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Rural Communities Access to Clean Cooking Fuel, Energy and Technologies: Socioeconomic Implications and Progress Toward Sustainable Development in Africa

Dostęp społeczności wiejskich do czystego paliwa do gotowania, energii i technologii: implikacje społeczno-ekonomiczne i postęp w kierunku zrównoważonego rozwoju w Afryce

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Abstract
This study investigates the impact of rural communities' access to clean cooking fuels and technologies on sustainable development and socio-economic outcome. With data collected from the World Development Indicators and the Sustainable Development Index from 2000 to 2023, this study divides 43 African countries into five regions. It analyses the data using Pooled OLS and Fully Modified OLS techniques. The result from the analysis reveals that an increase in rural access to cleaner cooking energy positively impact sustainable development in Africa. Likewise, a 1 percent increase in rural access to cleaner energy increases African socioeconomic outcome by 1.43 percent. While, rural population growth negatively impacts sustainable development and socioeconomic outcome, FDI serves as a catalyst for improved socioeconomic conditions and in promoting sustainable development in Africa. Among other things, government should expedite actions in ensuring total access to cleaner energy for cooking by reducing the commercialization timeline for the new clean cooking energy sources, providing subsidies and tax incentives for clean cooking energy sources, and establishing supportive financing policies. This study contributes to the existing body of knowledge by presenting empirical evidence of the positive impacts of access to clean cooking fuels and technologies on sustainable development and socioeconomic outcomes. Hence, this study offers valuable insights into the potential of access to clean cooking fuels and technologies in improving socioeconomic conditions and in achieving sustainability.

Key words: clean fuels and technologies, rural electrification, economic growth, socioeconomic development, energy access, Sustainable Development Goals (SDGs)

Streszczenie
W tym badaniu zbadano wpływ dostępu społeczności wiejskich do czystych paliw i technologii do gotowania na zrównoważony rozwój i wyniki społeczno-ekonomiczne. Na podstawie danych zebranych ze Światowych Wskaźników Rozwoju i Indeksu Zrównoważonego Rozwoju z lat 2000–2023 badanie to podzieliło 43 kraje afrykańskie na pięć regionów. Dane analizowano przy użyciu technik Pooled OLS i Fully Modified OLS. Wynik analizy ujawnia, że wzrost dostępu obszarów wiejskich do czystszej energii do gotowania pozytywnie wpływa na zrównoważony rozwój w Afryce. Podobnie, 1-procentowy wzrost dostępu obszarów wiejskich do czystszej energii zwiększa afrykańskie wyniki społeczno-ekonomiczne o 1,43%. Podczas gdy wzrost populacji wiejskiej negatywnie wpływa

na zrównoważony rozwój i wyniki społeczno-ekonomiczne, bezpośrednie inwestycje zagraniczne służą jako katalizator poprawy warunków społeczno-ekonomicznych i promowania zrównoważonego rozwoju w Afryce. Rząd powinien między innymi przyspieszyć działania w celu zapewnienia całkowitego dostępu do czystszej energii do gotowania poprzez skrócenie harmonogramu komercjalizacji nowych źródeł czystej energii do gotowania, zapewnienie dotacji i zachęt podatkowych dla źródeł czystej energii do gotowania oraz ustanowienie wspierających polityk finansowania. Niniejsze badanie przedstawia empiryczne dowody pozytywnego wpływu dostępu do czystych paliw i technologii do gotowania na zrównoważony rozwój i wyniki społeczno-ekonomiczne. Stąd też niniejsze badanie oferuje nowe cenne spostrzeżenia na temat potencjału dostępu do czystych paliw i technologii do gotowania w celu poprawy warunków społeczno-ekonomicznych i osiągnięcia zrównoważonego rozwoju.

Słowa kluczowe: czyste paliwa i technologie, elektryfikacja obszarów wiejskich, wzrost gospodarczy, rozwój społeczno-ekonomiczny, dostęp do energii, Cele Zrównoważonego Rozwoju (SDGs)

1. Introduction

By 2030, it is anticipated that everyone will have access to clean and affordable energy worldwide. This commitment is enshrined in the United Nations Sustainable Development Goal (SDG) 7, which aims for universal access to such energy by the year 2030. In particular, SDG indicator 7.1.2 emphasizes the percentage of the global population that depends on clean fuels and technologies for cooking purposes (Aminu et al., 2024; Chen et al., 2024). Africa is viewed as lagging in its efforts to meet the objectives of Sustainable Development Goal 7 by the year 2030. Data indicates that in 2010, the region represented approximately 19% of the global population lacking access to clean cooking fuels and technologies, a figure that increased to around 40% by 2021 (International Energy Agency, 2022; United Nations, 2023). In rural Africa, the majority of households continue to rely on traditional biomass fuels such as firewood, charcoal, kerosene, cow dung, and agricultural residues for cooking. These fuels are inefficient and highly polluting, contributing to serious health risks, particularly respiratory diseases caused by indoor air pollution. According to the World Health Organization (WHO), approximately 4 million people die prematurely each year due to illnesses related to household air pollution from traditional cooking methods (WHO, 2018).

In retrospect, the unsustainable utilization of solid biomass for cooking leads to the degradation of forests and a reduction in forest cover in rural regions. Additionally, the inefficient combustion of biomass for cooking plays a major role in greenhouse gas emissions. Prolonged exposure to smoke from inefficient stoves is a major cause of respiratory diseases, while the labour-intensive process of collecting fuel—mostly carried out by women and children (World Bank, 2015). This results in missed chances for enhancing income, acquiring education, and exposes them to risks related to safety and security. The continued use of these fuels has wide-ranging negative effects on health, the environment, and socioeconomic development (Mishra et al., 2024; Hu et al., 2024). The lack of access to clean cooking technologies in rural areas exacerbates existing socioeconomic inequalities. Women and children, who are primarily responsible for gathering fuel, often spend hours that could otherwise be devoted to education or income-generating activities in collecting firewood (Imandojemu & Nathaniel, 2018; Practical Action, 2016). In addition, the high cost of certain fuels, such as charcoal, places a significant financial burden on low-income households, deepening economic disparities (International Energy Agency, 2020). Inadequate access to energy services stifles economic progress, restricts educational opportunities, and impedes access to healthcare (Nizami et al., 2023). The aforementioned enshrines the vicious cycle of poverty, restricting economic prospects and impeding human capital development.

Clean cooking fuels are characterized as those that do not contribute to indoor air pollution within residential settings (IEA, 2010). A broader concept related to this is *modern energy* for cooking, which the International Energy Agency describes as energy solutions that are deemed safer, more efficient, and environmentally sustainable compared to traditional solid biomass methods prevalent in sub-Saharan Africa (IEA 2014). Examples of such fuels include biogas, ethanol, and liquefied petroleum gas (LPG) (GACC 2012). Transitioning to cleaner cooking fuels and technologies is essential for improving public health, promoting environmental sustainability, and fostering economic development in rural areas (Clean Cooking Alliance, 2019). Access to clean cooking technologies is crucial for improving the quality of life in rural Africa, where more than 80% of the population depends on traditional biomass fuels (International Energy Agency, 2021).

The presence of fuel-efficient cookstoves that produce reduced emissions; the development of alternative and effective biomass fuel production technologies; the introduction of innovative business models; the expanding market potential; and the availability of carbon financing opportunities. The shift to cleaner energy sources is not only a public health necessity but also a socioeconomic imperative, as access to clean cooking fuels has profound effects on income levels, education, social welfare, and gender equality (Global Alliance for Clean Cookstoves, 2017). As rural communities' transit to clean energy sources, they experience a reduction in fuel expenses. This enables them to redirect more resources towards food, healthcare, investment and education, thereby enhancing their welfare and increasing the overall GDP per capita.

A number of recent initiatives have been implemented to promote the adoption of clean cooking technologies, such as LPG, biogas, ethanol stoves, and improved cookstoves, across rural Africa (United Nations, 2020). More specifically, the World Bank introduced the Africa Clean Cooking Energy Solutions (ACCES) initiative to tackle Africa's enduring energy issues and leverage new possibilities for revolutionizing the cooking sector. The primary goal of ACCES is to encourage the widespread adoption and distribution of clean cooking solutions through enterprise-based approaches across Africa. By enhancing access to modern technologies and cleaner fuels, this initiative aims to mitigate the negative health, environmental, and socio-economic effects associated with traditional cooking methods in the region. Albeit, the clean and enhanced cooking sector in Africa has made notable progress; however, it remains largely underdeveloped.

Currently, only 11% of the African population utilizes *clean* cookstoves powered by modern fuels, including liquefied petroleum gas (LPG) at 5% and electric stoves at 6%. Kerosene, employed by 7% of Africans, often fails to meet the criteria for a clean cooking solution due to mounting evidence of the health risks associated with conventional kerosene stoves in the region. Stoves utilizing renewable energy sources such as biogas, ethanol, and solar power are rare, accounting for less than 1% of usage, while the adoption of *advanced* biomass gasifier cookstoves, remains in the pilot phase with less than 0.1% penetration. Overall, Africa's access to clean and improved cooking solutions (25%, excluding legacy stoves) is significantly lower than that of any other global region (World Bank, 2014).

Although a variety of studies acknowledge the impact of access to clean cooking fuel on socio-economic outcomes and sustainable development (Mishra et al., 2024), little emphasis has been placed on assessing the impact of rural communities' access to clean cooking fuel on socio-economic outcomes and sustainable development, particularly in the African context. However, it is necessary to conduct the research at the rural community level in order to establish suitable macroeconomic policies, as this spectrum is regarded particularly vulnerable to the malaises of energy poverty in Africa. This study addresses key gaps in the literature on the sustainable development and socioeconomic impacts of rural energy access, specifically focusing on clean fuels and technologies for cooking in African countries.

The study's use of pooled OLS and Fully Modified OLS (FMOLS), also provides a more sophisticated analysis, addressing endogeneity and unobserved heterogeneity, which are often overlooked in previous studies. This methodological contribution enhances the reliability of the findings. By focusing on 43 African countries and regions, the study fills a regional gap in the literature, offering new insights for policymakers and contributing to the broader discourse on energy access, labour dynamics, and economic development in rural contexts.

2. Literature Review and Stylised Facts

2.1. Literature Review

In this review, we explore the socioeconomic impacts of transitioning to cleaner cooking technologies, such as Liquefied Petroleum Gas (LPG), electric stoves, and improved biomass stoves, across rural Africa. This transition is critical for improving health, enhancing economic productivity, promoting environmental sustainability, and advancing gender equality (Clean Cooking Alliance, 2019). The following sections examine the implications of access to clean fuels in four key areas: health outcomes, income and economic productivity, gender equity, and environmental sustainability.

These strands of literatures collectively explore the intersections of economic growth, sustainability, environmental governance, and financial stability across diverse regions, including Asia, Africa, and ASEAN. Guo et al. (2025) examine the influence of political institutions and natural resources on sustainable development in Asia, while Osabohien et al. (2024) highlight operational risk management's role in financial stability in West Africa. Wang et al. (2024) focus on strategies for reducing carbon emissions and postharvest losses to enhance environmental sustainability.

Imandojemu et al. (2025) and Osabohien et al. (2024) investigate renewable energy's impact on carbon footprints and economic growth, complementing Zheng et al. (2023), who explore renewable energy and business density as sustainable development drivers. Abd Majid et al. (2025) discuss national gender policies' moderating role in women directors' empowerment and carbon emissions disclosure. Further, Osabohien (2024) links nutrition to SDG 8 – decent work and economic growth – while Osabohien et al. (2024b) analyze global value chain participation and energy globalization in ASEAN. Jaaffar et al. (2024) assess how CEOs' and board members' environmental governance experience affects green management adoption in energy-intensive industries. Together, these works provide critical insights into sustainability, energy transitions, and institutional roles in fostering global economic and environmental resilience.

Access to clean cooking technologies significantly reduces the incidence of respiratory diseases, particularly among women and children, who are most exposed to indoor air pollution. Studies indicate that traditional biomass fuels produce large amounts of smoke and harmful particulate matter, which contribute to chronic obstructive pulmonary disease (COPD), lung cancer, and pneumonia. According to the WHO, household air pollution from inefficient stoves is one of the leading environmental health risks globally, with women in rural areas experiencing higher mortality rates due to prolonged exposure (WHO, 2018).

A study by Pope et al. (2017) demonstrates that the adoption of LPG and improved cookstoves reduces household air pollution by up to 90%, significantly lowering the risk of respiratory illnesses. Additionally, clean cooking technologies reduce the need for open fires and traditional stoves, decreasing the incidence of burns and injuries, which are common in rural areas where safety protocols may be lacking (Global Alliance for Clean Cookstoves, 2017). Hu et al. (2024) examined the spatial network structure of ethnic regions in Northwest China, particularly Ningxia, by analyzing the flow of people, goods, and information during the COVID-19 pandemic. The study made use of social network analysis highlighted regional development disparities and spatial interdependencies. This approach aligns with the econometric and regional disaggregation methods in the African clean cooking study, offering methodological parallels for understanding access disparities across African subregions.

In another study, Chen et al. (2024) introduced a novel AI-based approach using Visual Question Answering (VQA) to address carbon neutrality challenges. This work emphasizes the role of artificial intelligence in enhancing environmental sustainability by improving decision-making and visualization in carbon emission contexts. Further, Liu et al. (2025) explored the asymmetric effects of monetary policy uncertainty on renewable energy development. The study found that renewable energy investments are more vulnerable to negative economic shocks, underlining the importance of stable policy environments for energy transition.

The transition to clean fuels also has a profound impact on household income and broader economic productivity in rural communities. Traditional biomass fuels require hours of daily labour, primarily by women and children, to collect firewood. The time invested in this activity could otherwise be used for income-generating work or education, leading to greater economic output (Practical Action, 2016). A study by Lewis and Pattanayak (2012) shows that households that switch to clean cooking technologies experience an average increase of 10–15% in productive time, which is redirected towards farming, entrepreneurship, or formal employment. Furthermore, clean fuels, particularly LPG, can be more cost-effective in the long run than traditional biomass fuels, reducing overall household expenditure on energy. A 2018 report from the International Energy Agency (IEA) found that the use of efficient cooking solutions can save households up to 30% of their energy costs annually (International Energy Agency, 2020).

The impact of clean cooking technologies on gender equity is particularly profound. In rural communities, the burden of collecting firewood and managing household cooking largely falls on women and girls, who can spend up to six hours daily gathering biomass fuels. This time-consuming task limits their opportunities for education, economic participation, and social engagement (World Bank, 2015). Improved access to clean cooking solutions allows women and girls to reclaim time for education, thereby increasing literacy rates and enhancing long-term socioeconomic prospects (Practical Action, 2016). Moreover, with reduced fuel collection responsibilities, women are better able to engage in paid employment, contributing to household income and advancing gender equality. Evidence from studies in Kenya and Tanzania highlights that women in households with clean cooking technologies are more likely to participate in local markets and have greater access to financial resources, leading to improved social welfare outcomes (Global Alliance for Clean Cookstoves, 2017).

Transitioning to clean cooking technologies has significant environmental benefits, particularly in reducing deforestation and mitigating climate change. The demand for firewood and charcoal is a major driver of deforestation in Africa, leading to soil erosion, loss of biodiversity, and reduced agricultural productivity (United Nations, 2020). In regions where deforestation rates are high, such as sub-Saharan Africa, the shift to LPG, biogas, and ethanol stoves has helped slow the depletion of forest resources, promoting environmental sustainability. In addition to deforestation, traditional biomass fuels emit large quantities of carbon dioxide (CO_2) and black carbon, both of which contribute to global warming. The adoption of cleaner cooking technologies can significantly reduce greenhouse gas emissions. For instance, a study by the International Institute for Roche et al. (2024) found that the widespread use of improved biomass stoves in East Africa reduced CO_2 emissions by approximately 30%. This underscores the importance of clean cooking initiatives in achieving broader environmental goals, such as the United Nations' Sustainable Development Goals (SDGs), particularly Goal 13 on climate action (United Nations, 2020).

Access to clean cooking technologies can lead to significant improvements in household income and welfare. By reducing the time and labour required for fuel collection, particularly for women and children, clean cooking technologies free up time that can be redirected toward productive economic activities, such as farming, small businesses, or paid employment (Practical Action, 2016). Studies show that households using cleaner cooking technologies experience improved economic productivity, leading to higher income and enhanced household welfare (International Energy Agency, 2020). As rural communities reduce their reliance on traditional biomass fuels, they also spend less on fuel costs, allowing them to allocate more resources to food, healthcare, and education, all of which contribute to improved welfare and overall GDP per capita.

By reducing the burden of fuel collection, clean cooking technologies can have a positive impact on employment, especially for women. The time saved can be used for income-generating activities or pursuing education, thereby improving employability (World Bank, 2015). Additionally, the clean cooking sector itself creates new jobs, from

the manufacturing of stoves to fuel supply chains (Clean Cooking Alliance, 2019). This can stimulate local economies and increase rural employment, particularly in regions where unemployment rates are high.
In many rural African communities, girls are tasked with collecting firewood, which consumes a significant amount of time and often prevents them from attending school (Practical Action, 2016). Access to clean fuels reduces the need for such labour-intensive tasks, allowing girls to spend more time in school, thus improving literacy rates and overall educational attainment. Improved education contributes to human capital development, which is essential for long-term economic growth and development (World Bank, 2015).

2.2. Stylised Facts
Figure 1 depicts the percentage of total population with access to clean fuels and technologies for cooking in all regions and in the world as a whole, from 2000 to 2020 with an interval of 5 years. About 49.3 percent of the total world population had access to clean energy in 2000. There were improvements over the years and by the year 2020 about 71.3 percent of the world population were with access to clean energy for cooking. This represents about 44.6 percent growth rate from 2000 to 2020. Even though all regions experienced progresses in the access to clean fuels and technologies for cooking between 2000 and 2020, sub-Saharan Africa (SSA) region had the lowest and embarrassing access to clean energy for cooking.
In 2000, about 8.9 percent of people in SSA had access to clean energy for cooking. Even though, there were positive growths over the years, these growths were small and negligible, such that by the year 2020 the total access in SSA was 19.9 percent. This region was followed by South Asia (SAS) with 59.4 percent access to clean fuels and technologies for cooking in 2020. However, people from the North America (NAC) and the European Union (EUU) had total access to clean energy for cooking throughout the years. Moreover, in 2020 Europe and Central Asia (ECS) and Middle East and North Africa (MEA) had 97.5 percent and 95.1 percent access to clean fuels and technologies for cooking respectively. While all regions that have not fully transferred to clean energy for cooking should endeavour to do so, South Asia and especially sub-Saharan Africa should expedite actions (through policies) towards the implementation of access to clean cooking energy. This will swiftly influence both sustainable growth and socio-economic condition of its citizenry.

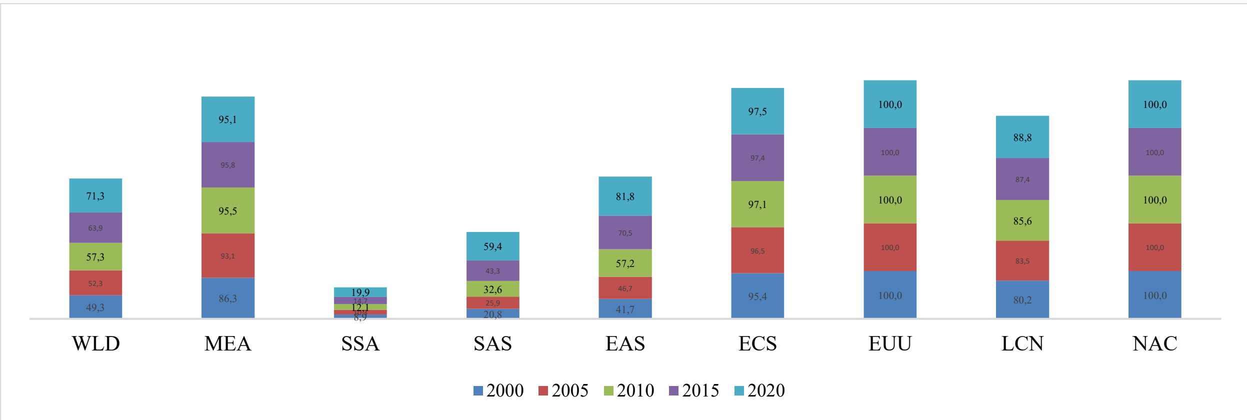

Figure 1. Access to clean fuels and technologies for cooking (% of population), source: Authors' own work using world development indicators data
WLD means World, MENA means Middle East & North Africa, SSA stands for Sub-Saharan Africa, SAS represents South Asia, EAS means East Asia & Pacific, ECS represents Europe & Central Asia, European Union means EUU, Latin America & Caribbean LCN, North America is NAC

Meanwhile figure 2 shows the percentage of rural population with access to clean fuels and technologies for cooking. Globally, in 2000 about 24.2 percent of rural population had access to clean energy for cooking and this increased to 50.1 percent in 2020. From 2000 to 2020, sub-Saharan Africa and South Asia had the least percentage of rural access to clean energy for cooking. 2.5 percent of rural population in SSA had access to clean energy for cooking, and by the year 2020 it grew to 7.3 percent. This was 5.9 percent in the year 2000 and 43.3 percent in the year 2020 for South Asia. Apart from Europe Areas (EMU) and North America (NAC) whose rural population had total access to clean energy for cooking, other regions like LAC and EAS had 62.7 percent and 66.7 percent rural access to clean fuels and technologies for cooking in 2020, respectively. Increasing rural access to clean energy for cooking will make rural communities more resilient to the impacts of climate change. Access to reliable and affordable energy is crucial for the wellbeing and socio-economic development of the rural communities.

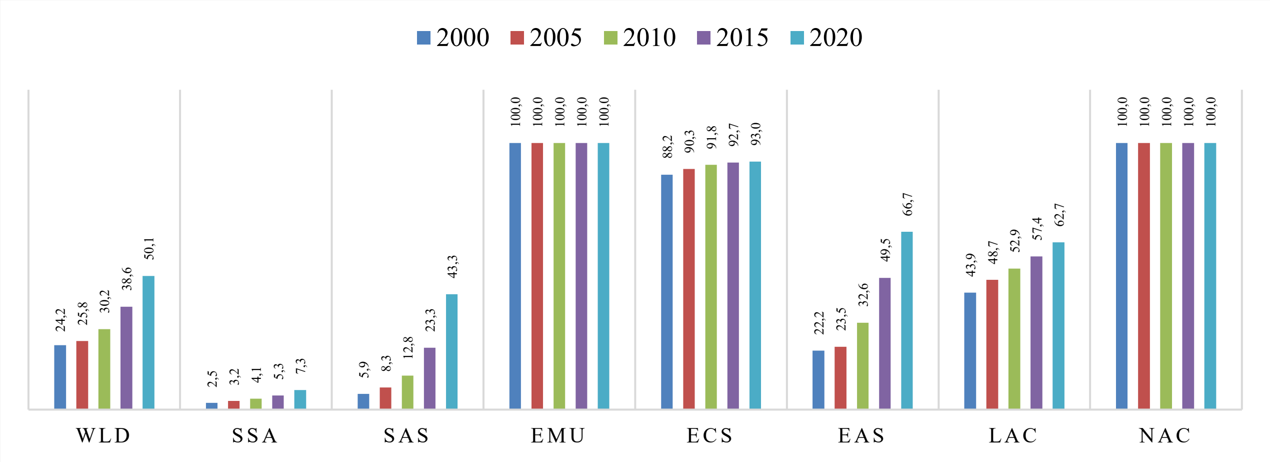

Figure 2. Access to clean fuels and technologies for cooking, rural (% of rural population), source: Authors' own work using world development indicators data
Note: WLD is World, SSA is Sub-Saharan Africa, SAS is South Asia, Euro Area (EMU), Europe and Central Asia (ECS), East Asia & Pacific (EAS), Latin America and Caribbean (LAC), North America (NAC).

Figure 2 depicts cooking fuel usage across African subregions, disaggregated by rural and urban areas, offer compelling insights into the continent's progress toward achieving Sustainable Development Goal 7 (SDG 7) — *Ensure access to affordable, reliable, sustainable and modern energy for all*. The patterns revealed in the graphs also intersect with other SDGs, including SDG 3 (Good Health and Well-being), SDG 5 (Gender Equality), and SDG 13 (Climate Action), highlighting the multifaceted implications of energy access. In rural areas, the data show a heavy reliance on traditional biomass fuels such as wood, charcoal, agricultural waste, and dung. This is particularly pronounced in East, West, and Central Africa, where more than 80% of rural households still cook with solid fuels.

Southern Africa performs relatively better, with more notable use of LPG and electricity in rural zones, though wood and charcoal remain present. The limited use of modern fuels in most rural regions signals a major bottleneck in achieving universal energy access by 2030, a core target of SDG 7. Without significant investments in rural infrastructure and clean energy distribution, millions of Africans will remain trapped in energy poverty. By contrast, urban areas in North and Southern Africa display widespread use of clean fuels like LPG, electricity, and kerosene, indicating stronger policy implementation, infrastructure, and market penetration. Urban households in these regions have largely transitioned away from biomass, aligning more closely with SDG 7 objectives. However, urban areas in West and East Africa still exhibit significant dependence on charcoal and wood, reflecting persistent economic and infrastructural inequalities that hinder the urban poor from accessing clean energy.

The health implications of this disparity are enormous. The continued use of polluting fuels in rural areas leads to high levels of household air pollution, contributing to respiratory diseases, cardiovascular illness, and premature deaths – issues directly related to SDG 3 (Good Health and Well-being). Women and children, who are often responsible for

cooking and fuel collection, suffer the most. Therefore, expanding clean cooking solutions is vital not just for energy access but also for improving public health outcomes. The data also tie into SDG 5 (Gender Equality). In rural Africa, the burden of collecting firewood and preparing meals with inefficient stoves disproportionately falls on women and girls. This limits their time for education, income-generating activities, and participation in community decision-making.

Access to clean cooking fuels would free up significant time, allowing women and girls greater opportunities for empowerment and social mobility. Finally, the widespread use of solid biomass fuels contributes to deforestation and greenhouse gas emissions, undermining efforts to combat climate change, as outlined in SDG 13 (Climate Action). Encouraging a transition to cleaner fuels like LPG and electricity – especially when powered by renewables – can significantly reduce environmental degradation and the carbon footprint of cooking. In conclusion, the graphs underscore that achieving SDG 7 is not only a standalone priority but a foundational requirement for meeting multiple sustainable development goals. Bridging the rural-urban energy gap must become a central policy focus. Governments and development partners must prioritize affordable, accessible, and culturally appropriate clean cooking solutions, particularly in rural areas. This approach would catalyze progress across health, gender equality, environmental sustainability, and inclusive economic growth in Africa.

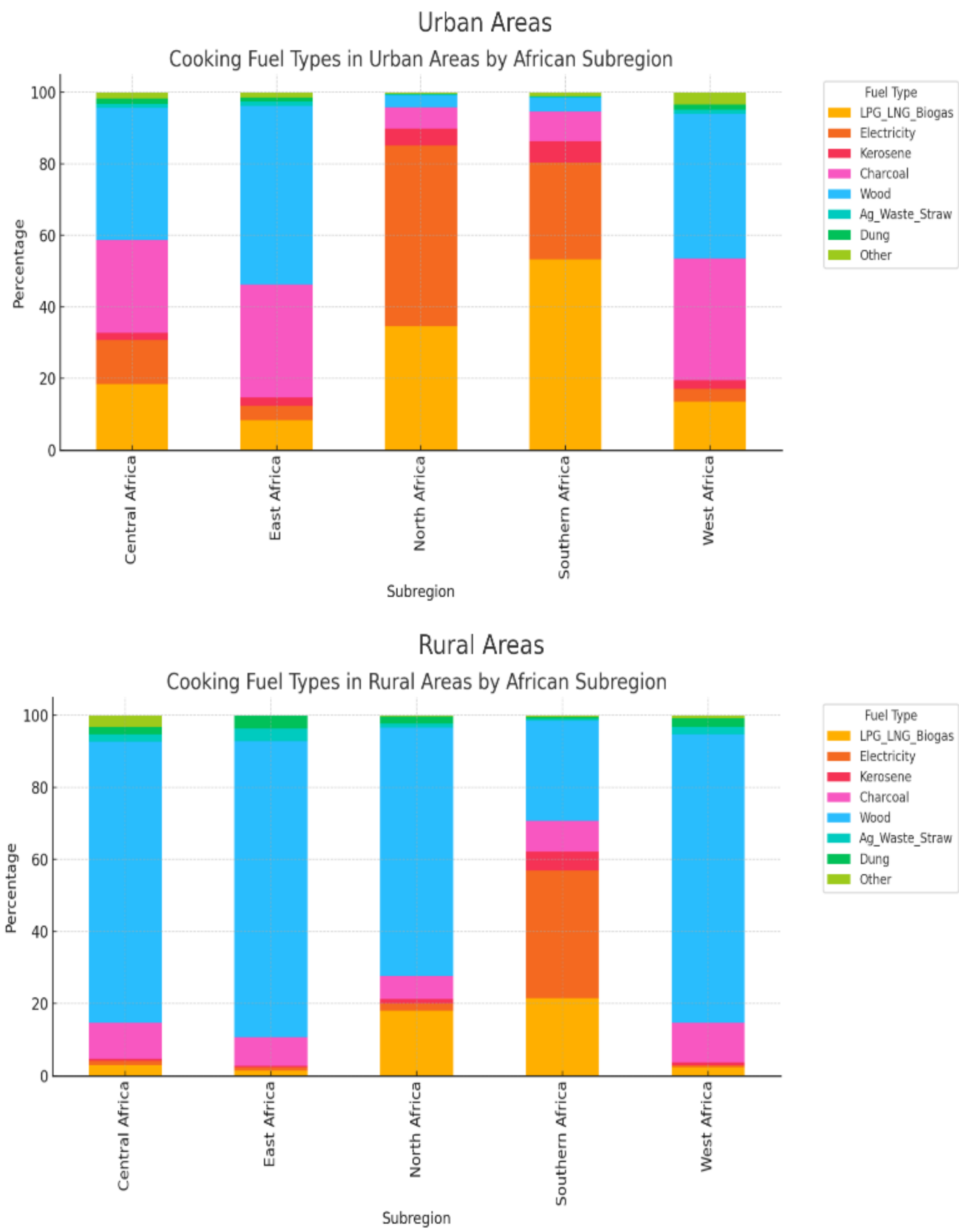

Figure 3. Disparities in Cooking Fuel Use Across Urban and Rural Areas in African Subregions, sources: WHO, DHS, MICS, National Census data, Dalberg analysis.

3. Material and Method

3.1. Research Methodology

The study employed panel data econometric estimations. The use of panel data enhances the sample size and increases statistical precision, allowing for more robust conclusions (Baltagi & Baltagi, 2008; Hassan et al., 2020). Additionally, panel data elucidates the effects observed among different groups of countries over various time periods. It offers strong statistical evidence, greater variability, reduced multicollinearity, increased degrees of freedom, and more effective results (Baltagi & Baltagi, 2008; Hassan et al., 2020). Consequently, the forthcoming econometric model aims to examine the relationship between the explanatory variables and the dependent variable. This paper initially develops a multivariate econometric model aimed at examining the influence of access to clean cooking energy on sustainable development and socio-economic outcomes. The model is presented in equations (1) and (2)

$$ln\, sdi_{it} = \delta_0 + \delta_i\, ln\, ac_{it} + \delta_2 X_{it} + \varepsilon_{it} \quad (1)$$

$$ln\,sec_{it} = \delta_0 + \delta_i\, ln\, ac_{it} + \delta_2 X_{it} + \varepsilon_{it} \quad (2)$$

where $lnsdi_{it}$ denotes the logarithm of the sustainable development index for country i in year t; $lnsec_{it}$ connotes social economic condition, $lnac_{it}$ represents the logarithm of the access to clean cooking energy during year t, where country i is situated; X_{it} includes control variables that account for the economic characteristics and people capabilities of each individual countries, with definitions of these variables provided in the subsequent subsection, and ε_{it} is a stochastic error term that follows a uniform distribution. $lnsdi_{it}$ and $lnsec_{it}$ represents the dependent variables of interest. The potential endogeneity between the variables of interest could lead to biased estimations.

Nevertheless, this issue can be effectively mitigated. Since access to clean cooking energy data is aggregated at the country level, a single country is unlikely to have a substantial impact on the overall access to clean cooking energy. Therefore, we conduct the regression analysis in accordance with equation (1) and (2). The study utilized two econometric methods to examine the long-term relationship among the variables under investigation. These methods facilitate the assessment of the impact of independent variables on the dependent variable by employing unbiased and efficient estimators. Consequently, the econometric techniques applied in this study comprise the Panel Ordinary Least Squares (POLS) and the Fully Modified Ordinary Least Squares (FMOLS). In this study, we opt for the fully modified OLS model to mitigate the influence of individual heterogeneity among countries and regions.

The FMOLS technique, introduced by Phillips & Hansen (1990), represents a semi-parametric strategy for addressing association challenges while maintaining unbiasedness. This method is an adaptation of least squares that accounts for endogeneity in the independent variables and the effects of serial correlation associated with cointegration. The FMOLS method is particularly effective in detecting spurious regressions by applying ordinary least squares (OLS) regression techniques to nonstationary data characterized by unit roots.

3.2. Data source

This study employs data from forty-three (43) African countries over a 23-year period from 2000 to 2023 to evaluate the role of access to clean cooking energy on sustainable development and socio-economic outcome (See Table A). The study period spans from 2000 to 2023, due to the availability of the data for the selected variables. The African countries were selected for this study premised on notoriety for implementing lax environmental rules, maintaining primordial cooking energy sources, and limited promotion of technology advancements in the context of climate change. The data pertaining to certain variables is obtained from the databases of WDI and HDI database. Detailed descriptions of all variables are presented in Table 1.

The countries used for the study include The countries under investigations are Cameroon, Angola, Democratic Republic of the Congo, Republic of the Congo, Gabon, São Tomé and Príncipe (Central Africa); Burundi, Djibouti, Kenya, Malawi, Madagascar, Mauritius, Mozambique, Rwanda, Tanzania, Uganda (East Africa); Algeria, Egypt, Libya, Morocco, Tunisia (North Africa); Botswana, Eswatini, Lesotho, Namibia, South Africa, Zimbabwe and Zambia (Southern Africa); Cabo Verde, Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Guinea, Liberia, Mali, Mauritania, Nigeria, Niger, Senegal, Sierra Leone, Togo, Benin (West Africa). See table A in the appendix for the countries.

Table 1. Variables Description, Expectations and Sources, source: Authors' own work

Variables		***Measurement***	***'a priori***	**Source**
Sustainable Development	*sdi*	Sustainable Development Index	N/A	HDI
Access to clean cooking energy	*ac*	Rural access to clean fuels and technologies for cooking (% of rural population)	+	WDI
Population	*pop*	population growth (annual %)	+	WDI
Foreign Direct Investment	*fdi*	Foreign direct investment, net inflows (BoP, current US$)	+	WDI
Socio-economic Condition	*sec*	Socio-economic Index created using Unemployment, total (% of total labor force) (modeled ILO estimate), GDP per capita growth (annual %) and Inflation, consumer prices (annual %)	N/A	Authors

Table 2 provides an overview of the variables utilized in this research along with their summary statistics. Throughout the study period, it was observed that Northern Africa and Southern African nations are primarily accountable for high sustainable development index. In contrast, Western African nations have made the smallest contribution to sustainable development, with an average individual country contributing only -0.579 indexation of sustainable development. Socio-economic condition has seen improvements across Africa, with the Central Africa identified as the most socio-economic improved economies and Western Africa as the least. Additionally, the access to clean cooking energy is highest in North Africa, while it is lowest in Central African countries. Furthermore, the Central

African countries stand out as the most populated, boasting an average population growth of 2.904.

Table 2. Descriptive Statistics of Variables, source: Authors' compilation

Variable	Mean	S. D	Min	Max	Mean	S. D	Min	Max
	Full Sample				Central Africa			
SDI	0.554	0.268	0.000	4.7	0.561	0.147	0.000	0.754
AC	16.636	30.336	0.000	99.9	7.252	11.976	0.000	49.000
POP	2.307	0.942	-2.617	5.906	2.904	0.601	1.100	4.142
FDI	0.000	0.000	-0.000	0.000	0.000	0.000	0.000	0.000
SEC	6.706	10.357	-5.928	185.496	10.413	19.673	1.285	169.097
	East Africa				North Africa			
Variable	Mean	S. D	Min	Max	Mean	S. D	Min	Max
SDI	0.507	0.142	0.000	0.814	0.6847	0.157	0.000	0.291
AC	8.847	25.880	0.00	0.814	73.012	40.761	0.000	99.900
POP	2.407	0.906	-0.301	5066	1.461	0.675	-2.617	2.3054
FDI	0.000	0.000	0.000	0.000	2.900	0.000	0.000	0.000
SEC	6.651	12.293	-4.432	185.496	6.932	4.539	-4.710	38.957
	Southern Africa				West Africa			
Variable	Mean	S. D	Min	Max	Mean	S. D	Min	Max
SDI	0.5804	0.493	0.00	-745	-0.579	0.256	-1.273	1.548
AC	25.085	0.144	0.00	71.4	1.025	2.145	-2.303	4.604
POP	1.289	17.065	-0.920	2.953	0.712	0.696	-6.079	1.776
FDI	0.000	0.000	0.000	0.000	19.326	2.071	6.908	24.428
SEC	9.631	2.510	-.889	16.995	1.613	0.822	-4.479	5.223

Note: SD means standard deviation; Min means minimum value; Max means maximum value; SDI stands for Sustainable Development Index; AC represents Access to clean cooking energy; pop means Total Population; FDI is Foreign Direct Investment; Sec is socio-economic Condition

3.3 Preliminary Analysis

This section provides a preliminary analysis. Descriptive statistics are presented in Table 2. A multicollinearity test was conducted for all variables in the model, with the results detailed in Table 3. The Variance Inflation Factor (VIF) for each group remained below 5, indicating that significant multicollinearity is not present in the models for any group. Prior to conducting the regression analysis, we assessed the stability of the variables to prevent pseudo-regression. We employ both the cointegration test and unit root tests to ascertain the appropriateness of our model.

The results of the cross-sectional dependence test, presented in Table 3, indicate that the null hypothesis of cross-sectional independence can be rejected at the 1% significance level for all series, confirming the presence of cross-sectional dependence among the four variables. To account for this dependence, we utilize the Augmented Dickey Fuller (Fisher-ADF) panel unit root test and the Fisher Phillips-Perron (Fisher-PP) panel unit root test. The results displayed in Table 3 demonstrate that all variables exhibit stability at the 1% significance level, indicating their stationarity.

Table 3. Variance inflation factor and Panel Unit Root, source: Authors' calculation.

	Variance inflation factor		Panel Unit Root	
Variables	**VIF**	**1/VIF**	**ADF**	**PP**
Lnac	1.580	0.631	14.1333***	6.0551***
Lnpop	1.510	0.662	5.8736 ***	2.8993 ***
Lnfdi	1.130	0.887	23.3407***	3.0716 ***
Mean VIF	1.410		15.1033***	10.0334***
			29.7530***	38.8831***

Note: **** denotes significance level at 1%, respectively; prefix l denotes Logarithm.*

4. Econometric Results

Subsequently, the study employs a fully modified OLS utilizing panel data from 43 African countries spanning from 2000 to 2023 to explore the effects of clean energy on sustainable development. The fundamental regression outcomes for Equations (1) are detailed in Table 4. The findings from column (1) indicate that access to clean cooking energy positively influences sustainable development, achieving significance at the 5% level. Specifically, a 1% rise in access to clean cooking energy corresponds to an average increase of 0.0674% in sustainable development. This outcome aligns closely with previous studies, including those by Casati et al. (2023), Garba & Bellingham, (2018), Bhattacharyya, (2012), Aemro et al. (2021), Hollands & Daly, (2023), and Mukisa et al. (2023). Notably, Aemro et al. (2021) observed that electric cookstoves, in comparison to conventional wood fuel cookstoves, can lead to a reduction in energy consumption by 95.7%, eliminate CO_2 emissions by 100% (given the use of renewable carbon-free electricity), and decrease life cycle costs by 94%. Furthermore, they noted that this transition could prevent over 180 mg/m3 of PM2.5 concentrations per household annually. The study emphasizes the necessity for a robust and collaborative effort among key stakeholders to facilitate the transition from traditional and unsustainable cooking technologies and fuels to cleaner and more sustainable development. Rosenthal et al. (2018) propose a model indicating that programs utilizing liquefied petroleum gas (LPG) stoves and fuel are likely to achieve more significant reductions in Disability Adjusted Life Years and Global Warming Commitment in the specified countries compared to those employing improved biomass stoves.

The underlying economic rationale is consistent with the random utility theory random utility hypothesis, which posits that which postulates that individuals make choices that maximize their utility (Tornel-Vázquez et al., 2024). As access to clean cooking energy rises, the prices of clean cooking energy-related products also reduce, thereby creating greater opportunities for households to acquire same to meet unfulfilled demands, as well as enhancing sustainable. Consequently, policy makers in Africa, are motivated to enhance access to clean cooking energy in the current phase of Africa's economic landscape.

Column (2) illustrates the impact of access to clean cooking energy on sustainable development amidst the presence of control variables. The coefficient associated with the access to clean cooking energy is both positive and statistically significant at the 1% level. Specifically, a 1% rise in access to clean cooking energy results in a 0.0628% greater increase in sustainable development within the control variables scenario. Findings from Column (2) suggest that sustainable development is more susceptible to the influences of access to clean cooking energy. Given the current patterns of access to clean cooking energy, economic entities such as households and clean cooking energy firms are more likely to be motivated to enhance their efforts towards clean cooking energy transition.

This is largely due to the inherent challenges in adjusting fossil energy production in the short term. As clean cooking energy escalates, the associated marginal costs also decrease rapidly, leading to a decline in clean cooking energy prices. This dynamic renders sustainable development particularly responsive to fluctuations in the access to clean cooking energy. Additionally, the increase in population is likely to reduce sustainable development. On the contrary, foreign direct investment has a positive but insignificant influence on sustainable development.

Table 4. Baseline regression Tests on the impact of access to clean cooking energy on sustainable development, source: Authors' compilation

	POLS		**FMOLS**	
	(1)	**(2)**	**(1)**	**(2)**
	Lnsdi	**Lnsdi**	**Lnsdi**	**Lnsdi**
Lnac	0.0655^{***}	0.0603^{***}	0.0674^{***}	0.0628^{***}
	(0.0033)	(0.0043)	(0.0113)	(0.0143)
Lnpop		-0.0120		-0.0178
		(0.0122)		(0.0407)
Lnfdi		0.0083^{**}		0.0052
		(0.0038)		(0.0125)
Linear			-0.0001	-0.0001
			(0.0001)	(0.0001)
Cons	-0.6492^{***}	-0.7892^{***}	-0.6145^{***}	-0.6859^{***}
	(0.0078)	(0.0707)	(0.0503)	(0.2371)
N	941	842	940	841
adj. R^2	0.700	0.698	0.897	0.794

Note: Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.1. Robustness check

To enhance the credibility of our findings, we conducted a robustness check that involved reassessing the relationship between clean cooking energy and sustainable development. This was achieved in two folds. First, we carried out the analysis without considering the year 2019-2020 which coincidentally was the Covid-19 period marked by

oscillations that can affect the estimation result. Second, we substituted the econometric techniques employed by considering the two cointegration techniques to assess the long run relationship among study variables. These techniques allow to evaluate the effect of regressors on regressand by selecting unbiased and competent estimators. Thus, these cointegration techniques include the DOLS (Dynamic Ordinary Least Square) by Pedroni (2000), and Canonical Cointegration Regression (CCR) by Park (1992).
The outcomes of this analysis are presented in Table 5-6. As indicated in Table 5, the analysis without considering the year 2019-2020 which coincidentally was the Covid-19 period yields consistent results. The coefficient for the access to clean cooking energy remains positive and is statistically significant at the 5% level. Specifically, a 1% increase in access to clean cooking energy correlates with an average increase of 0.0674% in sustainable development. When the DOLS (Dynamic Ordinary Least Square) by Pedroni (2000), and Canonical Cointegration Regression (CCR) by Park (1992) is utilized as an alternative estimator, the coefficient for access to clean cooking energy continues to show a positive significance at the 1% level. Consequently, it can be generally concluded that access to clean cooking energy has a more pronounced effect on stimulating sustainable development, as evidenced by the results from both robustness checks.

Table 5. Robustness Tests on the impact of access to clean cooking energy on sustainable development exempting 2019-2020 (COVID-19 Era), source: Authors' compilation

	POLS		FMOLS	
	(1)	**(2)**	**(1)**	**(2)**
	Lnsdi	**Lnsdi**	**Lnsdi**	**Lnsdi**
Lnac	0.0654***	0.0614***	0.0674***	0.0632***
	(0.0035)	(0.0047)	(0.0122)	(0.0155)
Lnpop		-0.0066		-0.0218
		(0.0141)		(0.0467)
Lnfdi		0.0080**		0.0046
		(0.0040)		(0.0132)
Linear			-0.0001	-0.0001
			(0.0001)	(0.0001)
_cons	-0.6538***	-0.7923***	-0.6231***	-0.6787***
	(0.0084)	(0.0746)	(0.0540)	(0.2499)
N	863	775	862	774
adj. R^2	0.284	0.283	0.280	0.285

Note: Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 6. Robustness Cointegration Tests on the impact of access to clean cooking energy on sustainable development, source: Authors' compilation

	CCR		DOLS	
	(1)	**(2)**	**(1)**	**(2)**
	Lnsdi	**Lnsdi**	**Lnsdi**	**Lnsdi**
Lnac	0.0682***	0.0643***	0.0659***	0.0634***
	(0.0123)	(0.0158)	(0.0133)	(0.0182)
Lnpop		-0.0328		-0.0094
		(0.0478)		(0.0582)
Lnfdi		-0.0047		0.0035
		(0.0140)		(0.0176)
_cons	-0.6565***	-0.5306**	-0.6539***	-0.7050**
	(0.0291)	(0.2621)	(0.0304)	(0.3247)
N	862	774	858	770
adj. R^2	0.8300	0.7303	0.6281	0.7277

4.2 Heterogeneous impact of access to clean cooking energy on sustainable development

All FMOLS estimates presented in Table 7 consistently indicate that the coefficients for access to clean cooking energy are statistically significant and negative across Africa. This suggests that increasing the access to clean cooking energy significantly contributes to the actualization of sustainable development. Specifically, a one percent increase in the for access to clean cooking energy is projected to increase sustainable development by approximately 0.0611 percent in Central Africa and by about 0.0508%,0.0838%, 1.3518% and 0.0557% in both Eastern, Northern, Southern, and Western Africa, respectively. These results align with the findings of Osabohien et al., (2024) and Gui et al. (2025).
Conversely, in the Central and Eastern African region, all FMOLS estimations indicated statistically insignificant negative effects of population on sustainable development. This may be due to the relatively underutilization of the massive population during the study period, potentially insufficient to significantly improve sustainable development. Albeit, in the case of Northern African region, all FMOLS estimations indicated statistically significant

and positive across East and Northern Africa, while that of the Central, Southern and West African countries which was negative.

Table 7. Heterogenous impact of access to clean cooking energy on sustainable development, source: Authors' compilation

	Central Africa		**Eastern African**		**Northern Africa**	
	POLS	**FMOLS**	**POLS**	**FMOLS**	**POLS**	**FMOLS**
Lnac	0.0653***	0.0611***	0.0547***	0.0508**	0.1059***	0.0838***
	(0.0064)	(0.0128)	(0.0063)	(0.0198)	(0.0155)	(0.0306)
Lnpop	-0.3018***	-0.1467	-0.0505***	-0.0524	0.0871***	0.1223***
	(0.0684)	(0.1410)	(0.0141)	(0.0433)	(0.0131)	(0.0266)
Lnfdi	-0.0099	-0.0058	0.0287***	0.0386***	0.0189***	0.0332**
	(0.0069)	(0.0141)	(0.0028)	(0.0092)	(0.0053)	(0.0131)
Linear		0.0024***		-0.0001		-0.0004
		(0.0009)		(0.0003)		(0.0007)
_cons	-0.0837	-0.4437*	-1.1587***	-1.3287***	-1.2171***	-1.4127***
	(0.1072)	(0.2684)	(0.0525)	(0.1648)	(0.0841)	(0.2000)
N	98	97	230	229	93	92
adj. R^2	0.540	0.631	0.661	0.7311	0.698	0.590
	Southern Africa				**West Africa**	
	POLS	**FMOLS**			**POLS**	**FMOLS**
Lnac	0.9800**	1.3518***			0.0623***	0.0557
	(0.0815)	(0.2045)			(0.0128)	(0.0350)
Lnpop	0.0167	0.0543			-0.0225	-0.00869
	(0.0179)	(0.0834)			(0.0294)	(0.0828)
Lnfdi	-0.0104**	-0.0342**			-0.0116	-0.0228
	(0.0043)	(0.0137)			(0.0100)	(0.0271)
Linear		0.0001				-0.00144**
		(0.0010)				(0.000672)
_cons	-4.5769***	-5.7776***			-0.403**	0.0126
	(0.3576)	(0.8927)			(0.192)	(0.517)
N	82	81				
adj. R^2	0.638	0.7427			294	293

Note: Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.3 Socio-economic empirical analysis

The findings from the earlier empirical analysis indicate that access to clean cooking energy has the potential to foster sustainable development, especially when viewed through the lens of the addition of covariates. In this section, we validate this finding by focusing on the role of access to clean cooking energy on socio-economic outcomes. Utilizing data from WDI on unemployment, inflation and real gross domestic product, we developed a socio-economic outcome index (sec) using the PCA methodology. Additionally, we explore the heterogeneous effects of access to clean cooking energy on socio-economic outcomes in Africa.

The quantitative assessments aim to determine whether the relationship between access to clean cooking energy on socio-economic outcomes varies in the current context of Africa. A comprehensive understanding of these matters could assist the government in developing differentiated and effective policies for sustainable development. The regression outcomes for Equation (2) are presented in Table 8. This table indicates that a 1% rise in access to clean cooking energy on results in an increase of 0.1053 times more in socio-economic outcomes. This finding suggests that heightened access to clean cooking energy is anticipated to improve socio-economic outcomes, aligning with the findings from the sustainable development analysis.

The corroboration from socio-economic outcomes evidence reinforces the validity of this result. This finding aligns with the conclusions of Zheng et al. (2023), who noted that rising access to clean cooking energy stimulates socio-economic outcomes. Theoretical evidence supports this, demonstrating that the significant substitution effect of cleaner cooking sources enhances the likelihood of increasing the share of new clean cooking innovations through market mechanisms with concomitant increment in economic entity such as household and clean cooking emerging firms' earnings. Consequently, any rise in access to clean energy, whether direct or indirect, positively influences the socio-economic outcomes.

Column (2) illustrates the impact of access to clean cooking energy on socio-economic outcomes, while taking cognizance of covariates. The result showed that shift towards greater access to clean cooking energy results in a positive impact on socio-economic outcomes. Specifically, a 1% rise in access to clean cooking energy corresponds to a 0.0913% reduction in socio-economic outcomes. This observation underscores that the transformation towards cleaner cooking energy is responsible for improving socio-economic outcomes. This is attributed to the capacity of clean cooking energy source to fundamentally alter the prevailing livelihood structure. Zheng et al. (2023) support this assertion, noting that clean cooking energy tends to increase their consumption, while dirty cooking energy contributes to a decrease in consumption pattern. Consequently, the transition towards clean cooking energy culminates in an increased socio-economic outcome.

Table 8. Baseline regression Tests on the impact of access to clean cooking energy on socioeconomic out-comes, Source: Authors' compilation

	POLS		FMOLS	
	(1)	(2)	(1)	(2)
	Lnsec	Lnsec	Lnsec	Lnsec
Lnac	0.1050***	0.0772***	0.1053***	0.0913***
	(0.0120)	(0.0159)	(0.0208)	(0.0271)
Lnpop		-0.0845*		-0.0711
		(0.0480)		(0.0817)
Lnfdi		0.0372***		0.0097
		(0.0143)		(0.0244)
Linear			-0.0008***	-0.0009***
			(0.0002)	(0.0002)
_cons	1.4772***	0.8399***	1.8721***	1.7036***
	(0.0285)	(0.2692)	(0.0921)	(0.4621)
N	931	830	930	829
adj. R^2	0.076	0.077	0.158	0.142

	POLS		FMOLS	
	(1)	(2)	(1)	(2)
	Lnsec	Lnsec	Lnsec	Lnsec
Lnac	0.1050***	0.0772***	0.1053***	0.0913***
	(0.0120)	(0.0159)	(0.0208)	(0.0271)
Lnpop		-0.0845*		-0.0711
		(0.0480)		(0.0817)
Lnfdi		0.0372***		0.0097
		(0.0143)		(0.0244)
Linear			-0.0008***	-0.0009***
			(0.0002)	(0.0002)
_cons	1.4772***	0.8399***	1.8721***	1.7036***
	(0.0285)	(0.2692)	(0.0921)	(0.4621)
N	931	830	930	829
adj. R^2	0.076	0.077	0.158	0.142

Note: Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

As depicted in Table 8, FDI also exhibits a positive response to socio-economic outcomes, indicating that the FDI fosters an increase in available resources and earnings, ultimately leading to enhanced socio-economic outcomes. This relationship has been substantiated by the findings of Osabohien et al. (2024b). It indicates that the FDI consistently contributes to the sustainable growth of the economy. The underlying logic is straightforward: the entrance of FDI leads to increased resource utilization and capital investment, which subsequently fosters sustainable growth. These findings align with the current objectives of Africa's economic transformation, which aims to achieve high levels of FDI and socio-economic outcomes. Simultaneously, the remaining variable, primarily POP has a detrimental effect on socio-economic outcomes. Based on empirical evidence of FMOLS, the findings indicate that a unit rise in the variable POP leads to a reduction in socio-economic outcomes by 0.0711%, albeit the relationship is statistically insignificant.

4.4 Heterogeneous Analysis of Clean Cooking Energy and Socioeconomic Outcomes

The differences in regulatory rigor and the clean cooking energy sources vary among countries with differing income levels, which may result in inconsistencies in estimates. Consequently, we divided the sample into four categories based on the African Union's classification criteria, with the objective of identifying both commonalities and differences in the non-linear effects of access to clean cooking energy (ac) on socio-economic outcomes (sec) across African countries, thereby enabling the formulation of targeted policy recommendations for distinct nations. The results of the heterogeneous regression analysis for these categories are presented in Table 9.

The results reveal a variation in the impact of access to clean cooking energy (ac) on socio-economic outcomes (sec) across different sub-regional groups in Africa, which facilitates the development of more targeted policy recommendations that consider the distinct characteristics of each group and their non-linear effects. In the Central Africa category, a significant negative yet statistically insignificant effect of access to clean cooking energy (ac) on socio-economic outcomes (sec) was noted, reflecting a mixed pattern observed in the overall sample. Specifically, an increase of one unit in access to clean cooking energy (ac) resulted in an insignificant reduction of 0.0035% in socio-economic outcomes (sec). Conversely, in the Southern African region, access to clean cooking energy (ac) had a detrimental effect on socio-economic outcomes (sec), with a unit change in access leading to a decline of 0.0646% in socio-economic outcomes (sec).

In contrast, within the Eastern African region, access to clean cooking energy (ac) had a positive effect on socio-economic outcomes (sec), although this relationship was not statistically significant. Specifically, a one-unit increase in access to clean cooking energy (ac) resulted in a 0.1697% improvement in socio-economic outcomes (sec). Similarly, for the Northern and Southern African regions, access to clean cooking energy (ac) demonstrated a positive correlation with socio-economic outcomes (sec). In the Northern African region, a one-unit increase in access to clean cooking energy (ac) led to a 1.5714% rise in socio-economic outcomes (sec), and this effect was found to be statistically significant. In a similar vein, the Western African region, access to clean cooking energy (ac) was associated with favourable socio-economic outcomes (sec), although this association did not reach statistical significance.

Notably, an increase of one unit in access to clean cooking energy (ac) led to a 0.0134% enhancement in socio-economic outcomes (sec). The findings indicate a uniformly positive influence of population (POP) on socio-economic outcomes (sec) throughout all subregions in Africa, with the notable exception of the Southern African region, where a significant negative impact was observed between population (POP) and socio-economic outcomes (sec). Similarly, the analysis of the relationship between foreign direct investment (FDI) and socio-economic outcomes (sec) across all African subregions revealed a consistently positive relation, except for the Northern region, which demonstrated a negative association between the variables of interest.

Table 9. Heterogeneous impact of access to clean cooking energy on socioeconomic outcomes, source: Authors' compilation

Central Africa			Eastern African		Northern Africa	
	POLS	**FMOLS**	**POLS**	**FMOLS**	**POLS**	**FMOLS**
Lnac	0.0257	-0.0035	0.0628	0.1697	1.4311**	1.5714**
	(0.0463)	(0.0991)	(0.0475)	(0.1054)	(0.5489)	(0.7809)
Lnpop	0.2593	0.7079	0.0996	0.3031	0.1719	0.8135**
	(0.4677)	(1.0433)	(0.1030)	(0.2229)	(0.1171)	(0.3251)
Lnfdi	-0.0395	0.0749	0.0621**	0.0539	-0.0711**	-0.1371***
	(0.0493)	(0.1092)	(0.0244)	(0.0604)	(0.0289)	(0.0522)
Linear		0.0154**		-0.0021		0.0073**
		(0.0067)		(0.0018)		(0.0037)
_cons	2.2268***	-1.2604	0.3450	0.5920	-3.2600	-3.0729
	(0.7687)	(2.0761)	(0.4606)	(1.0682)	(2.4073)	(3.4012)
N	104	103	244	243	90	89
adj. R^2	-0.020	0.023	0.026	-0.003	0.076	0.160
Southern Africa					**Western Africa**	
	POLS	**FMOLS**			**POLS**	**FMOLS**
Lnac	-0.0144	-0.0646			0.0564*	0.0134
	(0.0512)	(0.0556)			(0.0338)	(0.0458)
Lnpop	-0.1566***	-0.2694***			-0.168**	-0.0647
	(0.0450)	(0.0500)			(0.0793)	(0.110)
Lnfdi	0.0550***	0.0923***			0.0459*	0.0554
	(0.0171)	(0.0232)			(0.0261)	(0.0352)
Linear		-0.0021*				-0.00319***
		(0.0012)				(0.000877)
_cons	1.2504***	0.8060**			0.452	0.664
	(0.2737)	(0.3556)			(0.502)	(0.671)
N	100	99				
adj. R^2	0.142	0.051			292	291

Note: Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

5. Conclusions and policy implications

5.1. Conclusions

The transformation towards cleaner cooking source, which emphasizes a shift in energy innovation towards environmentally friendly practices, is considered a pivotal strategy to address the challenges posed by slower economic growth, and escalating environmental pollution during Africa's new normal phase. Given Africa's limited access to cleaner cooking energy, this study initially assesses the impact of access to cleaner cooking energy on the sustainable development and socio-economic outcomes in rural communities. Furthermore, the research aims to elucidate the heterogeneous effects of access to cleaner cooking energy on sustainable development and socio-economic outcomes. Employing two estimation techniques—the POLS model and the FMOLS model—this paper draws on data from a panel of 43 African countries to conduct a comprehensive investigation of the aforementioned topics. The dual estimation findings offer detailed and robust insights that differ from previous studies that concentrated on overall one methodology. The principal conclusions are outlined as follows.

Initially, it can be observed that an increase in access to cleaner cooking energy relates with a rise in sustainable development. Specifically, a 1% rise in access to cleaner cooking energy results in an average increase of 1.21% in sustainable development. In terms of socio-economic outcome analysis, a 1% increase in access to cleaner cooking energy results in a 1.43-fold increase in socio-economic outcome. Consequently, any rise in access to cleaner cooking energy, whether direct or indirect, can facilitate the transformation towards sustainable development and socioeconomic outcome, as evidenced by dual validations.

Population growth has a distinctly negative impact on sustainable development and socio-economic outcomes. This situation contrasts sharply with the population dividend effect observed in clean cooking energy innovation concerning sustainable development. The essence of population growth lies in the accelerated growth of clean cooking energy innovations compared to dirty sources, which fundamentally alters the clean cooking energy consumption framework. Furthermore, there exists a mutually beneficial relationship between FDI, sustainable development and socio-economic outcomes. On one hand, this suggests that robust FDI serves as a significant catalyst for stimulating innovative activities and promoting sustainable development. On the other hand, it is evident that the high levels of FDI growth within Africa's economy are closely linked to the socio-economic outcomes. This shift in FDI contributes positively to enhancing socio-economic conditions of the populace.

5.2. Policy implications

Empirical evidence leads to several implications for energy policy. Firstly, the overall positive impact of the increased access to clean cooking energy on achieving sustainable development and socio-economic outcomes. Consequently, sustainable policies aimed at promoting access to clean cooking energy could facilitate sustainable development and improved socio-economic outcomes. It is imperative for the government to promote and expedite the implementation of access to clean cooking energy, allowing this advancement will swiftly influence both sustainable development and socio-economic condition. This can be achieved through measures such as reducing the commercialization timeline for new clean cooking energy sources, providing subsidies and tax incentives for clean cooking energy sources, and establishing supportive financing policies.

Furthermore, the government must strive to maintain a stable policy framework while fostering ongoing innovation to enhance the effectiveness of clean cooking energy policies, with a focus on improving the alignment between research and development support and market demand stimulation. The impact of clean cooking energy on sustainable development suggests that policies aimed at enhancing access to clean cooking energy will serve as a significant catalyst for sustainable development, aligning with the objectives of Africa's clean energy-driven economic transformation.

Therefore, it is essential for the government to devise appropriate policies for the energy sector and to foster a more scientific and rational clean cooking energy framework, ensuring that clean cooking energy transformation aligns with the future requirements of sustainable economic development. Furthermore, FDI will, in turn, stimulate the sustainable development and social outcomes. Hence, the government should expedite socio-economic transformation through the optimization of investment structures, ensuring the efficient allocation of resources and accelerating supply-side reforms to facilitate the transition towards sustainable development.

This study highlights a notable deficiency in the current study concerning the relationships among clean cooking energy sustainable development and socio-economic outcomes. It is crucial to recognize certain limitations that suggest avenues for further research. Firstly, the analysis employs an aggregated analysis of clean cooking energy instead of a decomposed analysis which is capable of exposing some nuances in rural communities. The limitation is premised on the restriction of data availability, which confines the research. Future investigations should incorporate decomposed clean cooking energy analysis to enhance the contributions and references for related scholarly work. Furthermore, although this research focuses on baseline regression detailing the inclusion of control variables, there may exist additional moderating channels of influence that warrant exploration. We plan to undertake further mechanism analyses in subsequent studies.

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Appendix

Table A. List of countries, source: Authors' compilation

Central Africa	Eastern African	Northern African	Southern African	Western African
Cameroon, Angola, Democratic Republic of the Congo, Republic of the Congo, Gabon, São Tomé and Príncipe	Burundi, Djibouti, Kenya, Malawi, Madagascar, Mauritius, Mozambique, Rwanda, Tanzania, Uganda	Algeria, Egypt, Libya, Morocco, Tunisia	Botswana, Eswatini, Lesotho, Namibia, South Africa, Zimbabwe and Zambia	Cabo Verde, Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Guinea, Liberia, Mali, Mauritania, Nigeria, Niger, Senegal, Sierra Leone, Togo, Benin