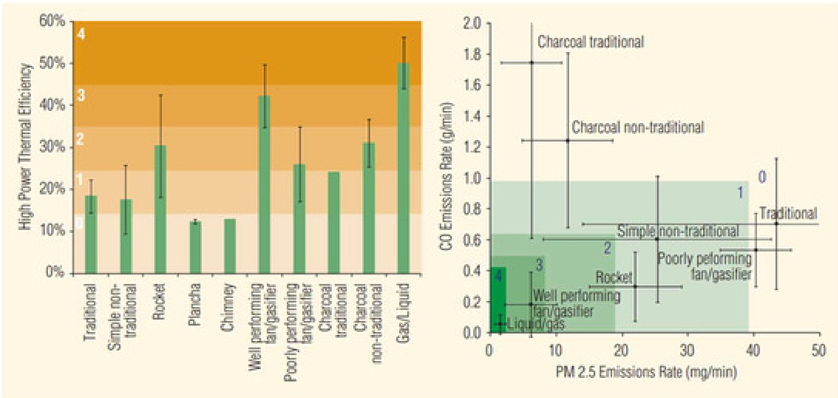

Figure 1. Health impacts and climate impacts of cooking technologies. Source: [23].

4. Economic and Opportunity Cost Impacts

Switching to using clean and modern energy sources for cooking has benefits beyond health and the environment, including a wide range of economic and opportunity benefits. These include job creation, gender equality/balance, reduced inequalities, reducing rural poverty, and enhancing energy security while at the same time reducing dependency on imported fossil fuels and their associated demand for foreign reserves, as well as wider economic sector growth (e.g., in agriculture productivity and food security).

Evidence shows that women face a disproportionate burden of societal roles, which expect women to collect fuel and prepare and cook food [11]. Ref. [3] identified the following implications of use of bioethanol for gender equality: first, in terms of time saving that would be otherwise be spent on fuel collection; second, this newly available time offers women the opportunity to engage in income generation, education, or leisure activities [11]; third, a reduced exposure to HAP and related illness; and fourth, time and fuel savings resulting from bioethanol for cooking (ECF) technology, which is efficient and has a higher energy concentration compared to other fuels. Generally, in a day, women and children spend 4.5 h on unpaid work [24].

There has been historical concern about bioethanol production and its potential implications for food security, environmental degradation, and water profligacy; however, this has been comprehensively disproven in the academic literature [25][26]. Instead, where bioethanol cooking fuel is replacing charcoal, which itself is the main cause of deforestation and desertification of land, as well as a major local cause of death due to household air pollution, there are very significant local benefits to a fuel switch which may have major positive implications for poverty alleviation and food security if a local bioethanol industry can attract investment into agricultural processing.

In Kenya, the government, through its bioethanol cooking master plan, has seen the development of a local bioethanol cooking industry as valuable for economic development as well as for its social and environmental impact, and it can attract more investment into the local existing sugar industry, is not a concern regarding food security or land use. South Africa in contrast has deployed a legislative reach, restricting production to the needs of local markets and requiring registration of producers for fuel tax rebates [27]. Rather than threatening food security, Cartwright in his study concludes that there is a probability that investment in Southern African Development Community (SADC) rural economies could enhance food security through the provision of infrastructure, the transfer of skills, the supply of animal feed by-products, and reduced exposure to oil-driven food price inflation.

Table 1 compares the impact estimates of using bioethanol fuel and stove technology for cooking with that of biomass at the household level, national level, and Sub-Saharan Africa in general. Comprehensive impact estimates, including those that focus on monetary values for both fuel and stove cooking technologies, are limited and are less well developed for modern and clean fuel and stove options such as bioethanol [5]. Thus, the possibilities of underestimating the health, environment, and wider economic impacts remain a concern that affects policy discussions on clean cooking transitions globally.

Table 1. Impact estimates of using bioethanol fuel and stove technology for cooking.

Impact Category	At the National Level (Kenya) Biomass	At the Household Level (Kenya) Bioethanol	At the National Level (Kenya) Bioethanol	Sub-Saharan Africa Solid Fuels [a]
Environmental	• Deforestation and forest degradation: Kenya loses 10.3 million m^3 of wood from its forests every year from unsustainable charcoal and wood fuel use [c,e] • A major contributor to the 0.3% per year deforestation rate [e] • GHG emissions: Household fuel use in Kenya contributes 22–35 million tons of CO_2 eq. each year, (equivalent to 30–40% of total Kenya GHG emissions) [c,e]	• Up to 30 trees saved per HH annually from switching from charcoal [e] • Slows down rate of deforestation and, consequently, its impact on food insecurity [e] • 0.7–5.4 ton reduction in GHG emissions per HH per year from switching from kerosene and charcoal, respectively [e]	• Deforestation averted: Up to 54 million trees saved [c] • GHG emissions: Up to 13.5 billion kg of C02 equivalent saved [c]	• Total Environment in billion USD: low ($0.6), mid ($6.3), and high ($11.9) [f] • GHG emissions (fuel consumption) in billion USD: low ($0.2), mid ($2.1), and high ($3.9) [f] • GHG emissions (charcoal production) in billion USD: low ($0.2), mid ($0.7), and high ($1.2) [f] • Deforestation in billion USD: low ($0.2), mid ($3.5), and high ($6.7) [f]
Health	• Indoor air pollution: 728 k disability-adjusted life years (DALYs) and 16.6 k deaths annually [e] • 8–10% of early deaths in Kenya [b,c]	• ~0.25 DALYs saved per HH per three-year intervention period from switching from charcoal and kerosene [e]	• Disability-adjusted life years (DALYs) averted: Up to 507,000 DALYs [c] • Deaths averted: ~3700 deaths could be averted [c]	• Total health in billion USD: low ($0.6), mid ($0.8), and high ($1.5) [f] • Mortality from household air pollution in

Impact Category	At the National Level (Kenya) Biomass	At the Household Level (Kenya) Bioethanol	At the National Level (Kenya) Bioethanol	Sub-Saharan Africa Solid Fuels [a]
	• Lower respiratory tract disease is the third largest contributor to deaths in Kenya [e] • Pneumonia is a major cause of death in children under the age of five, largely due to indoor air pollution [e]	• Reduction of ~50 deaths per 25,000 households from reduced indoor air pollution [e] • Safety risks of storage, handling, and use are lower for a liquid than pressurized gas [e]	• Economic value of deaths averted and DALYs saved: ~KES 372 million in lost wages [c]	billion USD: low ($0.3), mid ($3.5), and high ($6.8) [f] • Morbidity from household air pollution in billion USD: low ($0.2), mid ($0.7) and high ($1.1) [f] • Other health conditions (burns, eye problems in billion USD: low ($0.1), mid ($0.8) and high ($1.5) [f]
Economic/Opportunity costs	• Food insecurity: deforestation resulting from the use of dirty fuels exacerbates food insecurity and harms the agriculture sector [c,e] • Foregone incomes for avoidable time spent cooking and cleaning [c,e] • Avoidable spending on expensive fuel [e] • Tax revenue loss for government given informality of market [e]	• Distributed in smaller volumes, making it more accessible to lower income users [e] • Existing domestic bioethanol sector could be expanded, creating formal, taxable jobs and boosting smallholder farming income [e] • 20–40 min saved per HH per day from switching away from charcoal [e]	• Jobs created: Up to 370,000 jobs (with the majority in feedstock production) [c] • New income generated: Up to KES 51 billion, with additional income of up to KES 180,000 per year for smallholder farmers [c] • Increased demand in the agricultural sector for producing fuel from agricultural residues and wastes [d] • New opportunities for value-added investment in the	• Total economic in billion USD: low ($4.2), mid ($20.6), and high ($36.9) [f] • Spending on solid fuels in billion USD: low ($0.4), mid ($3.8), and high ($7.3) [f] • Time wastage (fuel collection) in billion USD: low ($0.6), mid ($6.5), and high ($12.4) [f] • Time wastage (cooking) in billion USD: low ($3.3), mid ($10.2), and high ($17.2)

Impact Category	At the National Level (Kenya) Biomass	At the Household Level (Kenya) Bioethanol	At the National Level (Kenya) Bioethanol	Sub-Saharan Africa Solid Fuels [a]
			agricultural sector [d] • Greater financial resources and boosted GDP from reduced fossil fuel imports, demand for foreign earnings, and guarantees security of energy supply [d,c]	

[a] Annual economic losses and opportunity costs associated with solid fuel dependencies in Sub-Saharan Africa (in billion USD). [b] High possibilities of underestimation of the full disease burden, as many negative cooking health effects have not yet been quantified (e.g., burns, eye diseases, physical injuries from carrying firewood, etc.). [c] [3]. [d] [11]. [e] [5]. [f] [4].

5. Contribution to SDGs

Using bioethanol for cooking supports several sustainable development goals, briefly presented in **Table 2**.

Table 2. Bioethanol for cooking and its contribution to SDGs.

SDGs	Bioethanol for Cooking Contributions
SDG 1: No Poverty	The time saved by cooking with bioethanol can be spent on income-generating activities [11]. Potential for cheaper fuel using discounts from carbon credits generated from fuel switch (KOKO model). Potential for additional income for small shopkeepers from bioethanol fuel dispensing machines. Potential to support farmer incomes from locally sourced fuel
SDG 2: No Hunger	Investing in the bioethanol industry enhances agricultural productivity and food security [27][28]
SDG 3: Good Health and Well Being	Switching from using wood and other biomass fuels to using bioethanol for cooking improves health conditions through a reduction in exposure to both PM2.5 and CO [11][28]
SDG 4: Quality Education	Using bioethanol instead of traditional biomass can help children, especially girls, stay in school by reducing the time spent on cooking and collecting fuel for the household [11][28]
SDG 5: Gender Equality	The time saved as a result of using bioethanol for cooking instead of traditional biomass reduces the burden of unpaid care work, especially among women, which remains a major cause of gender inequality [11][28]. Additional potential impacts from the ability to move to two-burners stoves
SDG 7: Affordable and clean energy	The ability of bioethanol to be distributed in even smaller volumes enhances accessibility and affordability of bioethanol fuel, especially among lower-income populations [11]
SDG 8: Decent Work and Economic Growth	Demand for bioethanol for cooking spurs employment generation beyond bioethanol processing plants, distilleries, and distribution to other sectors and enhances overall economic growth [11][28]
SDG 9: Industry, innovation and infrastructure	Development of the bioethanol industry will require innovations in bioethanol production, introducing innovative farming practices and agricultural zoning research. A clear concept for the supply chain, involving local stakeholders from an early planning stage, supports several intersecting industries [28]. Bioethanol for cooking requires investment in technology (hardware and software), storage, and transportation infrastructure.
SDG 10: Reduced inequalities	Saved time associated with bioethanol for cooking reduces inequalities represented in the form of reduced time spent on income generation, education, or leisure activities [11]
SDG 11: Sustainable Cities and Communities	Clean cooking addresses household and ambient air pollution, resource efficiency, and climate vulnerability [11]
SDG 12: responsible	Sustainable bioenergy production helps to prevent deforestation. Careful planning conserves environmentally sensitive areas, making use of rehabilitating abandoned, intensively use farmland

SDGs	Bioethanol for Cooking Contributions
consumption and production	or moderately degraded land [28]
SDG 13: Climate Action	Bioenergy supports resilience against climate change. Bioethanol replaces fossil fuel and traditional biomass, reducing greenhouse gas emissions [11][28]
SDG 15: Life on Land	Bioethanol for cooking reduces the amount of wood required for cooking, thereby reducing environmental degradation and pressure on forest resources [11] Bioethanol is carbon neutral/biodegradable, since the amount of carbon dioxide that is emitted during combustion is almost equal to the amount of carbon dioxide absorbed by the plants during photosynthesis for growth [28]

6. Understanding Barriers to Scalability of Bioethanol Fuels and Stove Technologies for Cooking

Historically, increasing the adoption and use of clean and modern cooking technologies in Sub-Saharan Africa has been hampered by a range of factors, including poverty, stove functionality, stove design, fuel availability/accessibility, fuel costs/affordability, awareness [29], and a relatively high cost due to unfavorable tax and tariff treatments relative to cooking fuel alternatives like charcoal, kerosene, and LPG [5][28][30]. The potential impact of bioethanol cooking has made it attractive for a number of clean cooking companies and development institutions. However, until the explosive growth of the KOKO business model, many of the same barriers to scale have held back the growth of the industry. This section reviews previous studies of these scaling barriers. According to [1][5], the success of clean cooking programs in developing countries is possible by prioritizing accelerating awareness creation. According to [4], in their study that focuses on bringing clean, safe, and affordable cooking energy to households across Africa, governments in Sub-Saharan Africa could encourage the uptake of clean cooking stoves and their components by removing taxes and duties to exempt technologies that are imported and by reducing the number of licenses required by cookstove manufacturers and distributors. A study by [5] also found that increasing uptake is possible through affordable prices for clean cooking stoves and fuels. Bioethanol cooking fuel is less expensive because of climate-financed discounts, which support its clean, sustainable production and sale in affordable bundles. Bioethanol cooking fuel is thus a viable and scalable modern cooking fuel with the potential to be sold at prices affordable to most urban Kenyans currently relying on kerosene and charcoal [4]. The study notes that if the government of Kenya made (denatured technical) bioethanol zero-rated for VAT and eliminated tariffs, it would be among the cheapest cooking fuel options in Kenya and could displace charcoal and kerosene.

Ref. [1] examined the background, challenges, and possible policy solutions for clean cooking in Asia. The study has several findings and recommendations on how to strengthen consumer preference and demand. The study first establishes that clean cooking programs are mainly successful in cities; households in rural areas face difficulties in receiving the incentives for the programs. Furthermore, the study observed that a considerable number of clean cooking programs in Asia are subsidies for fossil fuels, as they target the promotion of LPG for cooking. The study asserts that enhancing the awareness of women about clean cooking technologies and improved cookstoves is fundamental, and that a comprehensive set of actions for enhancing awareness is necessary to guarantee the success of clean cooking programs in developing countries. The study also suggests that conducting impactful research on modelling of consumer choices for cooking fuels in countries, as well as developing the right business model for scaling-up the clean cooking market, is helpful for successful design and implementation of clean cooking policies and programs.

A hindrance to scale-up of bioethanol programs has been the lack of access to business and startup finance to access cookstoves and fuel distribution technology [4]. Access to financial support for clean cooking business and low-income households' stoves has been investigated by several authors [3][4][28][31][32]. These studies provide recommendations for access to finance for businesses and low-income households. The underlying message is that access to financial support should be addressed based on the use of the finances; generally, either for capital investment and end-user finance for final products produced, or as end-user subsidies to support low-income households for access to clean cookstoves. Scaling up of bioethanol for cooking also requires specific technology for the production and collection of sufficient raw materials, their purchase at a fair price, and their conversion into a final product that is attractive enough to be sold in a competitive market and meet local requirements. Feedstock availability and sizing market demand for bioethanol over the entire project duration is also a consideration [28]. Refs. [1][4][33] separately examined stove and fuel technology as challenges for clean cooking in

Asia and Africa. They recommended that local innovation be aligned with customer feedback and matched with finance and policy access support that is easily accessible by international partners.

Several studies [1][3][4][28][33][34] have analyzed the effects of stakeholder's participation on bioethanol cooking scaleup from the government, donor community, private sector, internal partners, and specialized agencies. These studies conclude that actors in the bioethanol sector have unique roles they play, covering the provision of financing [3][33], creation of technology/knowledge transfers [3], promotion of stoves [1][4][34], development of policy [28], and development of a specialized agency focused on the promotion of the bioethanol industry [4][34].

In addition to stakeholders' involvement, finance, and development of technology, ref. [28] argues that to enable energy transition and sustainable development in developing countries, the implementation of bioethanol plants, management, and the organization of the supply chain requires feedstock supplies to be specific, affordable, adequate, and of reliable quality and quantity. According to [28], a preliminary study of the bioethanol sector value chain is critical; it enables the identification of challenges and possible mitigation measures, thus ensuring sustainability of the value chain.

Addressing challenges in both the supply chain and initial/preparatory phases is crucial for scaling up bioethanol for cooking. Similar findings were also reported by ref. [30]. The study reports that ethanol as a household fuel demonstrates some potential for scale-up and commercialization, but it may require simultaneous stabilization of the ethanol supply, growth of a city-wide distribution infrastructure, and affordably priced stoves and fuel.

Policies, standards, and the regulatory environment [4] can each pose implementation challenges for companies. According to [28], bioethanol cooking fuel faces a lack of policy support, as most governments are unaware of their economic, social, and environmental benefits. They even face some unfair competition in relation to technologies using subsidized fossil fuels. Analyses of plans, policies, standards, and regulations for supporting the growth of the bioethanol and clean cooking subsectors has been done by several authors. Refs. [32][33][35] conclude that new stove designs should be subjected to safety and quality standards as well as product labelling to guarantee their performance and standards. In addition, with regards to the bioethanol businesses for cooking value chain, refs. [4][28] suggest that the government should reduce the number of licenses and simplify the business registration procedures, respectively.

Given the importance of creating awareness and communication on the benefits of cooking with bioethanol and the risks thereof, a range of empirical evidence show that both governments and non-governmental organizations have been responsible for effectively undertaking information and educational campaigns [3][4][29][31][35]; providing various training on bioethanol for cooking, including stove manufacture and micro-distillery installation) [28][31][33][34]; and supporting the demonstration of projects and access to credit [4][30][33][36].

Governments are accountable for ensuring that there is an enabling environment and policy that promotes healthy competition in the energy cooking subsector. Evidence shows that for some countries, funding of LPG for cooking has been favored and supported by subsidies and lower/no taxation over time [3][4][29][33]. To support bioethanol for cooking, governments working with non-governmental organizations should introduce the use of subsidies or facilitate climate finance to help with affordability, targeting both the businesses in the upstream level of the value chain and lower-income end users to finance the purchase of stoves [4]. This will offer a level playing field where bioethanol enjoys a zero-rated VAT and import duty of machinery required for bioethanol processing and distribution, enabling and boosting domestic production [3][4][29][33]. Furthermore, ref. [3] concludes that the provision of tax rebates by governments is critical for strengthening the local production of bioethanol.

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