Unlocking the Potential of Bioethanol in Development Setting Contexts: From Theory to Practice and Policy Implications

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H.E. President Dr. Samia Suluhu Hassan visited UNIDO's bioethanol booth to advance Tanzania's clean cooking roadmap aligned with national policies during the clean cooking conference in 2022.
(Photo credit: UNIDO)

EXECUTIVE SUMMARY

Background

Despite significant investments in clean cooking initiatives, over 80% of households in Tanzania continue to rely on traditional biomass fuels such as charcoal and wood, contributing to environmental degradation, indoor air pollution, and energy poverty (WHO, 2022). Bioethanol presents a viable alternative, offering health, economic, and environmental benefits; however, its large-scale adoption remains constrained by affordability, supply chain inefficiencies, policy barriers, and cultural resistance.

In response, the UNIDO Bioethanol and Clean Cooking Programme was launched in partnership with the Tanzanian government, private stakeholders, and international funders (Global Environmental Faciality and European Union). The vision behind the program was to distribute 500,000 ethanol cookstoves, covering 40% of Dar es Salaam's households, to demonstrate a scalable clean cooking solution that could spur commercial investment. At the time of its inception (2017), Tanzania faced severe electricity shortages and had no other viable renewable fuel alternatives, making bioethanol a strategic clean energy transition pathway. However, due to funding constraints, increased per-unit subsidy costs, and the impact of COVID-19, the funded target was revised to 160,000 households (UNIDO, 2023a). While progress has been made in local stove assembly, ethanol production, and private-sector engagement, persistent challenges underscore the chicken-and-egg dilemma in scaling bioethanol: stoves without fuel lead to low demand, while fuel without a critical mass of stoves results in market failure.

This study applies a mixed-methods approach to assess the scalability of bioethanol adoption, integrating qualitative focus group discussions and an expert poll leveraging a modified Analytical Hierarchy Process (AHP). By systematically ranking and evaluating key influencing factors, the study provides an evidence-based assessment of Tanzania's clean cooking transition.

Key Findings

1. **Persistent Barriers to Bioethanol Scale-Up**
    - **Financial Constraints**: High ethanol production costs, import duties (18% VAT), and limited access to climate finance hinder affordability.
    - **Regulatory Bottlenecks**: Licensing complexities and a lack of policy harmonization slow private-sector investment.
    - **Supply Chain Challenges**: Feedstock shortages, inconsistent fuel availability, and bottlenecked distribution networks disrupt supply.
    - **Technological Gaps**: Stove maintenance issues, limited access to spare parts, and safety concerns undermine consumer confidence.
    - **Fuel Stacking Behaviour**: Many households view bioethanol as a supplementary rather than a primary fuel, reinforcing continued dependence on both clean and non-clean fuel usage.

2. **Key Enablers Driving Adoption**

- **Public-Private Partnerships:** Collaborations with companies like Consumer Choice Limited (CCL) for distribution and Azam Bakhresa Group for molasses-based ethanol production have strengthened supply chains.
- **Localized Market Innovations:** Selling bioethanol in small, affordable units (e.g., half litre, one litre bottles) has improved affordability and expanded consumer access.
- **Community Engagement:** Cooking demonstrations in culturally relevant contexts have shifted perceptions, increasing trust in ethanol stoves.
- **Carbon Finance & Digital Solutions:** Kenya's KOKO Networks demonstrates how smart fuel dispensers (KOKO Points), mobile payments (M-Pesa), and carbon credit schemes can accelerate adoption and reduce stove prices.

3. Comparative Insights: UNIDO vs. KOKO Networks

Comparing bioethanol scale-up models for UNIDO's Bioethanol and Clean Cooking Programme in Tanzania and KOKO Networks in Kenya/Rwanda reveals fundamental differences in strategic intent, scale-up complexity, and financing approaches. However, these models are not directly comparable—their primary and secondary aims differ, and their approaches address distinct market and institutional constraints.

- **UNIDO (Tanzania)**: A development-led intervention, with a primary focus on creating market conditions for bioethanol through public-private partnerships, marketing grants, and stove distribution subsidies. The secondary objective includes capacity building and policy standardization, supporting long-term sectoral growth.
- **KOKO Networks (Kenya/Rwanda)**: A private-sector-driven model, prioritizing retail-based fuel distribution infrastructure, digital innovation, and scalable financing. KOKO's primary aim is to establish a self-sustaining bioethanol business, leveraging carbon finance, digital payments, and decentralized retail integration.

A key **complexity in comparison** lies in the **chicken-and-egg dilemma**: UNIDO's approach, which initially subsidized stove distribution, encountered challenges with fuel supply gaps, slowing adoption. Conversely, KOKO Networks adopted a fuel-first strategy, ensuring widespread ethanol availability through embedded dispensers (KOKO Points) before aggressively pushing stove sales. Both models require synchronized growth of stoves and fuel markets to achieve large-scale adoption.

KOKO Networks and UNIDO adopt different strategies for bioethanol adoption, making direct comparisons challenging. **KOKO's private-sector-led model** is driven by investments, carbon finance, and consumer revenue, ensuring self-sustaining growth. In contrast, **UNIDO focuses on market facilitation,** using donor funding to build infrastructure, support policy, and reduce investment risks. While their objectives differ, both approaches play complementary roles in fostering bioethanol market development.

Policy & Investment Recommendations

To unlock the potential of bioethanol cooking in Tanzania, targeted interventions are required:

1. **Regulatory Reforms**:
    - Reduce **import duties and VAT (currently 18%)** to enhance ethanol affordability.
    - Harmonize **regional ethanol policies** across East Africa to support cross-border trade and investment.
2. **Market & Financial Innovations**:
    - **Expand carbon credit mechanisms to lower stove costs while ensuring long-term carbon sustainability.** UNIDO could explore carbon financing, leveraging successful models like BURN, to support clean cooking initiatives that balance affordability, emissions reduction, and sustainable carbon offset strategies**.**
    - **Expand PAYG financing options to include eCooking and bioethanol stoves, leveraging mobile money** (e.g., M-Pesa). While LPG PAYG is already in place, PAYG for eCooking and bioethanol stoves is still in the planning and pilot stages and not yet fully implemented.
3. **Supply Chain & Infrastructure Development**:
    - Expand local production of **bioethanol stoves and spare parts** to lower costs and ensure supply chain resilience.
    - Establish **retail-integrated bioethanol distribution** via **fuel dispensers, petrol stations, and fast-moving consumer goods (FMCG) networks**.
4. **Consumer Awareness & Cultural Integration**:
    - **Aspirational marketing** strategies should position bioethanol as a **modern, clean, and high-status cooking fuel**.
    - Scale up **live cooking demonstrations** and **localized recipe-sharing platforms** to address cultural perceptions.
5. **Gender & Social Inclusion**:
    - Expand **women-led bioethanol stove distribution models**, ensuring affordability for **low-income households and food vendors**.

1. INTRODUCTION

Access to clean and affordable cooking energy remains a challenge in Tanzania, where reliance on biomass fuels such as firewood and charcoal accelerates environmental degradation and poses serious health risks (WHO, 2022). Bioethanol presents a viable alternative with significant health, environmental, and economic benefits; however, its adoption is limited by affordability, infrastructure, policy barriers, supply chain inefficiencies, and cultural resistance. In response, the UNIDO Bioethanol and Clean Cooking Program, in collaboration with the Tanzanian government and private stakeholders, and grant support from GEF and EU had launched to promote bioethanol use. The program initially set a visionary target of distributing 500,000 ethanol cookstoves—representing around 40% of households in Dares salaam—to inspire the government, funders, and industry with the potential of a renewable-based cooking fuel at a scale that could attract significant commercial investment. When this target was established around 2017, severe electricity shortages and the absence of other viable renewable fuel options reinforced its necessity. However, due to funding constraints, increases in subsidy levels per stove, and the impact of the COVID-19 pandemic, the funded target was revised to 160,000 households (UNIDO, 2023a). Despite progress in local stove assembly, bioethanol production, and private-sector engagement, large-scale adoption remains limited, underscoring the need for targeted interventions to overcome persistent barriers (UNIDO & TIB, 2023).

This research builds on and extends existing literature on clean cooking solutions by exploring the underexplored dynamics of bioethanol adoption. Previous studies have predominantly focused on technological and regulatory challenges, often overlooking critical factors such as consumer behaviour, maintenance needs, capital, fuel & stove prices, and localized marketing strategies. The primary objectives of this study are to assess the scalability of bioethanol as a clean cooking fuel within Tanzania's socio-economic and cultural contexts, identify key barriers and enablers influencing its adoption, evaluate the role of multi-stakeholder coordination in scaling clean cooking initiatives, analytical comparison of KOKO Networks and UNIDO scale ups approaches and provide evidence-based recommendations for enhancing the effectiveness of such programs.

To achieve these objectives, the study employs a mixed-methods approach, integrating qualitative and quantitative analyses. Focus group discussions were conducted with UNIDO representatives and private-sector stakeholders to gain insights into the challenges and opportunities associated with bioethanol adoption. Additionally, an expert poll involving Modern Energy Cooking Services (MECS) researchers and industry practitioners was conducted to identify and prioritize the most critical factors affecting bioethanol scale-up. The study utilizes a modified Analytical Hierarchy Process (AHP), a structured decision-making framework that systematically ranks and weights key influencing factors. By combining thematic analysis from qualitative and quantitative rankings from expert assessments, this research provides a comprehensive and evidence-based evaluation of bioethanol adoption in Tanzania, contributing to the broader discourse on clean energy transitions.

The study identifies a range of barriers and enablers influencing the scale-up of bioethanol as a clean cooking solution in Tanzania. Investment and financing challenges remain a significant barrier due to high production costs, tax constraints, and limited access to climate finance. Regulatory bottlenecks, such as import duties and licensing complexities, hinder the market's expansion, while supply chain vulnerabilities—such as feedstock shortages and inconsistent fuel availability—impact affordability

and accessibility. Technological gaps in stove efficiency, maintenance issues, and consumer awareness further impede adoption, as many households continue to perceive bioethanol as a supplementary rather than primary cooking fuel. However, enablers such as strategic public-private partnerships, targeted stove subsidies, and flexible purchasing options (e.g., bioethanol sold in small, affordable units) have enhanced affordability and access. The integration of local production—such as Azam Bakresa Group's commitment to molasses-based ethanol—and regional supply chain diversification has strengthened resilience and reduced dependence on imports. Furthermore, community engagement efforts, including cooking demonstrations in culturally relevant contexts, have begun to shift consumer perceptions, illustrating bioethanol's practicality and long-term cost benefits.

The progress of the UNIDO Bioethanol and Clean Cooking Programme in Tanzania highlights the critical role of multi-stakeholder coordination in overcoming adoption challenges. UNIDO collaborated with private sector actors like Consumer Choice Limited (CCL) for distribution, Azam Bakresa Group for stove giveaways, and Burn Manufacturers in Nairobi for local stove production. This approach localized the supply chain, reducing logistical inefficiencies and costs while fostering economic linkages between bioethanol production and agriculture. The programme also engaged community organizations in awareness campaigns tailored to specific cultural contexts. Notably, the design of the programme has spurred additional companies, such as Bukona Agro and Multiplex Systems, to join the market, further stimulating competition and investment. However, all players in the Tanzanian market have faced the challenge of raising their own capital, a point that underscores the need for expanded financial models. While Tanzania's Bioethanol and Clean Cooking Programme has made notable strides through targeted partnerships (i.e., Global Environment Facility, Tanzania Investment Bank, local sugar industries, and the Tanzania government), the study highlights the need for regulatory streamlining, technology-driven solutions, and sustainable financial mechanisms to drive large-scale adoption and long-term success.

Comparing bioethanol scale-up for KOKO Networks and the UNIDO Bioethanol Clean Cooking Programme is complex, as they are not an apple-to-apple comparison. Scaling bioethanol is like the classic chicken-and-egg dilemma: it's challenging when you have stoves without fuel or fuel without stoves. A fuel-first approach faces low demand without stoves, while a stove-first strategy struggles with fuel scarcity. Both need to grow together for the market to thrive. Moreover, the fundamental difference in their approaches adds another layer of complexity: UNIDO, as a development organisation, has focused on introducing bioethanol-based clean cooking in Tanzania, with a primary focus on offering a marketing grant to local companies to set up distribution operations (stoves and continuing fuel), alongside secondary objectives like capacity building and the development of local standards. The stove subsidies are structured with a pay-on-performance model to protect donor funds. In contrast, KOKO Networks is a private company, raising grant and other funding to develop its business. These distinct approaches, motivations, and areas of activity, along with the emphasis on secondary objectives like local capacity building, make direct comparison between the two quite tricky.

Lessons from KOKO Networks in Kenya demonstrate that integrating digital infrastructure—such as smart fuel dispensers (KOKO Points), cloud-based monitoring, and mobile payment solutions like M-Pesa—can enhance accessibility and consumer convenience. Additionally, partnerships with

companies like Vivo Energy for fuel distribution have played a crucial role in ensuring reliable bioethanol supply. Financing mechanisms such as carbon credit schemes have also been leveraged to support clean energy bringing down ethanol stove prices to affordable levels, creating incentives for investors to scale up bioethanol adoption. On the manufacturing side, collaborations with Saarus Innovations for stove production have enabled localized, cost-effective solutions. Policy and regulatory frameworks, particularly around bioethanol taxation and licensing, remain a critical area requiring further harmonization to promote affordability and market growth.

This paper is structured into six sections. The Introduction outlines bioethanol's role in clean cooking and the study's objectives, followed by the Literature Review on the Modern Energy Cooking Transition Theory of Change (MECS TToC) framework and its relevance to bioethanol scale-up. The Methodology covers research design, data collection, and analysis, including thematic and modified AHP analysis. The Findings examine key themes such as consumer demand, supply chain, economic impact, marketing, and policy. The discussion and extended analysis explore UNIDO bioethanol scaling strategies, emerging lessons, and a comparison of KOKO Networks and UNIDO's scale-up approaches. Finally, the Conclusions and Policy Recommendations summarize key insights and propose strategies for sustainable bioethanol adoption.

UNIDO officer handling over Bioethanol cooking stove and fuel to the deputy PS from Ministry of health during the world environment day commemorations in Dodoma. Photo credit: UNIDO

2. LITERATURE REVIEW

2.1 Revisiting MECS Transition Theory of Change (MECS TToC) and Bioethanol Scale-Up

Although the MECS TToC framework is an internal organizational tool rather than a universally enforced standard, it provides a structured, evidence-based approach to evaluating program success, making it applicable for analysing bioethanol scale-up by identifying key impact pathways, barriers, and enablers within a clean energy transition. Its focus on Consumer Demand Dimensions, Supply Chain Dynamics, Marketing and Digital Support, Economic and Infrastructure Factors, and Policy and Enabling Environment offers a comprehensive analytical lens. These dimensions collectively influence adoption rates, market sustainability, and long-term impact, making the framework a valuable tool for assessing bioethanol programs, even if it was not originally designed as a global standard.

Challenges in Scaling Up Bioethanol

Building on the previous work of Osiolo et al. (2023), this study analyses the scale-up of bioethanol using the Modern Energy Cooking Services Transition Theory of Change (MECS TToC) framework. The analysis aims to provide a comprehensive understanding of the key factors influencing the scale-up, focusing on MECS program insights and experiences that have not been extensively researched. Close consideration of the three dimensions — consumer demand dimensions, supply chain dimension, and policy and enabling environment — of the MECS TToC reveals that the challenges to scaling up bioethanol adoption are multifaceted. Investment and finance barriers stem not only from high production costs linked to unfavourable tax regimes and limited access to climate finance but also from the substantial costs associated with establishing an entirely new distribution supply chain. In contrast, scaling up LPG usage requires significantly lower investment, as its supply infrastructure is already in place. Additionally, regulatory hurdles—such as excessive import duties and complex licensing requirements for manufacturers and distributors—further constrain market growth. Significant technological gaps, particularly in stove design, functionality, safety, and quality standards, further hinder local adaptation and innovation, compounding the investment challenges. Supply chain issues present additional challenges, with feedstock shortages and unreliable bioethanol availability affecting fuel affordability and accessibility. Additionally, as this is a new solution, fuel production will not immediately align with market demand. There will always be a lag due to the significant investment and time required for production expansion.

Lastly, low consumer awareness remains a significant barrier, requiring stronger stakeholder engagement, demonstration projects, and policy interventions to position bioethanol as a viable cooking fuel. However, addressing this challenge is complex—broad marketing efforts can create household demand that may outpace limited distribution capabilities. Despite these challenges, scaling up bioethanol offers significant social, economic, and environmental benefits, supporting job creation, promoting gender equality, and advancing Sustainable Development Goals (SDGs) related to clean energy and poverty reduction.

Underexplored Factors Influencing Bioethanol Scale-Up

While existing studies have addressed key barriers to bioethanol scale-up, several underexplored factors warrant further attention. One critical factor is maintenance and access to spare parts. Limited availability of affordable spare parts and a shortage of qualified technicians frequently result

in stove abandonment. For instance, Benka-Coker et al. (2018) found that 10% of ethanol stove users in Ethiopia reported maintenance-related issues, though the specific nature of these issues was not thoroughly detailed in their study. Consumer acceptance and confidence also play a vital role in adoption. At the household level, consumers generally do not differentiate between first-generation bioethanol (derived from food crops like corn and sugarcane), second-generation bioethanol (produced from agricultural waste and non-food biomass), third-generation bioethanol (sourced from algae and other advanced feedstocks), or fourth-generation bioethanol (which involves carbon capture and genetically modified organisms to enhance production efficiency). Research by Isabella et al. (2017) highlighted that consumer preferences are shaped not only by economic considerations but also by the perceived reliability, convenience, availability, accessibility, and sustainability of cooking solutions.

Equitable access is also crucial, as promoting bioethanol adoption must ensure inclusivity, especially for low-income and marginalized groups. Prioritizing subsidies, accessible financing, and inclusive policy frameworks can help ensure that no one is left behind in the energy transition (UNIDO, 2023a). Investment and finance remain pivotal for bioethanol expansion, as significant financial resources are required to support infrastructure, technology development, and market entry. For instance, Kenya's use of climate finance facilitated the mass adoption of bioethanol through investments in advanced technology and production capacity (Osiolo et al., 2023). Infrastructure and supply chain development are equally essential for efficient bioethanol production, storage, and distribution. Local production of stoves can help lower costs, reduce reliance on imports, and strengthen supply chain resilience (UNIDO, 2023a).

Marketing and consumer engagement are also vital for promoting bioethanol adoption. Platforms like KOKO Club and eChefs Recipes have demonstrated how aspiration-driven marketing and digital support can influence consumer preferences and strengthen brand trust (Lambe et al., 2015.). Lastly, effective waste management is critical for maintaining the environmental sustainability of bioethanol production. Recycling by-products like vinasse and bagasse into biofuels or fertilizers supports circular economy principles, while carbon capture and reuse technologies enhance sustainability (Benka-Coker et al., 2018; Miftah & Mutta, 2024). By addressing these underexplored factors, this study aims to contribute new insights to the growing discourse on bioethanol scale-up, providing practical recommendations for policymakers, investors, and industry stakeholders.

A comprehensive review of the literature revealed five key thematic areas/topics that guided the development of the focus group discussion guide and structured discussions with stakeholders. These themes include: (1) Consumer Demand Dimension, which focuses on understanding consumer preferences, behaviours, and market needs; (2) Supply Chain Dimensions, encompassing marketing strategies and technological advancements that influence supply chain efficiency; (3) Economic and Infrastructure Impact, addressing the broader economic implications and infrastructural requirements of the sector; (4) Marketing and Digital Support, which highlights the role of digital tools and promotional strategies in market engagement; and (5) Policy Enabling Environment, which emphasizes the regulatory frameworks and policy conditions necessary for sustainable growth and sectoral development.

3. METHODOLOGY

3.1 Research Design

This study aimed to investigate strategies for upscaling bioethanol within development settings, using the UNIDO Bioethanol and Clean Cooking Programme in Tanzania as a case study. The study employed a mixed-methods research design to ensure a comprehensive analysis. The methodology included a literature review to synthesize existing academic and scholarly knowledge, alongside document analysis of project reports, policy documents, and official records related to the program. Data collection was further enriched through focus group discussions with key stakeholders, including private sector investors and representatives from the implementing organization, UNIDO and its project management team in Tanzania. To refine the thematic framework, expert polls were conducted to identify and prioritize sub-themes emerging from the focus group discussions, ensuring a rigorous and systematic approach to data triangulation and analysis.

3.2 Study Setting

The study is set within the context of Tanzania's efforts to transition to cleaner cooking solutions. It is implemented by the United Nations Industrial Development Organization (UNIDO) through its Bioethanol and Clean Cooking Programme. The program aims to reduce the reliance on traditional biomass fuels such as charcoal and wood, which are major contributors to environmental degradation, and health-related issues from indoor air pollution (UNIDO, 2023a). The UNIDO Bioethanol and Clean Cooking Program, in partnership with the Tanzanian government, private stakeholders, and with grant support from GEF and the EU, was launched to promote bioethanol use. Initially, it aimed to distribute 500,000 ethanol cookstoves—covering 40% of Dar es Salaam households—to showcase the potential of renewable cooking fuel for large-scale investment. However, due to funding constraints, increased subsidies, and the impact of COVID-19, the target was revised to 160,000 households (UNIDO, 2023a). This effort is intended to promote the adoption of clean cooking technologies, mitigate environmental degradation, and improve public health outcomes (UNIDO, 2023a).

The program strengthens the local economy by promoting the domestic value chain development such as assembly of ethanol cookstoves, boosting local manufacturing capacity and creating job opportunities. Initially, bioethanol stoves were manufactured in Durban, South Africa, but production has since shifted to Nairobi, Kenya. This shift has strengthened regional supply chains, increasing the availability and affordability of ethanol cookstoves in Tanzania. To secure a steady bioethanol supply, the program promotes local ethanol production from molasses, a by-product of Tanzania's key sugarcane industry. This initiative maximizes its use, advancing a circular economy, reducing waste, and strengthening ethanol fuel production and distribution for clean cookstoves. Additionally, UNIDO, in collaboration with the Tanzania Development Bank (TIB), has provided financial grants to entrepreneurs in the bioenergy sector to drive innovation and expand bioethanol production. The Global Environment Facility (GEF) grant has supported sugar producers, ethanol manufacturers, biofuel distributors, and clean energy startups in modernizing production facilities, optimizing supply chain logistics, expanding sustainable fuel distribution networks, and improving bioethanol processing efficiency from agricultural waste, strengthening the country's renewable energy infrastructure (UNIDO & TIB, 2023). This multi-stakeholder initiative highlights UNIDO's commitment

to promoting sustainable energy solutions while simultaneously advancing Tanzania's socio-economic development goals.

3.3 Sampling Strategy

The data collection process involved undertaking focus group discussing with representatives from UNIDO (2) and two private sector actors (2). The expert poll was conducted among Modern Energy Cooking Services Programme research and professional staff (10). The use of a small sample in case study research is justified by its focus on depth over breadth, with participants purposefully selected as "information-rich" sources (Patton, 2015). Small samples enable detailed exploration of key insights, with data saturation often achieved early when no new themes emerge (Guest, Bunce, & Johnson, 2006). This is especially relevant in focus group discussion, where the aim is to gather critical, context-specific perspectives from a few well-positioned informants (Yin, 2018).

3.4 Data Collection Tools and Data Types

The study utilized two primary data collection methods: the focus group discussion tool and the expert poll tool. A mini focus group discussion with four (4) participants was conducted to gather in-depth insights from stakeholders involved in the management and implementation of the Bioethanol and Clean Cooking Programme, including representatives from UNIDO and the private sector. The information collected was structured into five core themes, aligned with the Modern Energy Cooking Services (MECS) Transition Theory of Change (TToC). These themes included: (1) Consumer Demand Dimensions, (2) Supply Chain Dimension, (3) Marketing and Digital Support, (4) Economic and Infrastructure, and (5) Policy and Enabling Environment.

The expert poll tool was employed to gather input from ten (10) MECS research and professional staff, focusing on identifying and prioritizing sub-themes that emerged from the focus group discussions. The sub-themes for each of the five main topics were as follows: Consumer Demand Dimensions (cultural beliefs, fuel stacking, and consumer confidence); Supply Chain Dimension (component production, maintenance and space availability, system assembly, reliable supply chains, and customer support); Economic and Infrastructure (local economy and infrastructure); Marketing and Digital Support (mixed media promotion, recipe sharing, and aspirational/lifestyle/value-driven marketing); and Policy and Enabling Environment (access to modern energy, inclusivity, public good considerations, import tariffs, job creation, safety and standards, regulatory challenges, waste disposal, and carbon sustainability). These tools provided comprehensive and multi-dimensional insights to support the analysis of the Bioethanol and Clean Cooking Programme.

3.5 Data Analysis

This study aimed to analyse the scale-up of bioethanol from a development settings perspective. To achieve this objective, a mixed-methods approach was employed, incorporating both quantitative and qualitative analysis. Data from focus group discussion was subjected to thematic analysis, enabling the identification and categorization of key themes related to the bioethanol scale-up process. Simultaneously, data from the expert poll was analysed using a modified Analytical Hierarchy Process (AHP), a structured decision-making framework that facilitates the prioritization and weighting of sub-themes emerging from the focus group discussions. This combined methodological approach ensured a comprehensive and nuanced understanding of the bioethanol scale-up within development contexts.

3.6 Thematic and modified AHP analysis

Thematic analysis was conducted to provide an in-depth examination of the five core themes aligned with the Modern Energy Cooking Services (MECS) Transition Theory of Change (TToC).

The Analytical Hierarchy Process (AHP) model was employed to prioritize and assign weights to the sub-themes within the five core themes/topics (Saaty, 1980). The decision to use a modified AHP was motivated by the complexity of the themes and the numerous sub-themes under each, necessitating a systematic and quantitative approach to determine their relative importance. Given the large number of sub-themes, traditional pairwise comparisons were considered impractical. Consequently, a modified AHP approach was adopted, allowing for multiple comparisons of all sub-themes within each theme/topic. The modified AHP model development process involved two key stages. First, participants independently assigned weightings to each sub-theme using a standardized importance scale, where 1 = Equal importance, 3 = Moderate importance, 5 = Strong importance, 7 = Very strong importance, and 9 = Extreme importance. To capture more nuanced judgments, intermediate values (2, 4, 6, and 8) were also available to reflect cases where the relative importance of a sub-theme fell between two adjacent levels on the scale. This approach allowed for greater precision in capturing participants' subjective assessments of sub-theme importance (Saaty, 2008). Following this, a group discussion phase was conducted, during which participants reviewed, debated, and refined their individual scores to reach a consensus on the relative importance of the sub-themes. While the final weight was determined based on the group score, it was essential to assess the extent of alignment between individual and group perspectives. To achieve this, the mean of individual scores was compared with the group score, and the standard deviation of individual ratings was calculated to measure the degree of variation and consensus among participants (Ishizaka & Labib, 2011). This modified AHP approach provided a transparent, structured, and participatory method for prioritizing sub-themes, ensuring analytical rigor, reliability, and credibility in the decision-making process.

The modified AHP approach addressed key limitations of the original model by replacing traditional pairwise comparisons with multiple comparisons of sub-themes, thereby reducing cognitive burden and time constraints. The inclusion of a group discussion phase facilitated consensus building, enhancing the reliability and validity of the final weightings. Additionally, the use of individual and group scores, along with the calculation of standard deviations, mitigated issues of subjectivity and inconsistency (Ishizaka & Labib, 2011; Saaty, 2008).

3.7 Ethical Considerations

Ethical considerations are fundamental to the integrity of this study. Participants were assured of confidentiality and anonymity, with measures in place to protect their personal information and any sensitive data they shared. Given the involvement of stakeholders from UNIDO, private sector actors, and MECS research staff, the study adhered to ethical guidelines for working with organizational representatives, ensuring no conflict of interest or coercion influenced participation.

3.8 Validity and Reliability

The validity and reliability of the study were maintained through the use of robust methodological approaches and triangulation of data sources. Thematic analysis of focus discuss discussion data ensured construct validity by linking themes to the Modern Energy Cooking Services (MECS) Transition Theory of Change (TToC), thus grounding the findings in an established conceptual

framework. Reliability was enhanced through the consistent use of FGD interview guides and standardized procedures for data collection across all participants. Additionally, the expert poll data was analysed using a modified Analytical Hierarchy Process (AHP), a method known for its rigor in structuring decision-making processes. To further ensure validity, the study employed data triangulation by integrating insights from focus group discussion, expert polls, and document analysis, allowing for cross-verification of findings.

3.9 Study Limitations

The study has several limitations that may affect the robustness and broader applicability of its findings. It focuses on a single case in one country, specifically the UNIDO Bioethanol and Clean Cooking Programme in Tanzania, which limits the extent to which its insights can be generalized beyond this specific initiative, country context, and organizational approach. Additionally, the relatively small sample size of focus group discussion participants and expert poll respondents may have restricted the diversity of perspectives. To enhance the reliability of findings, purposive sampling ensured the inclusion of participants with relevant expertise, while data triangulation using focus group discussions, expert polls, and document analysis helped reduce reliance on self-reported data and verify key insights.

Household using ethanol clean cookstoves in Dar es Salaam. (Photo credit: UNIDO)

4. FINDINGS

The findings from the focus group discussion and expert poll, which are aligned with the five thematic areas outlined above, are presented in detail within this section. The discussion begins with an overview of the project background to provide contextual clarity and a foundation for the subsequent analysis.

4.1 Project Background

The bioethanol initiative in Tanzania serves as a compelling case study for clean energy adoption in developing contexts. It addresses critical issues such as energy access, affordability, local economic development, and environmental sustainability, offering insights into how innovative solutions can transform energy markets. The initiative reflects a concerted effort to promote bioethanol as a viable alternative to cooking fuels like wood, charcoal, and kerosene, which dominate the Tanzanian market and contribute to environmental degradation, indoor air pollution, and energy poverty. The project background section provides a comprehensive overview of the project's foundation, highlighting key aspects such as facilitation strategies, market reach and penetration, affordability, and pricing considerations, as well as the challenges associated with scaling and funding.

Project facilitation

The project relies on strategic facilitation and partnerships to overcome logistical and capacity challenges. UNIDO has played a pivotal role in engaging the Consumer Choice Company in late 2018 to manage bioethanol distribution, despite the company's lack of prior experience. As a stakeholder notes, *"Initially, Consumer Choice Company had no familiarity or experience in distribution, they were engaged in bulk transportation of ethanol through the region."* This decision underscores the importance of institutional support in building local capacity for sustainable energy projects.

Ethanol is sourced through a diversified approach, combining domestic production from Kilombero and Kagera Sugar Companies with imports from countries within the region, including Uganda and Tanzania. As one respondent explains, *"The new source of bioethanol was both inside and outside the country."* The use of cassava as a feedstock highlights the initiative's efforts to integrate local agricultural resources and mitigate supply risks, thereby enhancing supply security and promoting local agricultural development.

Market Reach and Penetration

Market penetration remains a gradual process, reflecting the challenges of entering a market dominated by traditional fuels. Initial growth was slow, with Consumer Choice Limited taking over two years to understand market dynamics and establish a foothold. As one stakeholder observes, *"They have grown slowly into the market, of course—it took them more than two and a half years to start, yeah."* Since 2021, the project has reached over 14,000 households in Dar es Salaam with the first distribution company Consumer Choice, marking a significant step towards broader adoption.

With charcoal accounting for 60% of household cooking fuel consumption in urban areas in Dar es Salaam, changing consumer behaviour has become a crucial aspect of market penetration. This reliance on charcoal, especially by low-income households, reinforces the importance of a strategic market approach. As intended in the project design, middle-income households with higher purchasing power have shown the highest adoption rates of bioethanol. In contrast, low-income

households are often constrained by affordability and accessibility issues. As one stakeholder with project management explains, *"Low-income households continue to rely on charcoal and kerosene because they perceive them as more affordable."*

Affordability and Pricing

Affordability continues to emerge as a central challenge, particularly for low-income households. Initially, the project targeted middle-income households, which had fewer alternative cooking options at the time. However, over the past five years, the market has changed significantly, with increased access to LPG, efficient electric cooking, and improved cookstoves. Consequently, the project shifted its focus to lower-income households, where the affordability barrier remains significant.

To address this, the project introduced a flexible purchasing model, offering bioethanol in smaller, more affordable units (half-litre, one-litre, and five-litre bottles). This approach enhances accessibility and competes well with LPG, which requires a significantly higher upfront investment for refills. This strategy enables households to purchase within their financial capacity and has increased access for low-income groups. As one stakeholder notes, *"For bioethanol, they sell fuel in bottles… allowing customers to choose what they can afford."* The introduction of smaller purchasing units, along with subsidy adjustments for stoves, aims to enhance affordability and expand access to bioethanol as a cooking fuel. However, this approach increases bottle costs and limits the economic benefits of returnable bottle systems. Additionally, by incorporating bioethanol into existing retail networks, the program makes it more accessible, reducing the need for special trips and promoting widespread use.

UNIDO o-i-c Ms. Lorence ANSERMET handover ethanol cookstove to Deputy Minister for energy Hon. Judith Kapinga during clean cooking symposium of the cook fund program. (Photo credit: UNIDO)

Scaling and Funding Challenges

Scaling efforts continue to face funding constraints and uneven resource allocation. Despite Zanzibar demonstrating high acceptability for bioethanol during the pilot phase, funding has been directed toward mainland programs, limiting opportunities for scale-up on the island. As one stakeholder notes, *"Scaling up would be feasible due to Zanzibar's smaller size… but funding was allocated for mainland programs, not Zanzibar."*

Scaling efforts have always aimed to engage well-capitalized private sector players to ensure long-term growth. However, the time-limited nature of development funding required UNIDO to collaborate with willing partners, often smaller, under-capitalized entities, to bridge funding gaps and expand market reach. As one respondent explains, *"We need bigger players who can look at the long term."* Larger players can help address capacity constraints, facilitate supply chain efficiency, and ensure sustainable market expansion. Key players in the bioethanol scale-up include Fast-Moving Consumer Goods (FMCG) companies, large conglomerates like Bakhresa, ethanol producers, logistics firms, and government agencies, all of which can drive production, distribution, and market sustainability.

Political factors have also influenced the project's progress. The distribution of clean cooking solutions is perceived as politically motivated in some instances, raising concerns about sustainability and community trust. This perception arose when the program was first piloted in Zanzibar—a semi-autonomous region with political sensitivities—before being implemented in Dar es Salaam, leading some to believe the rollout was influenced by political considerations rather than purely developmental goals. As one stakeholder observes, *"Distribution has often appeared politically motivated."*

The bioethanol initiative represents a complex interplay of logistical, market, economic, behavioural change, and political factors. While partnerships and pricing strategies have facilitated initial successes, challenges related to growth, funding, cultural belief, and political perceptions persist.

4.2 Consumer Demand Dimensions Theme

The findings highlight bioethanol's role as a clean, efficient, and complementary cooking fuel rather than a complete replacement for traditional fuels. Its adoption is influenced by cultural beliefs, fuel usage patterns, and consumer confidence, all of which shape its integration into household energy practices. These dimensions are examined under this theme in the following sub-sections.

I. Cultural Beliefs and Traditional Practice

Cultural perceptions significantly shape the adoption of bioethanol stoves. Many consumers associate traditional fuels like charcoal with superior taste for certain meals. As one stakeholder noted, *"Some meals, especially traditional ones like rice or beans, just taste better when they are cooked using charcoal. People often feel that bioethanol doesn't replicate the same flavour they are used to with traditional fuels."* This belief underscores the need for targeted campaigns to dispel myths and showcase bioethanol's suitability for diverse dishes.

Regional cooking traditions also present challenges. In Zanzibar and coastal regions, charcoal is preferred for specific cooking techniques, such as creating a crust on rice. As one respondent highlighted, *"Coastal communities favour charcoal for cooking rice in a specific way."* Demonstrations showing how bioethanol can replicate or adapt to these practices could bridge the cultural gap.

Despite resistance, bioethanol has been positively received in some areas. In Zanzibar, for instance, users appreciated its neutrality in flavour. One respondent noted, *"Bioethanol did not leave a lingering taste in food,"* making it a preferred alternative to kerosene, which often imparts an undesirable smell and taste. Another respondent added, *"Kerosene left a lingering taste in food, something bioethanol did not."*

The perception of bioethanol as limited to lighter meals and quick cooking tasks further hampers adoption. As one stakeholder explained, *"People tend to think bioethanol stoves are only good for quick, light meals like tea or breakfast dishes."* This perception restricts bioethanol's use to secondary roles, reinforcing its position as a complementary rather than a primary fuel.

Women, who are typically the primary cooks, value bioethanol for its convenience. As one stakeholder explained, *"Women appreciated the ability to turn the stove off and on quickly, unlike charcoal stoves that require time to prepare and manage the fire."* These time-saving benefits align with the needs of women managing household responsibilities, making them a key demographic for targeted campaigns.

Women use bioethanol stoves to cook traditional staple foods, preparing beans and frying cassava pieces. Photo credit: UNIDO

II. Fuel Stacking: Persistent Multi-Fuel Use

Fuel stacking remains a common practice among bioethanol users, driven by concerns over availability, compatibility, and cost. As one stakeholder observed, *"Even when people buy bioethanol stoves, they don't abandon charcoal or kerosene completely. They keep using them for certain meals or as a backup in case bioethanol fuel runs out."* This highlights both the ingrained reliance on traditional fuels and the lack of confidence in bioethanol's consistent supply.

Households often view bioethanol as a supplementary rather than a primary fuel. A respondent noted, *"Households often use bioethanol for quick meals like breakfast or reheating food, but for slow-cooked meals like beans or grains, they still use charcoal."* This perception underscores the need for demonstrations that highlight bioethanol's efficiency and versatility across meal types.

In Dar es Salaam, fuel stacking is driven not only by economic concerns but also by fuel availability and price fluctuations—such as periods when charcoal becomes cheaper. Additionally, challenges in expanding beyond the area-by-area approach and maintaining a consistent fuel distribution network across the city have further influenced fuel use patterns. While bioethanol is cost-effective in the long run, many consumers perceive charcoal as cheaper because it can be purchased incrementally. As one stakeholder explained, *"Even though bioethanol is efficient, people often think charcoal is cheaper because they can buy it in small quantities."* Educating consumers about bioethanol's cost savings over time is essential to addressing this barrier.

Some households conserve bioethanol by switching to traditional fuels for meals requiring longer cooking times. As one user shared, *"If using a liter continuously at full strength, it lasts approximately three and a quarter hour... conserving fuel by switching to charcoal stoves for cooking longer meals."* This conservation strategy highlights the complementary role of bioethanol, particularly in households balancing economic constraints with clean cooking aspirations.

People value versatility in their cooking practices, as evidenced by their hybrid use of fuels. This shows that while many are open to trying new options like bioethanol, they still hold onto traditional fuels as a fallback. As explained by a participant, *"This hybrid use of fuels shows that people want versatility in cooking. They will try bioethanol but keep traditional fuels as fallback until they're certain of its reliability and availability."*

III. Consumer Confidence and Infrastructure

Consumer trust is a critical factor for adoption. Reliable fuel supply is a major concern, particularly given past inconsistencies with other fuels like LPG and electricity. As one stakeholder noted, *"One of the concerns we've heard from customers is that they worry about running out of bioethanol fuel."* Ensuring a reliable supply chain is crucial, especially given instances in 2024 when CCL ran out of fuel for months, failing to meet its contractual obligation to maintain a three-month strategic stock. Effective communication, such as SMS updates on availability, is also essential to maintain consumer confidence. One respondent explained, *"We use SMS to send updates to customers about fuel availability, nearby outlets, and maintenance tips."*

After-sales support also builds confidence. Call centres allow users to seek assistance with technical issues or repairs. As a respondent noted, *"We've set up call centres where customers can ask questions about their stoves, get advice on efficient use, or even arrange for repairs."* This reinforces the commitment to user satisfaction and reliability.

Live demonstrations play a pivotal role in addressing scepticism. As one respondent explained, *"When we do live demonstrations, such as cooking beans in front of people, it helps them see for themselves that bioethanol stoves are capable of handling traditional dishes."* These hands-on engagements, as part of below-the-line promotions tied to fuel availability, effectively dispel doubts and demonstrate the practicality of bioethanol for everyday cooking.

Partnerships with established organizations also bolster confidence in bioethanol's availability and affordability. For example, Azam's distribution of stoves and plans for local production of bioethanol from molasses signal long-term market stability. As one stakeholder highlighted, "Azam Bakhresa

Group is reviewing a potential Corporate Social Responsibility (CSR) initiative to distribute 10,000 stoves to women food vendors. They are also exploring the possibility of producing bioethanol locally, though no formal commitment has been made yet."

IV. Addressing Cultural and Confidence Barriers Through Strategic Intervention

Addressing cultural preferences and misconceptions requires a multi-faceted approach. Awareness campaigns in local languages like Swahili emphasize bioethanol's time saving, clean, and cost-effective benefits, such as its efficiency and the ability to purchase fuel in small quantities. One respondent explained, *"For every stove we sell, we include materials in Swahili explaining the benefits of bioethanol."* Live cooking demonstrations further challenge misconceptions, showcasing bioethanol's compatibility with traditional dishes. Another participant noted, *"During events like cooking symposiums, we conduct live cooking demonstrations to show people how bioethanol can handle all kinds of meals."*

Drawing lessons from the LPG market, stakeholders aim to accelerate bioethanol adoption through better planning and collaboration. As observed by a participant, *"LPG took 40 years to build consumer trust and infrastructure, but bioethanol can follow a much faster trajectory if we plan and collaborate effectively."* These insights guide efforts to establish infrastructure, enhance supply chains, and foster trust.

V. Modified AHP Analysis: Consumer demand dimension theme

The modified AHP analysis (figure 1) on consumer demand dimension highlights the relative importance and variability of three sub-themes: cultural beliefs, fuel stacking, and consumer confidence, based on their mean, standard deviation, and group scores. Cultural beliefs stand out with the highest mean (5.27) and a group score of 7, indicating very strong importance. However, its standard deviation of 2.64 suggests notable variability in perceptions of its relevance. Consumer confidence follows with a mean of 4.57 and a group score of 6, signifying its strong importance and slightly less variability (standard deviation of 2.28). In contrast, fuel stacking has the lowest mean (4.15) and a group score of 3, reflecting moderate importance and a lower standard deviation of 2.00, indicating more consistent views among respondents. These results emphasize the need to prioritize cultural beliefs and consumer confidence in addressing consumer demand issues, while recognizing the moderate but consistent influence of fuel stacking in shaping consumer behaviour.

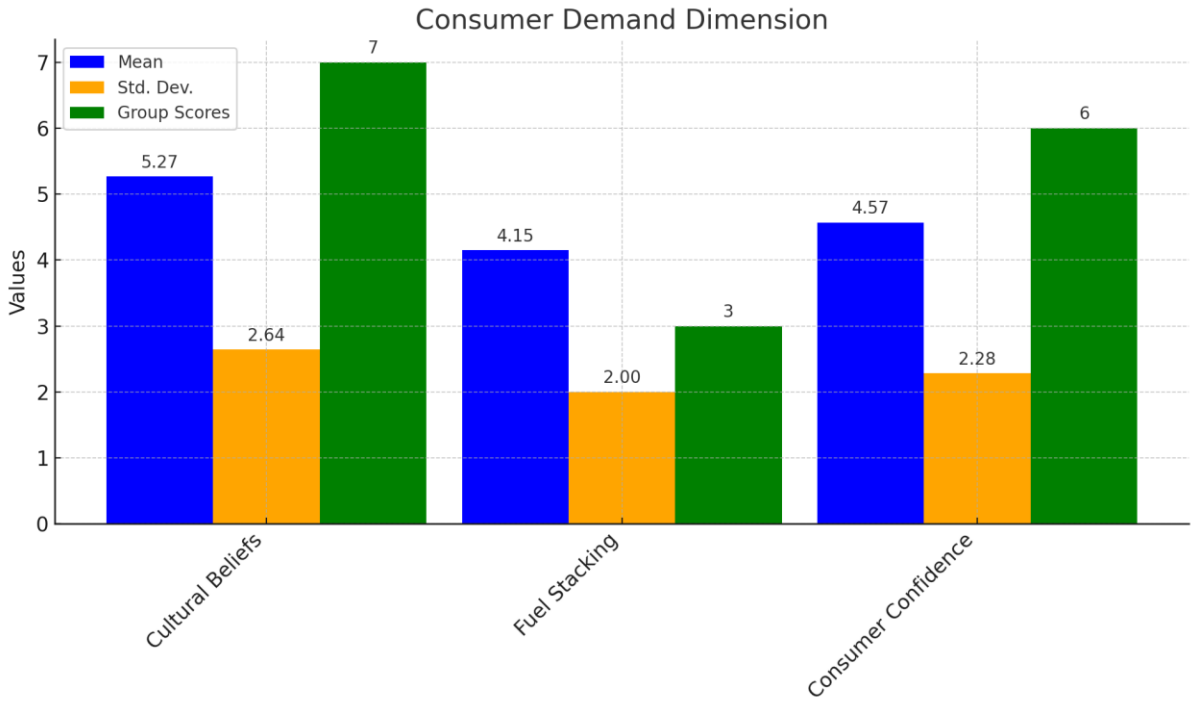

Figure 1: Modified AHP Analysis: Consumer demand dimension theme.

4.3 Supply Chain Dimensions Theme

The Supply Chain Dimension encompasses critical elements such as component production, maintenance and spare availability, system assembly, reliable supply chains, and customer support. These interconnected components collectively ensure operational efficiency, promote local capacity building, and enhance consumer trust, thereby supporting the seamless production, distribution, and sustained use of clean energy technologies. The analysis of these dimensions is presented in detail under this theme in the following sub-sections.

I. Component Production: Fostering Local and Regional Capacity

Ethanol production and stove assembling in Tanzania, and manufacturing in Kenya demonstrate significant efforts to integrate local and regional capabilities. Corporate social responsibility (CSR) initiatives play a pivotal role, as evidenced by one local company in Tanzania. According to one stakeholder, *"This company… is currently engaged in this as part of a corporate social responsibility initiative. Through their sugar production facilities, they are already generating raw materials essential for ethanol manufacturing."* This showcases how CSR efforts align with the strategic development of ethanol production, creating synergy between existing industrial capabilities and future sustainability goals.

Regional interest further highlights Tanzania's potential in the ethanol market. One respondent noted, *"There is one company… coming in from a neighbouring country. They plan to set up a production facility here because they see the potential for ethanol in this country."* This indicates

external confidence in Tanzania's market viability and the prospect of expanding regional collaboration.

The localization of stove production demonstrates the sector's evolution. Initially, *"stoves were produced in Durban by Clean Cook,"* but production has since shifted to Burn Manufacturers in Nairobi. This shift has improved supply chain efficiency and established regional manufacturing hubs closer to Tanzanian consumers. Burn's dedicated production line, which now includes a variety of energy-efficient cooking solutions such as biomass, gas, electric, and ethanol stoves, as well as cookware, enhances accessibility. As explained by one respondent, *"This has made stove accessibility much easier compared to earlier when they were produced in Durban and imported."*

II. Maintenance and Spares Availability: Ensuring Long-Term Reliability

The availability of spare parts and repair facilities is critical to fostering consumer trust and confidence. Practical solutions, such as allowing customers to replace damaged canisters, ensure system resilience. For example, *"Customers who damage their canisters or whose canisters go out of warranty can purchase replacements at a cost."* Users are also advised on simple maintenance techniques, such as placing canisters in sunlight to address condensation issues.

Local repair capacity has significantly improved. As one respondent noted, *"We now have the capacity to repair minor issues locally, while major repairs are sent to the Burn Manufacturers facility."* This approach reduces turnaround times and ensures consumers experience minimal disruption in stove usability.

III. Systems Assembly: Developing Local Technical Skills

Local assembly programs have been instrumental in building technical capacity and fostering sustainability. As one stakeholder explained, *"Initially, UNIDO required local teams to assemble the stoves from imported components to help them build technical skills and establish a local assembly process."* This deliberate strategy not only localizes the manufacturing process but also contributes to the development of a skilled workforce capable of supporting and expanding the ethanol ecosystem.

IV. Reliable Supply Chains: Addressing Accessibility Challenges

The supply chain for ethanol stoves has experienced both challenges and successes, particularly in ensuring consistent fuel availability. A key success factor is the requirement by UNIDO for distributors to maintain storage facilities with at least two to three months' worth of fuel supplies. This ensures that fuel remains consistently available, emphasizing the importance of well-stocked inventory. As one participant explained, *"Initially, we worked with independent distributors; however, these partners struggled to meet UNIDO's requirements, such as adhering to fixed prices and targeting specific geographical locations. As a result, we took distribution in-house, opening a warehouse in Nairobi, which allowed for better control over sales and alignment with project goals."* This transition has been pivotal in maintaining supply consistency and upholding the project's standards.

Another critical success factor for the ethanol stove supply chain is the emphasis on local partnerships to effectively manage distribution. The current model involves one distributor in Dar es Salaam, who collaborates closely with local suppliers and retailers. As one respondent explained, *"This partnership with a local distributor, who understands the dynamics and nuances of the*

community, ensures that bioethanol fuel reaches the market efficiently, even in more challenging areas." Additionally, the local distributor's flexibility in providing fuel *"either on a cash basis or credit basis"* reflects an understanding of the diverse financial capacities of stakeholders. This approach has helped improve availability by removing financial barriers to participation, as one respondent noted, *"This emphasis on building relationships within the community and adapting to its needs has significantly contributed to the reliability of the supply chain."*

The integration of warehousing, direct sales, and communication strategies has also played an essential role in optimizing supply chain performance. As one fuel distributing stakeholder shared, *"By choosing to manage direct sales through an in-house distribution team, we reduced our reliance on third-party actors, gaining better control over sales and alignment with project goals."* Another respondent added, *"We also maintained robust communication with agents and retailers, regularly tracking stock levels and providing additional stock as needed, which was crucial for preventing supply shortages."* As one participant concluded, *"The entire process, from sourcing raw materials to bottling and packaging fuel in half litre, one-Litre, and five-Litre containers, illustrates a fully integrated approach to ensuring the reliability of the fuel supply."*

V. Customer Support: Building Confidence and Knowledge

Customer support plays a vital role in fostering consumer trust and confidence. A 24/7 call centre offers a lifeline to consumers, ensuring access to timely assistance. As one stakeholder proudly noted, *"We also have a 24/7 call centre equipped with well-trained agents who provide assistance with technical issues and help customers locate nearby fuel retailers."* This accessibility ensures that help is never out of reach, fostering trust and satisfaction among users.

Education is also a critical component of consumer support. As one stakeholder shared, *"Educating customers about proper fuel usage is another critical component. We explain how to enhance the use of canisters and stoves, including sealing canisters properly and using flame regulators to conserve fuel. Our research shows that one litre of bioethanol is equivalent to about two kilograms of charcoal in energy output, making it a cost-effective alternative."* This educational approach not only demystifies the technology but also emphasizes its economic advantages, appealing to cost-conscious users.

Quality assurance serves as a final pillar of customer support. Collaborative efforts with regulatory bodies, such as the Tanzania Bureau of Standards and the Kenya Bureau of Standards, have resulted in consistent regional standards for cooking appliances and bioethanol. As one participant explained, *"UNIDO has worked closely with the Tanzania Bureau of Standards and collaborated with the Kenya Bureau of Standards to develop consistent regional standards for cooking appliances and bioethanol. These standards ensure that all products meet quality and safety requirements."* Such standards guarantee reliability, foster consumer confidence, and lay the foundation for widespread adoption.

VI. Modified AHP Analysis: Supply Chain Dimensions Theme

The modified AHP analysis (figure 2) on supply chain dimension illustrates the relative importance and variability of five key sub-themes based on their mean, standard deviation, and group scores. Maintenance & spares availability and customer support emerge as the most significant sub-themes, each with a group score of 8 (very strong importance) and identical means (3.64), despite high

standard deviations (3.42), reflecting divergent opinions on their implementation or impact. Reliable supply chain follows with a mean of 4.33 and a group score of 5 (strong importance), suggesting a moderate level of prioritization and slightly less variability (standard deviation of 2.91). In contrast, component production and system assembly are assigned lower group scores of 3 (moderate importance), with respective means of 2.08 and 2.91, indicating these are seen as less critical to the supply chain. Notably, system assembly exhibits the least variability (standard deviation of 1.14), indicating more consensus among respondents. These results highlight the need to prioritize maintenance & spares availability and customer support, while addressing variability in perceptions to ensure a robust and reliable supply chain.

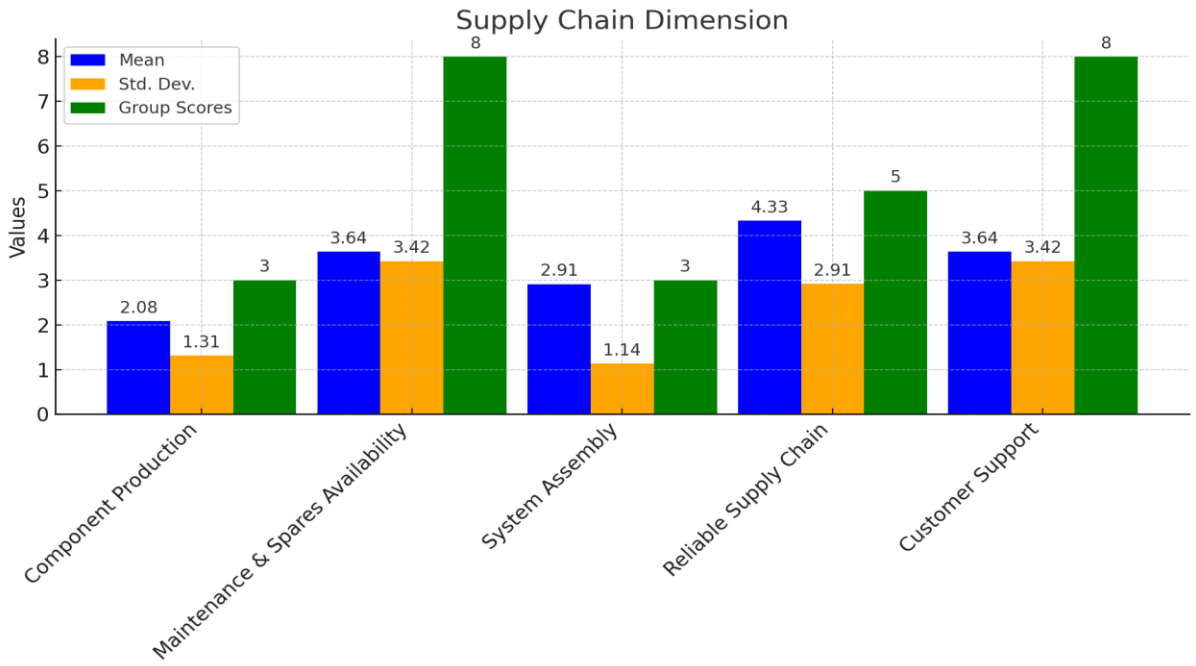

Figure 2: Modified AHP Analysis: Supply Chain Dimensions Theme

4.4 Economic and Infrastructure Impact Theme

Bioethanol programs have significant potential to transform local economies and infrastructure by promoting job creation, enterprise growth, agricultural linkages, regional integration, and infrastructure scalability. This sub-section provides an in-depth analysis of the two sub-themes: economic development and infrastructure, as outlined below.

I. Implications for the Local Economy

Bioethanol initiatives drive economic diversification by fostering robust value chains that generate income, support entrepreneurship, and create agricultural linkages. These initiatives extend beyond energy production, strengthening rural and urban economies through forward and backward linkages.

- **Job Creation**: Employment generation is a critical outcome of bioethanol programs, with a focus on gender inclusivity. One respondent noted, *"On the stove distribution side, there is an in-house distribution specialty. So far, there are 22 agents, mostly women or girls, who are*

generating income by selling stoves and fuel across the country." These opportunities create meaningful employment and income generation, especially for women, while contributing to gender inclusion. By aligning employment with social development goals, bioethanol initiatives empower marginalized groups and reduce income inequalities.

- **Local Enterprises**: The integration of retail businesses into bioethanol supply chains supports entrepreneurship and market penetration. A stakeholder shared, *"On the fuel side, we have nearly 500 retail outlets, with each retailer retaining a margin from every sale. This provides local businesses with a consistent source of income while expanding the availability of bioethanol fuel to communities."* This demonstrates the role of bioethanol programs in stabilizing income for local retailers while promoting clean energy solutions.
- **Employment in Companies**: Beyond distribution, bioethanol programs generate stable, long-term employment within the clean energy sector. As highlighted, *"Additionally, there are 16 permanent employees within the company, working across various roles such as technical support, marketing, finance, and operations. These positions are stable and long-term, contributing to the professional development of staff and strengthening the local workforce within the clean energy sector."* These roles ensure workforce sustainability and skill enhancement, supporting long-term sectoral growth and development.
- **Sugar Industries and Untapped Potential**: Despite small-scale bioethanol production by only one sugar industry on the mainland and one in Zanzibar, untapped potential exists to integrate additional sugar industries into the bioethanol value chain. A participant noted, *"Currently, only one sugar industry on the mainland and one in Zanzibar are producing bioethanol on a small scale. However, there are five sugar industries on the mainland, none of which are producing bioethanol as they are solely focused on sugar production."* Leveraging this potential could create synergies that diversify outputs, increase production capacity, and stimulate economic growth.
- **Feedstock Diversification**: Expanding bioethanol production beyond sugarcane molasses to include agricultural waste and cashew residues presents a significant opportunity for rural development. As one respondent explained, *"Bioethanol production is not limited to sugarcane molasses—it can also come from agricultural waste, and even residues from the cashew industry."* This diversification supports rural economies, promotes agricultural sustainability, and reduces risks associated with dependency on a single feedstock.
- **Backward Linkages and Outgrower Schemes**: Strengthening backward linkages by sourcing raw materials from local farmers creates rural economic benefits. A participant stated, *"These steps aim to stimulate backward linkages and create a larger bioethanol industry. By sourcing raw materials from local farmers and agricultural waste producers, the program enhances the connection between primary sectors and the bioethanol value chain, creating value and driving rural development."* Additionally, integrating smallholder farmers through outgrower schemes ensures stable markets and steady income. As noted, *"These untapped feedstocks can be integrated into outgrower schemes, providing smallholder farmers with a steady market and income while enhancing rural livelihoods."* This approach strengthens rural economies while fostering a more inclusive value chain.

- **Regional Integration**: Bioethanol programs have significant potential for regional trade and collaboration. A stakeholder highlighted, *"These steps aim to create a larger bioethanol industry that serves not only Tanzania but also the broader East Africa region and potentially the SADC region. This includes exploring opportunities for cross-border trade, knowledge-sharing, and collaboration across the region to expand markets and improve efficiencies."* This regional approach promotes economic integration, enhances cross-border trade, and increases access to larger markets for bioethanol-related products and services.

II. **Infrastructure Development and Challenges**

The success of bioethanol programs relies heavily on infrastructure investments to ensure scalability and supply chain efficiency. Bottling, storage, logistics, standardization, and market development remain critical areas of focus.

- **Bottling Facilities**: Investments in bottling infrastructure ensure the capacity to meet growing consumer demand. As stated, *"Bottling facilities have been established with a capacity of 400,000 litres per month, ensuring scalability to meet the growing demand for bioethanol fuel."* This reflects the commitment to building scalable and reliable supply chains.
- **Storage Facilities**: Adequate storage capacity is vital for preventing supply chain disruptions. A stakeholder explained, *"Storage facilities have been established to hold more than 20,000 units of stoves at any given time in Dar es Salaam and Nairobi. These facilities ensure that adequate inventory is maintained to meet consumer demand and avoid supply chain disruptions."* This storage capacity supports consistent supply, enhances consumer trust, and minimizes market fluctuations.
- **Transport and Logistics**: Efficient transport systems are essential for the regional distribution of bioethanol. As one participant noted, *"The company uses in-house tankers to transport fuel from distilleries, and there is potential to source fuel from other African regions, including Central Africa. This ensures flexibility and responsiveness in distribution while reducing dependency on external logistics providers."* By enhancing transport flexibility, bioethanol initiatives can scale operations and enter new markets, thereby increasing regional availability.
- **Standardization Challenges**: Uniform branding and packaging are crucial for consumer trust and market reliability. A participant observed, *"For example, variations in product packaging—such as different fuel colours (red, blue, etc.)—can confuse consumers. A consumer might wonder why one product is red and another is blue, leading to mistrust."* Standardization efforts, including consistent branding, address this issue and foster consumer confidence.
- **In-store Design**: Retail-level infrastructure must support effective operations. As a stakeholder noted, *"Facilities must include sufficient storage, warehousing, and tanks. Suppliers need their own branding facilities to ensure their products are distinct yet meet standardized requirements. This infrastructure is critical for ensuring effective retail operations and supporting market expansion."* Retail infrastructure plays a pivotal role in

ensuring operational efficiency, supporting consumer engagement, and driving market expansion.

- **Expansion Plans and Stakeholder Support**: Future plans for scaling production and distribution depend on stakeholder collaboration. As one respondent shared, *"Future plans include expanding manufacturing and packaging capabilities. Larger production facilities are being planned, and stakeholders' support, such as grants, is being sought to enhance production and distribution capacity."* Financial and technical support will be instrumental in realizing these expansion plans, supporting capacity development and market growth.
- **Untapped Markets**: Unlike LPG, bioethanol companies face the challenge of developing foundational infrastructure. As noted, *"Unlike LPG, where distribution systems are fully developed, bioethanol companies must build infrastructure from scratch. This includes creating new systems for bottling, storage, and distribution to ensure the product reaches consumers efficiently and reliably."* This underscores the need for investments in physical infrastructure and supply chain innovation to ensure bioethanol products reach end-users efficiently.

III. Modified AHP Analysis: Economic and Infrastructure Theme

The modified AHP analysis (figure 3) on economic & infrastructure implications highlights that both "local economy" and "infrastructure" sub-themes are evaluated with a group score of 1, indicating equal importance but minimal prioritization compared to other potential sub-themes. Infrastructure shows a higher mean value (3.00) compared to local economy (2.00), suggesting it is perceived as slightly more important. However, the high standard deviation for infrastructure (2.83) indicates considerable variability in responses, reflecting differing opinions about its significance. Conversely, the lower standard deviation for local economy (1.41) suggests more consistency among respondents in their evaluation of this sub-theme. Overall, while both sub-themes are considered equally important, their low group scores imply that they are not seen as critical priorities within the broader economic and infrastructure implications framework.

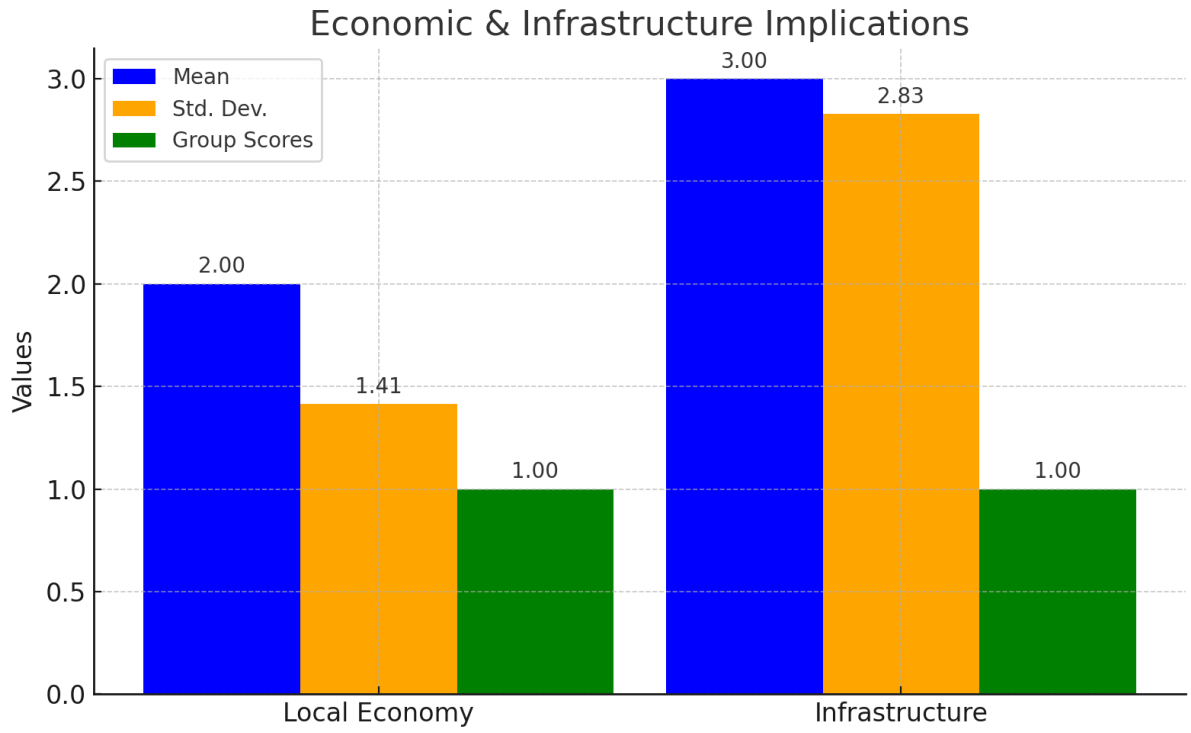

Figure 3: Modified AHP Analysis: Economic and Infrastructure Theme

4.5 Marketing and Digital Support Theme

The promotion of ethanol as a clean cooking alternative relies on innovative strategies to overcome financial and cultural barriers, engage diverse audiences, and establish it as a desirable energy choice. This section examines the use of mixed media, cultural demonstration events, and aspirational marketing, highlighting their roles in driving awareness and adoption.

I. Mixed Media Promotion

Ethanol campaigns have shifted toward cost-effective, digital-based approaches to overcome budgetary constraints and maximize audience reach.

- **Use of Non-Traditional Media**: Traditional media like television and radio have been replaced by alternative methods due to high costs. As a stakeholder shared, *"We are moving away from traditional forms of promoting ethanol, such as radio and television, toward alternative methods because of cost constraints. For instance, we have used some radio interviews, though television was minimal due to the expense. Instead, we have shifted toward more flexible, cost-effective digital platforms to reach consumers."* This adaptive approach highlights the strategic shift to affordable media options.
- **Digital and Social Media Campaigns**: Social media platforms have become central to ethanol promotion. According to one respondent, *"We have utilized social media platforms like Facebook, Instagram, and TikTok for low-cost paid ads, aiming to increase awareness and*

adoption of ethanol. Social media platforms also supported recipe-sharing events through demonstrations, which helped show the versatility of ethanol for cooking." These platforms allow for engaging, shareable content, such as videos that resonate with younger, tech-savvy audiences.

- **Engagement of Local Ambassadors and Chefs**: Partnerships with trusted community figures have proven effective but difficult to sustain due to costs. *"We partnered with a prominent chef in Dar es Salaam to showcase cooking with ethanol and even organized demonstrations that involved local dishes to highlight how ethanol stoves could be used. However, the expense of engaging influencers, such as chefs, has made this effort difficult to sustain."* These initiatives enhance cultural relevance and credibility but require innovative funding solutions to maintain momentum.

- **Retail Visibility and Branding**: Complementary to digital strategies, physical branding materials reinforce promotional messages. *"Posters in retail outlets provided clear information on pricing and compliance, as well as the benefits of ethanol stoves and fuel."* These materials ensure consistency and build consumer trust, preventing exploitation by retailers. However, another is the inaccurate promotion material. For instance, it is being advertised that 1L of ethanol should last for 4 hours, but it doesn't, and end users are complaining about the misinformation.

II. Recipe Sharing

Cultural demonstration events play a crucial role in showcasing the practicality and cultural compatibility of ethanol stoves.

- **Demonstration of Local Dishes**: Demonstrations enable participants to witness ethanol stoves in action, preparing culturally significant meals. One participant noted, *"During demonstrations, we successfully showed how ethanol stoves could cook a variety of local dishes, including meals that are commonly prepared by households in the region. Sampling played a key role in these events, as participants were able to see, smell, and taste the results."* This direct engagement builds trust and interest among potential users.

- **Inclusion of Cultural Elements**: By incorporating local music and other cultural aspects, demonstrations become more engaging. As shared, *"Demonstrations were accompanied by popular local music, which made the events engaging and more appealing to participants. By incorporating cultural elements like music, we were able to create a festive atmosphere."* Such efforts establish an emotional connection, fostering positive associations with ethanol use.

- **Targeting Women as Primary Users**: Women, as primary household cooks, are key stakeholders in adoption. As emphasized, *"These demonstrations, primarily targeting women, provided immediate proof that ethanol could be used to prepare familiar, culturally significant meals. Women were especially receptive because they could see firsthand how ethanol stoves could meet their everyday cooking needs."* Targeted demonstrations address their concerns while showcasing benefits like reduced smoke and cleaner cooking environments.

III. Aspirational/Lifestyle/Value-Driven Marketing

Positioning ethanol as a modern, desirable alternative to traditional fuels taps into consumer aspirations and values.

- **Promoting Clean Energy Benefits**: Ethanol is framed as a health-conscious and environmentally friendly choice. A stakeholder noted, *"Users might feel proud to use ethanol because it is cleaner, emits less pollution, and performs comparably to gas. Ethanol also provides an aspirational alternative to kerosene and other traditional fuels."* Campaigns emphasizing these benefits resonate with consumers who value sustainability and health.
- **Targeting All Income Levels**: Inclusive messaging dispels misconceptions about ethanol's affordability. *"Ethanol fits into households of various income levels—from low to middle and high income. Our campaigns have emphasized that ethanol is not just a luxury fuel for the wealthy but a versatile and affordable option for all households."* This broadens the target audience and avoids stigmatization.
- **Challenges with Budget Constraints**: Aspirational campaigns require significant investment, which has limited their scalability. *"While impactful, these efforts have been constrained by our limited budget. Aspirational campaigns, in particular, require significant investment, and our ability to scale them up to reach broader audiences has been limited."* This necessitates reliance on creative, low-cost methods that may not achieve the desired reach.
- **Building Historical Context**: A comparison to the LPG market underscores the time and investment required for widespread adoption. *"For ethanol, we are still in the early stages, but we are seeing signs of private sector interest since 2018, which could be the foundation for future growth by 2024 and beyond."* This perspective highlights the importance of sustained government and private sector involvement.

IV. Modified AHP Analysis: Marketing and Digital Support Theme

The modified AHP analysis (figure 4) on marketing & digital support compares three sub-themes: mixed media promotion, recipe sharing, and aspirational marketing, based on their mean values, standard deviations, and group scores. Among these, aspirational marketing stands out as the most significant, with the highest mean (3.91) and a group score of 8 (very strong importance), along with the lowest standard deviation (1.52), indicating consistent agreement among respondents. Mixed media promotion, with a mean of 2.97 and a group score of 5 (strong importance), reflects moderate prioritization. However, its standard deviation of 2.38 suggests variability in perceptions of its relevance. Recipe sharing has a higher mean (3.33) but the highest standard deviation (3.51), indicating diverse opinions about its effectiveness. Its group score of 7 (very strong importance) underscores its perceived significance despite the variability. These results suggest focusing on aspirational marketing as a key strategy, leveraging the strong emphasis on recipe sharing, and optimizing mixed media promotion to enhance its overall impact.

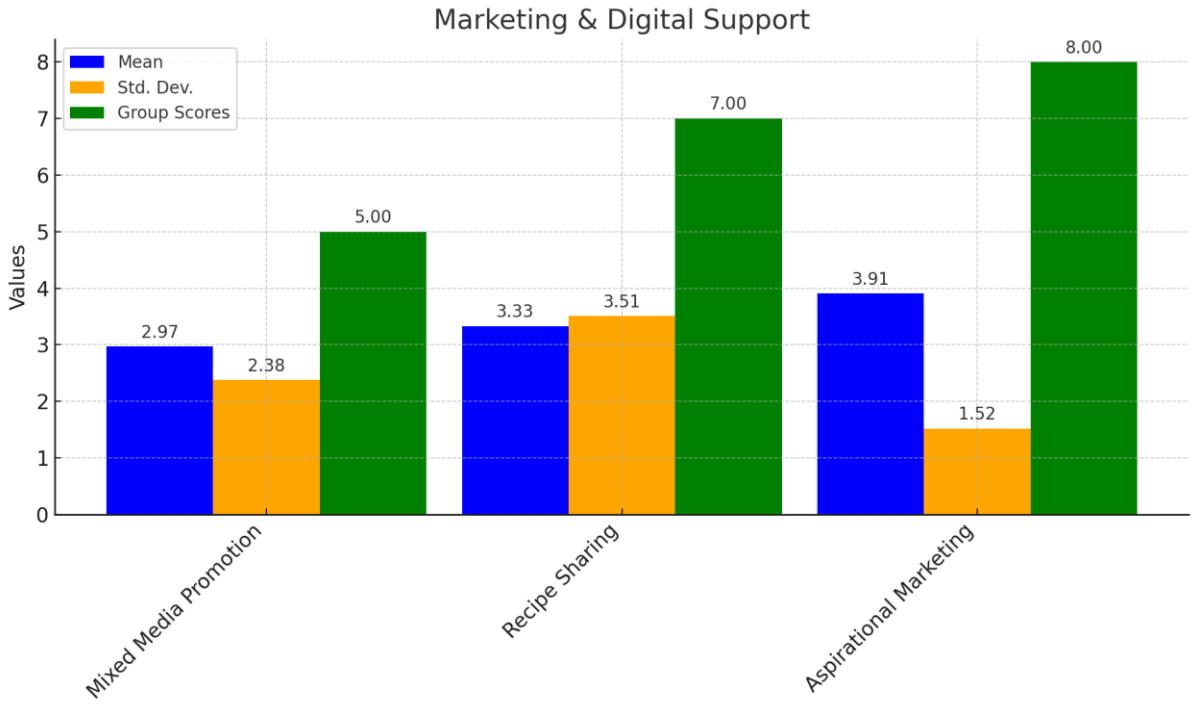

Figure 4: Marketing & Digital Support Theme

4.6 Policy Enabling Environment Theme

Tanzania's transition to clean energy represents a multifaceted effort to address public health challenges, environmental degradation, and socioeconomic disparities. By emphasizing modern cooking solutions, the adoption of ethanol-based energy systems aims to foster inclusivity, sustainability, and economic development. This discussion highlights the challenges and opportunities associated with this transition.

I. Access to Modern Energy

Achieving the goal of transitioning 80% of the population to modern cooking solutions by 2034 is an ambitious target that requires substantial collaboration. Stakeholders acknowledge, *"Electricity access has traditionally been the focus, but there's a need to transition 80% of the population to modern cooking solutions by 2034."* This shift necessitates partnerships between the government and private sector, alongside targeted investments in infrastructure and logistical support to reach marginalized communities.

- **Collaboration with the Private Sector**: Collaboration with the private sector **is crucial** for scaling clean energy solutions. As noted by one respondent, *"We need government and private sector collaboration, including tax incentives and infrastructure development, to address access issues."* Tax reforms, subsidies, and public-private partnerships **can attract**

investment and make clean energy solutions viable for low-income households. The government of Tanzania could learn from Kenya using KoKo Network as a case study and yard stick for scaling up ethanol uptake exponentially in Kenya.

- **Logistical Challenges**: Logistical challenges, particularly in rural areas, further complicate efforts to expand clean energy access. Transport and storage costs disproportionately impact low-income and marginalized communities. One respondent noted, *"Logistics, especially the high costs of transport and storage in rural areas, remain significant barriers."* Overcoming these challenges requires innovative distribution methods and targeted interventions for underserved regions.

II. Inclusivity

Inclusivity is central to the clean energy transition, with a particular focus on low-income households and women.

- **Low-Income Households**: Daily wage earners and low-income families, who **represent** *"around 60% of the population,"* often **cannot afford** modern cooking solutions. Tailored solutions, such as subsidies, instalment payment plans, or community-based financing, **are essential** to prevent their exclusion.
- **Gender Inclusion**: Women disproportionately bear the burden of traditional cooking methods, facing health risks from indoor air pollution (IAP) and the time-intensive task of collecting fuel. One respondent emphasized, *"Women, particularly those in marginalized groups, disproportionately bear the health and environmental burden of traditional cooking."* Clean energy initiatives that prioritize gender equity can reduce these burdens, improve health outcomes, and empower women economically by freeing up their time for education or income-generating activities.

III. Public Good Considerations

The adoption of clean cooking solutions addresses pressing public health and environmental concerns.

- **Public Health**: As one participant noted, *"Tanzania faces 33,000 deaths annually due to indoor air pollution (IAP), making it a major public health issue."* Clean cooking technologies offer a solution to reduce this preventable mortality rate, particularly for women and children who spend significant time near traditional stoves.
- **Environmental Protection**: Environmental degradation caused by deforestation is another critical issue. The demand for charcoal leads to the loss of 460,000 hectares annually, threatening Tanzania's ecological balance and biodiversity. As shared by one stakeholder, *"The demand for charcoal leads to the loss of 460,000 hectares annually, threatening Tanzania's ecological balance and biodiversity."* Ethanol-based fuels present a sustainable alternative that can curb deforestation and support environmental conservation.

IV. Import Tariffs and Regulatory Challenges

High VAT rates and import tariffs **create** significant affordability barriers for ethanol-based fuels and technologies.

- **Import Tariffs and VAT**: As one respondent explained, *"VAT on ethanol stands at 18%, creating cost barriers for both consumers and producers."* In contrast, the government has removed this tax on LPG, making it a more competitive alternative. Reducing these taxes **is** critical to making ethanol accessible to a broader population and fostering adoption. Furthermore, harmonizing policies across East Africa can enhance regional trade and competitiveness. As noted by a participant, *"Harmonization of tariffs and policies across East Africa will ensure a level playing field, reduce disparities, and enhance the competitiveness of clean cooking fuels."*
- **Production Costs**: High production costs also hinder sector growth. Stakeholders argue, *"High production costs are a major barrier to sector growth. Addressing these through policy incentives and private sector advocacy is critical."* Targeted subsidies and regulatory support are essential to reducing costs and attracting private sector investment, ensuring the long-term viability of the clean energy sector.

V. Job Creation

Ethanol production offers significant opportunities for job creation and income diversification, particularly in rural areas.

- **Job Creation in Production**: *"Ethanol production creates jobs, from farming to distilleries, employing an average of 20-24 staff per project,"* stated one stakeholder. Expanding this industry can provide stable employment, reduce rural unemployment, and strengthen local economies.
- **Feedstock Integration**: Feedstocks such as molasses offer additional economic benefits by linking ethanol production to agriculture. As noted, *"Feedstocks like molasses enable farmers to benefit from ethanol production, diversifying incomes and strengthening rural economies."* This integration fosters resilience in rural communities and aligns energy production with agricultural sustainability.

VI. Safety and Standards

Building consumer confidence in ethanol technologies **requires** robust safety standards and training programs.

- **Safety and Standards**: *"Collaborating with standards bureaus ensures safety and quality,"* as noted by a respondent. This ensures that ethanol products meet regulatory benchmarks. These efforts protect consumers and enhance trust in clean energy technologies.
- **Training and Capacity Building**: Training programs further support the adoption of ethanol stoves by addressing safety and operational concerns. As explained by a stakeholder, *"Training programs are crucial to building consumer trust… ensuring technology is adopted*

effectively and efficiently." By educating users, these initiatives promote broader and more effective adoption of clean cooking solutions.

VII. Waste Disposal

The ethanol industry aligns with circular economy principles by reusing waste products such as molasses.

- **Waste Minimization**: *"Circular economy practices like reusing molasses and byproducts align with agro-industry standards, ensuring waste is minimized,"* highlighted one respondent. These practices reduce environmental impact and contribute to the sustainability of the energy sector.
- **Compliance with Environmental Standards**: Compliance with environmental standards is equally important. Stakeholders emphasize, *"Waste disposal needs robust frameworks to ensure compliance with environmental policies."* Effective waste management minimizes the ecological footprint of energy production, enhancing the sector's credibility and sustainability.

VIII. Carbon Sustainability

Ethanol-based energy systems align with global climate goals by reducing carbon emissions.

- **Carbon Credits**: Carbon credits provide a financial incentive for clean energy initiatives, supporting their sustainability beyond subsidies. As noted by a stakeholder, *"Carbon credits provide financial sustainability for clean cooking initiatives."* Promoting low-carbon business models ensures alignment with international climate strategies.

IX. Modified AHP Analysis: Policy Enabling Environment Theme

The modified AHP analysis (figure 5) on the policy enabling environment highlights the relative importance of its sub-themes, with access to modern energy emerging as the top priority. This is supported by the highest mean (6.14) and a group score of 7, indicating it holds very strong importance, despite significant variability (standard deviation of 3.02). Inclusivity also stands out with a mean of 4.29 and a group score of 7, reflecting very strong importance and its prioritization in the enabling environment. In contrast, sub-themes such as import tariffs and job creation have lower mean values (3.43 and 3.71, respectively) and group scores of 5, suggesting they are perceived as having strong importance but are less emphasized compared to the top sub-themes. Regulation exhibits the least variability (standard deviation of 1.21), indicating a high level of agreement among respondents, while sub-themes like waste disposal and carbon sustainability have moderate means (4.86 and 4.00, respectively) and higher variability, reflecting diverse opinions. Their group scores of 5 indicate strong importance but not the highest priority. Overall, the results highlight a collective focus on access to modern energy and inclusivity, with other sub-themes like waste disposal and carbon sustainability receiving moderate attention, and sub-themes like import tariffs and job creation being less prioritized.

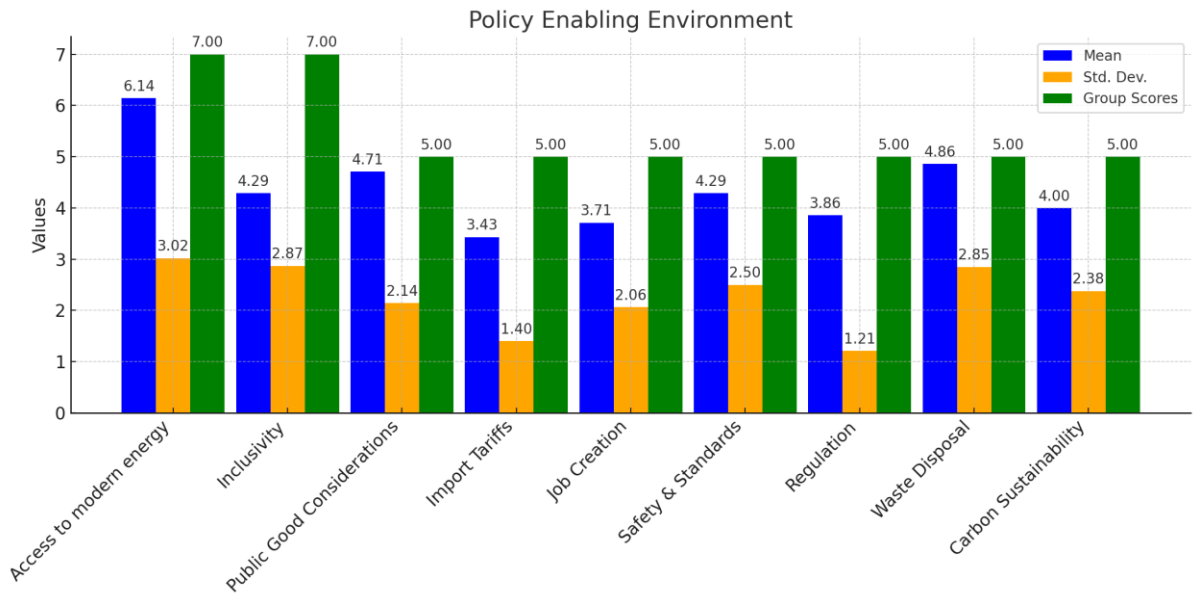

Figure 5: Policy Enabling Environment Theme

5. DISCUSSION AND EXTENDED ANALYSIS

5.1 Scaling Beyond Boundaries: Enhancing Bioethanol Adoption in Tanzania Through Multi-Stakeholder Integration

The UNIDO Bioethanol and Clean Cooking Programme in Tanzania exemplifies substantial progress in scaling up clean energy initiatives by transcending conventional theoretical frameworks (see Table 1). Through a multifaceted approach, the programme has successfully engaged diverse stakeholders, leveraging their complementary capacities to address critical scale-up dimensions. One key area of intervention has been market segmentation, where development agencies and private sector actors collaborated to align products with consumer-specific needs. These needs were defined by factors such as meal preferences, cooking customs, and taste variations.

The programme implemented an integrated marketing strategy that blended community-based education with targeted advertising efforts. This approach emphasized consumer engagement through cooking demonstrations and the use of culturally relevant materials presented in Swahili, which enhanced consumer trust and awareness. The strategy also incorporated promotional campaigns aimed at raising the visibility and appeal of bioethanol stoves. This dual approach mitigated cultural resistance to bioethanol stoves and fostered greater acceptance among consumers.

Financial accessibility represented another major focus area, with the programme introducing innovative pricing mechanisms to lower barriers to adoption. By offering bioethanol fuel in small, affordable units and emphasizing its long-term cost savings, the initiative incentivized consumer uptake. Moreover, strategic partnerships with corporations like Azam Bakhresa Group are being explored, with a potential plan to distribute 10,000 bioethanol stoves through Corporate Social Responsibility (CSR) schemes, though this is still under review and not yet contracted. This approach not only enhanced affordability but also broadened access for low-income households, which are typically excluded from clean energy transitions.

Inclusivity was another cornerstone of the programme, with targeted efforts to empower women. Capacity-building initiatives provided training for women to become stove vendors and agents, thereby enhancing their economic opportunities and promoting gender-inclusive energy access. By involving women in distribution and sales, the programme not only facilitated gender empowerment but also expanded its consumer base, as women often play a central role in household energy decisions.

Efforts to localize production, strengthen capacity building, and improve logistics further enhanced the programme's impact. Localizing the production of bioethanol stoves reduced reliance on imports, boosted the domestic supply chain, and created employment opportunities within Tanzania. While the programme has not achieved complete self-sufficiency, its holistic approach has significantly improved programme delivery and scalability. These combined efforts have established a more sustainable model for bioethanol adoption, laying a foundation for long-term energy transition within Tanzanian communities (see Table 1).

Table 1: Multi-Stakeholder Scale-Up Strategies in Development Settings: The UNIDO Bioethanol and Clean Cooking Programme in Tanzania

Scale-Up Focus Areas	Mandated Actor(s) & Roles	UNIDO Bioethanol Scale-Up Initiatives in Tanzania	Implications
Market Segmentation	**Development Agencies** (assess market needs) & **Private Sector** (target specific user segments)	1. Segment by meal type: Bioethanol for quick meals, charcoal for slow cooking. 2. Address regional customs: Demonstrations for coastal cooking styles. 3. Taste-based segmentation: Address perceptions about taste differences.	Enhances consumer targeting, customization of products, and increases bioethanol adoption.
Marketing Strategies	**Development Agencies** (community awareness) & **Private Sector** (advertising and brand visibility)	1. Live cooking demos: Showcase cooking of traditional dishes like beans. 2. Swahili education materials: Simplify understanding and usage. 3. Highlight taste neutrality: Promote bioethanol as flavour neutral.	Builds consumer trust, increases awareness, and addresses cultural barriers.
Pricing	**Private Sector** (pricing strategies) & **Development Agencies** (subsidies support)	1. Small-unit fuel sales: Sell bioethanol in small, affordable units. 2. Cost-savings education: Show cost benefits of bioethanol over time.	Increases affordability and consumer confidence, promoting sustained use.
Inclusivity	**Development Agencies** (promote gender equity) & **Government** (support women empowerment)	1. Women-focused campaigns: Target women as primary users. 2. Women capacity building: Women trained as stove agents and vendors.	Empowers women economically and promotes inclusive access to clean energy.
Education Campaigns	**Development Agencies** (design educational content) & **Private Sector** (promote user uptake)	1. Cooking demonstrations: Showcase stove capabilities for traditional dishes. 2. Swahili education materials: Clear, accessible user guides in local language.	Reduces consumer scepticism, improves user experience, and promotes stove adoption.
Subsidies	**Development Agencies** (subsidy provision) & **Government** (policy support)	1. Stove giveaways. A potential initiative under review by Azam Bakhresa Group's CSR aims to distribute 10,000 stoves to women vendors. Approximately 500 have been distributed by October 2024. 2. Subsidized stove pricing: Reduce cost barriers for low-income consumers.	Increases affordability, enhances access for low-income households, and builds public trust.
Efficiency	**Development Agencies** (promote efficiency) & **Private Sector** (ensure cost-efficiency)	1. Fuel efficiency education: Promote bioethanol's 3+ hour burn time per litre 2. Timesaving for users: Highlight ease of stove use, especially for women.	Promotes efficient energy use, reduces time burden for women, and ensures resource conservation.
Partnerships	**Development Agencies** (broker partnerships), **Private Sector** (resource support), & **Government** (policy facilitation)	1. Azam CSR stove distribution: A proposed initiative under review aims to distribute 10,000 stoves to women vendors, though it has not yet been contracted. 2. Local partnerships for distribution: Local distributors manage fuel access in Dar es Salaam.	Facilitates efficient distribution, strengthens supply chains, and promotes public-private cooperation.
Logistics	**Private Sector** (manage logistics) & **Government** (infrastructure support)	1. Fuel & stove storage: Warehousing for 20,000+ units in Dar es Salaam and Nairobi. 2. Flexible fuel distribution: Bioethanol provided on cash or credit basis.	Strengthens supply chain capacity, ensures availability, and enhances last-mile distribution.
Capacity Building	**Development Agencies** (fund capacity building) & **Private Sector** (support technical training)	1. Local stove assembly: UNIDO requires local teams to assemble stoves to develop skills. 2. Training for stove repair: Local technicians trained to manage stove repairs.	Builds technical skills, supports local employment, and enhances stove maintenance capacity.
Local Production	**Private Sector** (drive production) & **Government** (production policy support)	1. Molasses-based bioethanol production: Azam produces bioethanol from sugarcane molasses. 2. Regional stove production: Stove production shifted from Durban to Nairobi for efficiency.	Localizes production, reduces costs, and strengthens regional manufacturing capacity.

Source: Authors (2025)

5.2 Initial Emerging Lessons Learnt and Gained

The experience of scaling up bioethanol in Tanzania under the Modern Energy Cooking Services (MECS) Transition Theory of Change (TToC) framework reveals critical lessons for clean cooking energy transitions in development settings. Four key areas stand out as essential components of a successful scale-up: multi-stakeholder coordination, consumer demand flexibility, supply chain resilience, and affordability—including subsidies necessary to make the stove accessible. These components, supported by concrete examples from the UNIDO Bioethanol and Clean Cooking Programme, offer valuable insights for policymakers, development agencies, and private sector actors aiming to achieve large-scale clean energy adoption.

Multi-Stakeholder Coordination

One of the most significant lessons from Tanzania's bioethanol scale-up is the power of multi-stakeholder coordination. The process of bioethanol adoption requires the alignment of efforts by development agencies, governments, private sector actors, and local communities. Each stakeholder plays a unique role, from financing and policy advocacy to production, distribution, and consumer education. Azam Bakhresa Group, one of Tanzania's largest private-sector players, is reviewing a potential Corporate Social Responsibility (CSR) initiative to distribute 10,000 bioethanol stoves to low-income households, though it has not yet been contracted. This initiative focused on reaching marginalized groups, particularly women vendors, who are often financially excluded from the clean energy transition. By facilitating targeted distribution, the CSR effort improved stove affordability and broadened access to clean energy solutions for underserved communities. This approach also supported gender empowerment by promoting inclusive access to sustainable cooking technologies for vulnerable households.

Another example of successful multi-stakeholder coordination is the establishment of partnerships with local distributors. Local distributor (Consumer Choice Company) played a pivotal role in ensuring consistent availability of bioethanol fuel at community levels. By requiring distributors to maintain a minimum stock buffer of two to three months' supply, UNIDO mitigated the risk of stockouts, which are common in volatile fuel markets. This arrangement allowed distributors to fulfil community needs more consistently, particularly in urban areas like Dar es Salaam. By involving diverse stakeholders, UNIDO was able to localize operations, strengthen supply chain logistics, and provide technical training for local distributors, which improved their capacity to manage storage, retail, and after-sales support.

Consumer Demand Flexibility

The experience in Tanzania revealed that consumer behaviour and preferences are crucial determinants of bioethanol adoption. A key insight was that fuel stacking—the simultaneous use of multiple cooking fuels—remains a prevalent practice, even when households have access to bioethanol. Households did not entirely abandon traditional fuels such as wood, charcoal or kerosene but instead adopted bioethanol, biogas and eCooking as a complementary fuel. For instance, many households continued to use charcoal for cooking traditional dishes, such as rice prepared with a crispy crust (common in coastal regions like Zanzibar) because bioethanol stoves were perceived as unsuitable for achieving this texture.

To address this challenge, the programme shifted its communication strategy by promoting bioethanol as a fuel for quick and convenient meals such as tea, breakfast, or reheating food. This approach was reinforced by cooking demonstrations where consumers witnessed the ability of bioethanol stoves to prepare familiar local dishes. By engaging women—who are typically the primary household cooks—in these cooking events, the programme successfully challenged cultural misconceptions and highlighted the versatility of bioethanol for diverse cooking tasks. These live demonstrations, held at community events, allowed participants to sample meals prepared with bioethanol, fostering a sense of trust in the new technology.

Flexible pricing further played a critical role in driving adoption. Since low-income households typically purchase cooking fuel in small quantities, UNIDO's programme introduced half-litre, one-litre, and five-litre bottles of bioethanol fuel. This system mirrored the buying patterns for charcoal and kerosene, which are also sold in small, affordable units. By making bioethanol fuel accessible in small quantities, households were able to "test" the fuel before committing to larger purchases. This flexible purchasing option proved to be a game-changer in expanding access to clean cooking fuel for low-income households.

Supply Chain Resilience

Supply chain resilience is essential for achieving large-scale adoption of clean cooking solutions. In the early stages of the bioethanol scale-up, reliance on imports for fuel and stoves caused delays and price fluctuations. Imported stoves from Durban, South Africa, had to be shipped to Tanzania, increasing supply chain costs and causing delivery delays. Recognizing this challenge, UNIDO partnering with the local distributing company (Consumer Choice Company) facilitated the localization of stove production by partnering with Burn Manufacturers in Nairobi, Kenya. Burn established a local production line dedicated to manufacturing bioethanol stoves, significantly reducing costs and improving supply chain efficiency. This shift from imported stoves to local production enabled faster delivery and lower costs for consumers.

Another critical intervention was the development of a local maintenance and repair network. One of the main reasons for the abandonment of clean cooking technologies is the unavailability of spare parts or technical support. Drawing lessons from Ethiopia's bioethanol experience, where stove malfunctioning led to 10% of users abandoning the stoves, UNIDO partnering with the (Consumer Choice Company established a network of local repair agents and technical support centres. Call centres were set up to provide 24/7 assistance to stove users, allowing them to report stove malfunctions or request troubleshooting support. Local repair teams were trained to fix technical issues, reducing stove abandonment and boosting consumer confidence in the durability of bioethanol stoves.

The supply chain for bioethanol fuel was also restructured to promote availability and affordability. UNIDO partnering with the Consumer Choice Company facilitated the development of a multi-source fuel supply System by integrating domestic bioethanol production (sourced from sugar producers like Kilombero and Kagera) with imports from neighbouring countries like Uganda. This multi-sourcing strategy ensured a consistent supply of bioethanol fuel, even when local production was disrupted. It also contributed to price stabilization, ensuring that fuel prices did not spike due to supply shortages.

By requiring local distributors to maintain a three-month stock buffer, the initiative created a more predictable and reliable fuel supply for consumers.

Although bioethanol is considered a locally grown fuel, production levels in both Kenya and Tanzania remain insufficient, raising concerns about long-term energy security and self-sufficiency. To compensate for shortages, both countries depend on imports, highlighting the challenges of meeting demand solely through domestic production.

In contrast, electricity provides greater scalability and energy security, with less reliance on imports compared to bioethanol. While Kenya and Tanzania supplement their electricity supply through regional energy exchange contracts, these imports remain minimal relative to total domestic generation. Kenya imports some hydropower from Ethiopia and Uganda, benefiting from lower costs and enhanced regional power trade, while Tanzania sources limited electricity from Uganda and Zambia to strengthen its energy supply network.

5.3 Comparisons of KOKO Networks and UNIDO bioethanol scale up Approaches

The transition from traditional biomass fuels to bioethanol, biogas, and electricity for cooking is a key strategy for reducing environmental degradation, public health risks, and economic burdens associated with wood, charcoal, and kerosene use. The previous sections examined the United Nations Industrial Development Organization (UNIDO) approach, implemented in partnership with Consumer's Choice Limited (CCL) in Tanzania, which focuses on market facilitation through donor funding, infrastructure development, and policy support.

In contrast, this section introduces KOKO Networks, which follows a private-sector-led model in Kenya and Rwanda, leveraging investments, carbon finance, and consumer revenue for self-sustaining growth. While both initiatives aim to promote bioethanol as an affordable and accessible cooking fuel, their strategies differ significantly in scalability, financing, distribution networks, and policy engagement. Given these distinct approaches, direct comparisons are complex, but this analysis highlights their key success factors, challenges, and how they play complementary roles in fostering bioethanol market development.

5.3.1 Business Expansion and Geographical Penetration

Both KOKO Networks and UNIDO-CCL have identified urban centres with high charcoal dependency as key markets for bioethanol adoption. UNIDO's approach prioritizes urban areas first to achieve lower costs and rapid deployment, building a sustainable industry before expanding into rural areas. In contrast, KOKO Networks follows a different strategy, particularly in retail integration and infrastructure development.

KOKO Networks has adopted a retail-integrated approach, embedding approximately 3,000 KOKO Points (smart fuel dispensers with a proprietary valve system) within existing neighbourhood shops across Nairobi, Mombasa, Kisumu, and Nakuru. This decentralized distribution model ensures that urban consumers can access bioethanol within a five-minute walk, eliminating the logistical constraints of centralized fuel stations. By April 2024, KOKO had expanded to 1.2 million households in Kenya, with a goal of reaching 3 million by 2029, demonstrating the effectiveness of its model

(MIGA, 2024). Following its success in Kenya, KOKO expanded into Rwanda in 2022, replicating the same retail-integrated model. The company aims to grow its customer base from 20,000 households in 2024 to 1 million by 2027 (MIGA, 2024). A key enabler of KOKO's expansion has been its long-term partnership with Vivo Energy (since 2018), leveraging existing fuel logistics infrastructure to integrate bioethanol distribution into established fuel networks, reducing capital expenditure and improving affordability (KOKO Networks, 2018).

In contrast, UNIDO's approach in Tanzania has been infrastructure-intensive, prioritizing ethanol production and supply chain development before large-scale retail distribution. The initiative began in Dar es Salaam, with plans to distribute ethanol cookstoves to 500,000 households, of which CCL was contracted to supply 160,000 households between 2019 and 2024. Instead of embedding dispensers in neighbourhood shops, UNIDO established an ethanol blending and bottling plant in Dar es Salaam, operated by Consumer's Choice Limited (CCL), with a batch capacity of 2.4 million litres per year (UNIDO, 2023c). Despite these efforts, by September 2024, only 14,000 households had transitioned to ethanol cooking (UNIDO, 2023c). This adoption rate indicates that an infrastructure-intensive approach may not lead to rapid consumer uptake unless supported by an efficient retail distribution network. Unlike KOKO, UNIDO has relied on local ethanol production from Kilombero Sugar Company and TPC Limited, reducing import dependency but requiring high initial capital investment before achieving large-scale market penetration.

5.3.2 Financial Investments and Market Scalability

The financial strategies of KOKO Networks and UNIDO highlight a fundamental difference in how their approaches enable scalability in the bioethanol sector—one driven by private-sector-led, market-based expansion and the other reliant on donor-funded infrastructure development. KOKO Networks has successfully leveraged private investments, carbon finance, and grants to scale its operations in a way that is inherently self-sustaining and expandable. Each additional customer contributes to revenue generation through fuel sales and carbon credit issuance, creating a reinforcing cycle of growth. By December 2023, KOKO had issued 2.45 million tons of carbon credits, allowing it to subsidize fuel and cookstove costs by up to 40% (MIGA, 2024; BloombergNEF, 2019; KOKO Networks, 2023c). Additionally, its pay-as-you-go model, integrated with mobile payments like M-Pesa, ensures affordability and accessibility for low-income consumers, further driving adoption. With substantial private investments—such as Rand Merchant Bank's $125 million funding for Kenya and $10 million for Rwanda in January 2024—KOKO's model is structured for continuous expansion (KOKO Networks, 2024).

In contrast, UNIDO's ethanol initiative in Tanzania follows a project-based approach that lacks the organic scalability of KOKO's model. Its reliance on donor funding, including support from the Global Environment Facility (GEF) and the United Nations Capital Development Fund (UNCDF), has primarily facilitated one-time stove subsidies and infrastructure setup. The Bioenergy Incentive Fund (BIF) aimed to attract $100 million in private investment, and progress is ongoing (UNIDO, 2023c). Consumer's Choice Limited (CCL) has committed $1.1 million toward ethanol bottling, stove assembly, and distribution, which is a positive step, though it is lower than KOKO's private-sector financing (UNIDO, 2023c). Additionally, efforts to introduce pay-as-you-go models in Tanzania have

encountered challenges due to limited digital payment adoption, impacting the pace of consumer uptake (UNIDO, 2023c).

In contrast, the eCooking sector in both Kenya and Tanzania has seen initiatives aimed at promoting electric cooking solutions. In Kenya, the Energy and Petroleum Regulatory Authority (EPRA) introduced a new tariff band in April 2023 to encourage demand growth through cooking. This tariff offers a discounted rate for households consuming between 30 to 100 kWh per month, making electric cooking more affordable and accessible, and encouraging a transition from traditional fuels to electricity for cooking needs (Leary, Onjala, & Ochieng, 2023).

Similarly, Tanzania launched the eCooking Scale and Support Programme, pledging £3.5 million from UKAid to support the scaling of eCooking across the country from 2024 to 2026. This program aligns with the government's agenda to accelerate access to clean cooking solutions, especially with the increasing electricity generation from renewable sources like the Julius Nyerere Hydropower Plant (Clements, 2024). The emerging focus on eCooking, supported by strategic investments and favourable tariffs, offers an alternative pathway to enhance energy security and provide affordable, clean cooking options in the region.

5.3.3 Policy Support and Regulatory Challenges

Government policies play a crucial role in determining the competitiveness of bioethanol against traditional fuels. Kenya and Rwanda have implemented progressive policies, while Tanzania faces regulatory barriers that hinder market growth.

In Kenya, the Ethanol Cooking Fuel (ECF) Industry Masterplan (2021) institutionalized ethanol as a recognized cooking fuel, removing excise duties on ethanol imports to enhance price competitiveness (KOKO Networks, 2021). However, import duties (25%) and VAT (16%) on denatured technical bioethanol still increase its retail price, making it less competitive against LPG, which is tax-exempt (Dalberg, 2018; SouthSouthNorth, 2020). Rwanda has also taken proactive steps to support bioethanol adoption. In 2022, the Rwandan government partnered with KOKO Networks to launch the National Renewable Cooking Fuel Utility, positioning the country as a continental leader in clean cooking transitions (Rwanda Revenue Authority, 2024). Under the agreement, the Government of Rwanda will establish a supportive policy framework by removing VAT and import duties on ethanol fuel and equipment. This policy ensures that cost reductions directly benefit households through lower consumer prices.

Tanzania imposes import duties and VAT on ethanol, making it less price-competitive than charcoal (UNIDO, 2023C). Unlike Kenya and Rwanda, Tanzania lacks ethanol price standardization and direct government subsidies for ethanol stoves, further hindering adoption.

5.3.4 Consumer Adoption and Market Growth

The success of bioethanol adoption depends on affordability, accessibility, and consumer awareness. While KOKO's consumer-centric model has led to rapid adoption, UNIDO's infrastructure-driven approach has faced slower consumer uptake.

KOKO Networks has successfully implemented a consumer-first approach, leveraging carbon finance to lower prices and integrating fuel dispensers into neighbourhood shops. By incorporating digital microtransactions through M-Pesa, KOKO has facilitated seamless fuel purchases, making clean cooking more attractive to urban households (KOKO Networks, 2023). As a result, Kenya's bioethanol market grew from 50,000 households in 2020 to over 1.2 million in 2024 (KOKO Networks, 2023). The company's Rwanda expansion further reflects the effectiveness of this demand-driven model.

UNIDO's infrastructure-driven strategy in Tanzania has made progress, although adoption has been gradual. Despite targeting 160,000 households, 14,000 had transitioned by September 2024, with challenges such as the high cost of ethanol stoves, limited awareness campaigns, and the absence of flexible financing options like PAYG (UNIDO, 2023c). In response, UNIDO is exploring microfinance partnerships and instalment-based stove purchases to enhance adoption.

A proposed initiative by the Bakhresa Group aims to support small-scale food vendors by distributing 10,000 ethanol cookstoves to women in the food industry. While still under review and not yet contracted, the initiative has already donated 500 stoves by 2024, demonstrating the potential for further expansion through affordability-focused interventions (UNIDO, 2023c).

5.3.5 Technological Innovations in Bioethanol Distribution

Technological advancements play a significant role in the adoption and distribution of bioethanol as a clean cooking fuel. KOKO Networks and the United Nations Industrial Development Organization (UNIDO) have adopted distinct technological approaches to enhance supply chain efficiency and consumer accessibility. While KOKO Networks prioritizes digital integration and retail-based distribution, UNIDO focuses on production infrastructure and fuel storage capacity.

KOKO Networks has implemented a technology-driven approach that improves accessibility, efficiency, and affordability in bioethanol distribution. A key innovation is the KOKO Point smart fuel dispensers, which operate as "fuel ATMs" embedded within neighbourhood shops. These dispensers allow consumers to purchase bioethanol in precise quantities using digital payments, making the fuel more affordable by enabling small, flexible purchases instead of requiring a large upfront investment (KOKO Networks, 2018). To enhance supply chain efficiency, KOKO employs cloud-based monitoring systems that track fuel sales, dispenser activity, and inventory levels in real time. This system optimizes logistics, prevents fuel shortages, and ensures reliable distribution. Additionally, KOKO has integrated mobile payment platforms such as M-Pesa, allowing for seamless pay-as-you-go (PAYG) transactions. This model supports financial inclusion, particularly among low-income households, by enabling them to purchase bioethanol in smaller, more affordable amounts (KOKO Networks, 2021). In addition to fuel distribution, KOKO has been involved in ethanol stove manufacturing since April 2021, ensuring that stove availability aligns with fuel supply growth. This approach reinforces consumer confidence in bioethanol as a sustainable and reliable cooking solution. The success of this integrated technological model has contributed to KOKO's rapid market expansion, with over 1.2 million households in Kenya using KOKO bioethanol by 2024.

KOKO Networks and UNIDO's bioethanol initiatives take different approaches but share a common goal of expanding clean cooking solutions. KOKO has built a retail-based digital model, secured substantial private financing, and leveraged carbon finance to scale its operations.

In contrast, UNIDO's initiative in Tanzania has relied on donor-funded investment grants to develop the market. Approximately 80% of UNIDO's efforts have been focused on supporting local companies in setting up distribution operations and subsidizing stoves to lower costs and reduce barriers to adoption—both highly customer-centric strategies. While KOKO's model is driven by commercial investment, UNIDO has used available donor funding as a market catalyst. In partnership with Consumer's Choice Limited (CCL), UNIDO has developed an ethanol blending and bottling facility in Dar es Salaam, with a storage capacity of 2.4 million litres per year. This facility is intended to ensure a consistent ethanol supply while maintaining quality control. Unlike KOKO's smart fuel dispenser network, Tanzania currently lacks an automated retail distribution system for bioethanol. However, UNIDO and CCL have piloted mobile vending solutions and ethanol sales at petrol stations, offering alternative distribution channels. While these approaches are still in the early stages, they provide valuable opportunities to expand consumer access. To enhance affordability, UNIDO is exploring alternative financing models, such as microfinance partnerships and instalment-based purchasing schemes for ethanol stoves. Although the adoption of mobile payment systems in Tanzania has been slower than in Kenya, these efforts are contributing to increased opportunities for bioethanol access.

6. CONCLUSIONS AND POLICY RECOMMENDATIONS

The adoption of clean cooking fuels such as liquefied petroleum gas (LPG), electricity, biogas, and bioethanol remain limited in both Kenya and Tanzania. In Kenya, approximately 20% of households primarily use LPG for cooking, while electricity and biogas are utilized by about 3% and less than 1% of households, respectively. Bioethanol usage is also less than 1% among Kenyan households. In Tanzania, over 89% of households rely on traditional polluting fuels, with LPG usage at 3.2% and electricity at 3%. Biogas and bioethanol adoption rates are negligible. To address these challenges, both countries have introduced national strategies. Kenya's National Cooking Transition Strategy 2024–2028 aims to promote the adoption of clean cooking solutions, including LPG, electricity, biogas, and bioethanol, to reduce reliance on traditional biomass fuels. Similarly, Tanzania's National Clean Cooking Strategy 2024–2034 seeks to increase access to modern cooking energy to 80% by 2034, focusing on promoting the use of LPG, electricity, bioethanol, biogas, and briquettes.

The study highlights the complexities of scaling bioethanol as a clean cooking fuel in Tanzania, with a focus on the UNIDO Bioethanol and Clean Cooking Programme. While the program has made progress in establishing production and distribution infrastructure, key challenges remain in consumer adoption, supply chain resilience, financial accessibility, and policy support.

A comparison with Kenya's KOKO Networks underscores the impact of a market-driven, decentralized retail model, supported by private investment, carbon finance, and business-led expansion. KOKO's rapid growth has been fuelled by a combination of grants, carbon credits (currently under review), and major private investments, enabling a self-sustaining cycle where each new customer strengthens its financial sustainability.

In contrast, UNIDO's approach in Tanzania is infrastructure-intensive and donor-dependent, focusing on de-risking the market rather than direct scalability. Through funding from institutions such as the Global Environment Facility (GEF), UNIDO aims to create conditions for private-sector participation by building infrastructure, supporting policy development, and providing technical assistance. However, challenges such as mismatched fuel supply and demand and limited digital payment adoption continue to slow bioethanol adoption.

Rather than viewing these models as directly comparable in terms of scale, they can be seen as complementary. KOKO's private-sector approach demonstrates how commercial investment can rapidly expand bioethanol adoption when the right conditions exist, while UNIDO's intervention focuses on establishing those conditions where they do not yet exist. The findings suggest that for bioethanol to become a viable mainstream cooking solution in Tanzania, strategic interventions are needed across multiple dimensions, including consumer engagement, regulatory reform, supply chain optimization, and financial innovation to transition from donor dependency to a sustainable, market-driven model.

1. Consumer Behaviour and Market Adoption

Consumer behaviour plays a pivotal role in shaping bioethanol adoption, with fuel stacking emerging as a widespread practice. Many households continue to use bioethanol alongside charcoal and kerosene, while some also complement it with biogas, LPG, and electricity due to concerns about affordability, fuel availability, and cultural perceptions of cooking performance. This pattern

underscores the importance of clean fuel stacking, where multiple clean energy sources, such as bioethanol, LPG, biogas, and electricity, are used interchangeably to enhance cooking reliability, affordability, and energy security.

The synergies between eCooking and bioethanol are particularly noteworthy. Electricity offers precision, convenience, and speed, making it suitable for tasks like boiling, simmering, and reheating. However, challenges such as power outages, fluctuating tariffs, and limited rural grid access mean that electricity alone may not always be a reliable solution. In contrast, bioethanol provides a portable and independent alternative, ensuring continuous access to clean cooking even in off-grid or low-electrification areas. By integrating these two energy sources, households can maximize the strengths of each fuel, reducing reliance on inefficient and polluting traditional fuels.

Similarly, LPG and bioethanol complement each other in a stacked fuel system. While LPG is widely recognized for its high energy efficiency and fast cooking performance, its accessibility and affordability remain concerns for low-income households, particularly in rural areas. Bioethanol, being a renewable and locally produced fuel, can serve as an accessible alternative in cases of LPG supply shortages or price fluctuations. The same logic applies to biogas, which, despite being a sustainable solution, faces adoption challenges due to infrastructure limitations and the need for continuous feedstock supply.

Fuel stacking is often associated with continued biomass use, which undermines the health benefits of clean fuels due to household air pollution (HAP). However, clean fuel stacking—such as ethanol/LPG, ethanol/biogas, or ethanol/eCooking—ensures a healthier kitchen environment by avoiding harmful emissions. While LPG has climate and price concerns, its role in reducing indoor air pollution remains significant. Rather than viewing fuel stacking as an obstacle, a policy approach that supports clean fuel stacking could enhance energy security and cooking reliability. Strategies should focus on improving affordability, expanding last-mile fuel distribution networks, and increasing awareness of clean fuel combinations.

The perception that bioethanol stoves are more suitable for quick meals rather than heavy or traditional dishes limits their role as a transitory cooking solution. Comparative insights from Kenya's KOKO Networks show that positioning bioethanol as a clean, modern, and aspirational cooking fuel has been instrumental in shifting consumer perceptions. Tanzania has already implemented key initiatives such as targeted marketing campaigns and cooking demonstrations through CCL. Further leveraging these efforts, along with expanding digital engagement strategies, can enhance consumer confidence and drive broader acceptance of bioethanol cooking solutions.

Affordability remains a key determinant of adoption. Many consumers, particularly in low-income households, struggle with the high upfront costs of bioethanol stoves and the perceived expense of maintaining a consistent fuel supply. Kenya's KOKO Networks successfully integrated microtransaction-based purchasing through digital payment platforms, allowing consumers to buy bioethanol in small, affordable quantities. A microtransaction-based PAYG pricing model for eCooking and bioethanol stoves in Tanzania, leveraging mobile money, would enhance accessibility and align with consumer spending habits. While LPG PAYG is already in place, PAYG for eCooking and bioethanol stoves remains in the planning and pilot stages and is not yet fully implemented.

Furthermore, offering instalment-based financing for stoves through microfinance institutions would reduce the financial burden on households, encouraging higher adoption rates.

2. **Supply Chain Optimization and Local Manufacturing**

The study highlights supply chain inefficiencies as a major barrier to bioethanol adoption in Tanzania, with persistent challenges in fuel production, distribution, spare parts availability, and maintenance services, further limiting accessibility. For instance, while local ethanol production has improved, it remains insufficient to meet demand, leading to imports and raising concerns about long-term energy security and self-sufficiency. In contrast, electricity offers greater scalability and reliability, with minimal reliance on imports through regional energy exchange contracts. Given the uncertainties in the bioethanol supply chain, many consumers continue to use modern fuels alongside traditional fuels as a backup, emphasizing the need for a more stable and sustainable energy alternative.

Unlike Kenya's decentralized distribution system, where bioethanol is readily available at neighbourhood fuel dispensers, Tanzania's supply chain remains centralized, limiting accessibility for many households. While KOKO, which circumvents the opportunity for sales agents to participate in fuel delivery, UNIDO through CCL integrates sales agents into its vending approach, further supporting market expansion.

A more effective distribution model would involve embedding fuel dispensers in retail outlets, fast moving consumer goods (FMCGs) entities, and petrol stations, ensuring last-mile availability. Establishing regional storage hubs would further stabilize supply and prevent periodic shortages that discourage adoption.

Expanding local manufacturing of clean cooking stoves—including bioethanol and Tier 3 eCooking appliances such as the IoT-enabled ECOA Induction Cooker, which is expected to reach over 1 million households in East Africa—offers a strategic opportunity to reduce import dependence, lower costs, and create jobs (BURN Manufacturing, 2024). Investing in domestic production not only retains economic value within national borders but also strengthens industrial capacity. BURN Manufacturing in Nairobi exemplifies how transitioning from stove imports to local manufacturing enhances technical expertise, supply chain resilience, and employment creation. BURN's ability to produce both bioethanol and eCooking appliances highlights the potential for locally made solutions to improve affordability and accessibility while driving economic and environmental benefits.

Encouraging private-sector investment in clean cooking stove manufacturing can further enhance affordability and supply chain stability. While these appliances have traditionally been imported, local production reduces exposure to high import duties, foreign currency fluctuations, and logistical constraints. Additionally, regional manufacturing enables design customization to better align with local cooking habits, energy availability, and cost considerations.

Strengthening domestic production also fosters innovation, leading to the development of more efficient and user-friendly stove models over time. Governments that support local manufacturing can not only reduce trade deficits but also establish the clean cooking sector as a key driver of industrial growth. By prioritizing homegrown solutions, countries can advance both economic self-

reliance and sustainable energy transitions while expanding access to modern, high-efficiency cooking technologies.

The maintenance and repair ecosystem also requires enhancement. Many stove users abandon bioethanol technology when minor faults occur due to the lack of readily available technicians and spare parts. Establishing community-based repair centres, technical training programs, and after-sales support networks would improve consumer confidence and ensure long-term stove usability. A structured approach, where distributors and retailers collaborate with trained repair agents, would reduce product abandonment, and enhance the sustainability of bioethanol adoption.

While uncertainties in the bioethanol supply chain pose challenges to its adoption in Tanzania, significant progress has been made in electricity generation and access. As of December 2023, Tanzania's total installed power capacity reached 1,938.35 MW, with natural gas contributing 63%, hydropower 32%, fuel 4%, and biomass less than 1% (TanzaniaInvest, 2024). Electricity access has also improved significantly, rising from approximately 13% in 2008 to 45.8% in 2022 (World Bank, 2024). This expansion is driven by investments in hydropower, natural gas, and renewable energy, alongside initiatives such as the Rural Electrification Program and off-grid solar solutions, which have improved access in peri-urban and rural areas. Unlike bioethanol, where supply inconsistencies hinder adoption, the electricity sector benefits from structured national policies and investment frameworks that enhance reliability. However, just as no country has achieved universal electricity access without some form of subsidy 2022 (World Bank, 2024), ensuring widespread adoption of clean cooking solutions including bioethanol may also require targeted financial support and policy interventions.

3. Regulatory and Policy Reforms

Regulatory barriers, including high import duties, VAT on bioethanol, and complex licensing requirements, continue to hinder the affordability and competitiveness of bioethanol in Tanzania. Unlike Kenya and Rwanda, where bioethanol benefits from policy incentives, Tanzania has yet to introduce fiscal measures that support market expansion. The study finds that bioethanol fuel in Tanzania remains subject to an 18% VAT, increasing consumer costs and limiting affordability.

To create a more enabling environment, the government should consider reducing VAT and import tariffs on ethanol fuel and stoves, making bioethanol more price-competitive with traditional cooking fuels. Kenya’s Ethanol Cooking Fuel (ECF) Industry Masterplan offers a useful framework, providing a structured approach to integrating bioethanol into the national energy strategy. Tanzania could benefit from a similar policy framework, ensuring that bioethanol is positioned as a recognized clean cooking solution with financial and regulatory backing.

Regional trade harmonization is another critical area for intervention. Standardizing ethanol import policies across East Africa would facilitate cross-border trade, stabilize supply chains, and enhance price competitiveness. Furthermore, incentives should be provided to sugar industries to scale up ethanol production using agricultural residues such as molasses and cashew apple waste, strengthening the local supply chain while creating additional economic opportunities for farmers and agro-industrial stakeholders.

4. Financial Models and Investment Strategies

The financial sustainability and scalability of bioethanol adoption depend on funding mechanisms that reduce consumer costs while attracting private-sector investment. The experiences of KOKO Networks in Kenya and the UNIDO initiative in Tanzania illustrate key differences in financial strategies and their impact on scalability.

KOKO Networks has established a market-driven, self-sustaining model that integrates private investments, carbon finance, and a pay-as-you-go system. By issuing carbon credits, KOKO generates additional revenue, which subsidizes fuel and stove prices, making bioethanol more affordable for consumers. This creates a reinforcing cycle where each new customer not only drives fuel sales but also contributes to further carbon credit issuance, ensuring continuous financial sustainability and expansion.

In contrast, UNIDO's ethanol initiative in Tanzania has relied primarily on donor funding for infrastructure development and one-time stove subsidies. While this approach has facilitated initial market entry, it lacks sustainable financing mechanisms for organic growth. PAYG models for eCooking and bioethanol stoves are still in the planning and pilot stages, and the absence of fully implemented financing options, along with limited private-sector investment, has further slowed adoption and scalability. Expanding carbon credit mechanisms could help lower stove costs and create sustainable revenue streams, ensuring long-term carbon sustainability. UNIDO could explore carbon financing, leveraging successful models like BURN, to support clean cooking initiatives that balance affordability, emissions reduction, and sustainable carbon offset strategies.

Results-based financing (RBF) is a key driver in accelerating adoption, as demonstrated by the UNIDO project, where distributors are only paid upon successful stove sales to households. By linking financial incentives to performance benchmarks, RBF programs encourage private-sector players to invest in production, distribution, and consumer outreach, ensuring accountability and market-driven growth. This approach has also been effective in other clean energy sectors, where subsidies are disbursed based on actual adoption rates rather than upfront grants.

A strategic shift toward public-private partnerships is essential for mobilizing investment. Encouraging Corporate Social Responsibility (CSR) programs, such as the proposed Bakhresa Group initiative under review to distribute 10,000 ethanol stoves to food vendors, could enhance market penetration while providing economic opportunities for marginalized communities. Additionally, targeted financial interventions, such as low-interest loans and subsidy programs for first-time stove buyers, could further accelerate bioethanol adoption.

Kenya and Tanzania are scaling clean cooking solutions across multiple fuels through targeted financing and policy interventions. Kenya's discounted electricity tariff band and Tanzania's eCooking Scale and Support Programme aim to expand electric cooking adoption by improving affordability and accessibility. Meanwhile, bioethanol scaling follows divergent models—Tanzania's efforts rely on donor-funded initiatives like UNIDO's ethanol program, while Kenya's market-driven approach, led by KOKO Networks, leverages private investment, carbon financing, and PAYG models. To accelerate clean cooking transitions, policy interventions must integrate diverse financing mechanisms, scale up

domestic bioethanol production, expand carbon credit programs, and align subsidies and incentives across fuels to ensure sustainable growth in both countries.

5. **Consumer Engagement and Awareness Campaigns**

A key barrier to bioethanol adoption is the lack of awareness and persistent misconceptions about its safety, efficiency, and cost-effectiveness. While promotional campaigns and cooking demonstrations have had some success, their reach has been limited by financial constraints. The study emphasizes that awareness initiatives should be scaled up using digital platforms, social media engagement, and community-based outreach programs to ensure wider visibility.

Aspirational marketing has proven effective in Kenya, where bioethanol is marketed as a modern, clean, and desirable cooking fuel. Tanzania can adopt similar branding strategies, leveraging trusted community figures, chefs, and digital influencers to increase consumer trust. Additionally, integrating gender-focused campaigns that emphasize the health and economic benefits of bioethanol for women would enhance adoption, as women are the primary decision-makers in household energy use.

Expanding live cooking demonstrations and offering free trials of bioethanol stoves in target communities could further increase adoption rates. Consumers are more likely to switch fuels when they have firsthand experience of bioethanol's performance. Programs that allow households to borrow stoves for a trial period before committing to a purchase could help dispel doubts and encourage long-term usage.

Scaling up bioethanol in Tanzania requires a multi-pronged strategy that integrates policy reforms, market-driven distribution, financial incentives, and consumer engagement. A decentralized, retail-integrated model, like Kenya's KOKO Networks, is more effective than infrastructure-heavy solutions. To ensure adoption, Tanzania should reduce regulatory barriers, expand supply chains, improve financial access, and enhance consumer education. A coordinated effort among government, private sector, and community stakeholders will be key to making bioethanol a mainstream cooking solution, driving energy access, economic growth, and public health benefits.

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ABOUT THIS WORKING PAPER

The following blogs are part of the "Breaking Barriers, Unlocking Potential: Scaling Bioethanol for a Sustainable Future" series, are related to this working paper:

Blog 1: Unlocking the Potential of Bioethanol- Navigating Consumer Demand, Supply Chains, and Policy Frameworks.

Blog 2: Scaling Beyond Boundaries: Enhancing Bioethanol Adoption in Tanzania Through Multi-Stakeholder Integration.

Blog 3: Navigating the Complexities of Scaling Bioethanol: A Comparative Analysis of KOKO Networks and UNIDO Strategies

The Vice President of the United Republic of Tanzania, HE. Dr. Philip Mpango has commended the United Nations Industrial Organization (UNIDO) for promoting clean cooking solutions in the country. Photo credit: UNIDO

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