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RESEARCH ARTICLE

Global Disparities in Clean Cooking Fuel Adoption: Barriers, Opportunities, and Policy Pathways

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Abstract
Access to clean cooking fuel is a critical component of Sustainable Development Goal 7 (Affordable and Clean Energy) and is intrinsically linked to global health and climate action (SDG 13). Despite its importance, significant disparities in Clean Cooking Fuel adoption persist worldwide. This study presents a quantitative and comparative analysis of global, regional, and national inequalities using a comprehensive longitudinal panel dataset spanning 2000 to 2022. Drawing on data from authoritative sources, including the International Energy Agency (IEA), the World Bank, and the United Nations Statistics Division (UNSD), the paper contrasts adoption patterns across geographic regions and national income levels. The methodology employs descriptive trend analysis to illustrate adoption trajectories and paired t-tests to statistically validate the observed access gap against the global mean. The findings reveal a profound and persistent divide: high-income countries in Europe and North America have achieved nearly universal mean access (≈100%), while regions such as South Asia (e.g., Bangladesh, 15.24%) and Sub-Saharan Africa (e.g., Somalia, 3.49%) lag significantly behind from the year 2000 to 2022. Alarmingly, some low-income nations are experiencing declining adoption trends, posing a significant challenge to future progress. Formidable barriers, including high upfront costs of clean technologies, lack of infrastructure, and inconsistent policy frameworks, underpin these disparities. To bridge this gap, the study proposes actionable policy pathways implementing targeted financial incentives (such as subsidies and microloans) to lower upfront costs; expanding rural energy infrastructure leveraging carbon financing mechanisms; and adopting gender-inclusive strategies to accelerate a just energy transition.

Key Words: Clean Cooking Fuels**;** Sustainable Development Goals (SDGs)**;** Air Pollution**;** Energy Transition**;** Adoption Barriers

Introduction

Billions of people die prematurely each year due to household air pollution resulting from cooking with traditional fuels, such as wood, charcoal, and animal dung. This is a component of a larger disaster, namely biodiversity loss and climate change (BBC, 2016; UNO, 2024). Despite advancements in clean energy solutions, several households in developing regions still primarily rely on conventional fuels (Akash & Monir et al., 2024). This ongoing reliance presents serious issues: economic barriers, insufficient stove availability, risks associated with traditional cooktops, and ineffective policies for promoting clean cooking alternatives (Vigolo, Sallaku, & Testa, 2018; Adams, Jumpah, & Dramani, 2023). In rural areas, traditional stoves cause severe respiratory issues and disproportionately affect women, who are primarily responsible for cooking, as these stoves emit high levels of particulate matter, carbon monoxide, and carbon dioxide (González-Pedraza et al., 2024; Jaiswal et al., 2024; Banerjee et al., 2024). The effect on health and climate change is closely tied to greenhouse gas emissions (Wathore, Mortimer, & Grieshop, 2017).

In urban economies, people rely heavily on wood and charcoal for daily use (Pivot, 2024), driving deforestation (Kaputo & Mwanza, 2024). In China and India, many households still lack access to advanced cooking systems (WBG, 2019). Globally, 40% of the population relies on conventional renewable organic energy, which accounts for 9% of global energy use and 55% of harvested wood. In South Asia and East Africa, 300 million rural people have suffered environmental degradation linked to this reliance. Bioenergy contributes 18–30% of black carbon emissions, though its overall climate effect is relatively lower (2–8%) due to dependence on wood fuel (Masera et al., 2015). The World Health Organization's yearly reports show that approximately 2.9 million deaths are due to household air pollution, with women and children disproportionately affected by respiratory and cardiovascular diseases, stroke, chronic obstructive pulmonary disease, and lung cancer (WHO, 2023). The health impacts of air pollution are further exacerbated by climate variations in temperature and precipitation (Ayejoto et al., 2023).

Globally, disparities in the adoption of clean cooking fuels remain stark. While Europe and North America have nearly universal access, regions such as Sub-Saharan Africa report adoption rates of less than 10%. Figure 1 and Table 1 present a comparative overview of traditional versus clean cooking fuel usage across global regions, highlighting the urgent sustainability divide (IEA, 2023d).

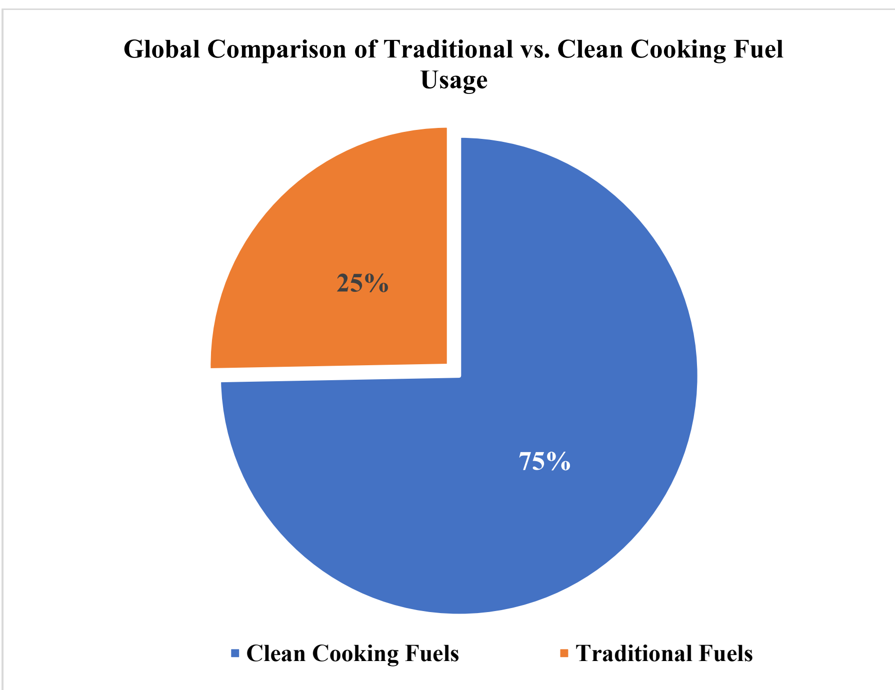

Figure 1. Global Share of Primary Cooking Fuels, 2023
Source: International Energy Agency (2023d)

Table 1. Comparison of Cooking Fuel Usage Across Different Regions – 2023

Region / Year	Asia Pacific	Central And South America	Europe	Middle East	North Africa	North America	Sub-Saharan Africa
2023	77.7	90.2	100	90.7	99.5	96.3	18.7

Source: International Energy Agency, 2025

Cooking fuels also influence economic sectors by contributing to GDP growth. For example, bioenergy is projected to create 504,000 jobs in 2030 and 4.18 million jobs by 2050 (Farghali et al., 2023). Traditional cooking fuels such as wood and charcoal remain more budget-friendly than modern fuels, keeping them attractive for lower-income households (Adeeyo et al., 2022; Awuor, Olajide, & Evans, 2022). As income levels rise, households gradually transition to cleaner fuels (Kariuki et al., 2021). However, the lack of education and awareness about indoor air pollution continues to perpetuate the traditional fuel use (Akintan, Jewitt, & Clifford, 2018). In contrast, urban households with higher incomes and greater environmental awareness are more inclined to adopt clean cooking solutions (Dai et al., 2025). These shifts align with broader policy adjustments supporting transitions toward greener energy (Ravindra, Kaur-Sidhu, & Mor, 2021).

The study therefore analyses the environmental impacts of traditional cooking fuels, including wood, charcoal, and dung, which contribute to household air pollution, biodiversity loss, and climate change. In rural nations, economic barriers, inefficient stoves, and weak policies all contribute to continued dependence on these fuels despite advancements in clean energy alternatives. This research emphasizes the significance of awareness campaigns and regulatory reforms in promoting sustainable cooking methods, ensuring both environmental and public health benefits.

The study specifically examines the causes and consequences of traditional cooking fuel usage across global regions, exploring patterns of clean fuel adoption, highlighting disparities, and assessing the environmental sustainability of traditional fuels. It also evaluates the effectiveness of clean cooking policies. By addressing these aspects, the study aims to provide insights into the challenges and opportunities associated with transitioning to sustainable cooking practices, ultimately contributing to strategies that promote cleaner, healthier, and more environmentally friendly cooking worldwide.

Literature Review

Clean cooking fuels and energy poverty are essential issues worldwide, especially for low- and middle-income countries. Theoretical literature on the relationship between energy poverty and health is lacking (Shobande, 2023). The use of fossil fuels and solid fuels for cooking contributes to air pollution and health hazards. This review will discuss the effects and acceptability of fuels in light of various studies.

Environmental Effect

Burning fossil fuels and biomass exacerbates respiratory diseases and neonatal mortality (Welsch & Biermann, 2017) while driving deforestation-induced climate change (Aro, 2016). Consequently, the transition to modern energy is critical for mitigation. Pande (2025) employed an ARDL bounds testing approach in Bangladesh, explicitly demonstrating that electricity access and economic growth are significant determinants of long-term CO_2 emissions, suggesting that development without clean infrastructure drives environmental degradation.

While achieving SDG 3 and SDG 7 requires government intervention to improve affordability, adoption remains slow due to persistent structural barriers (Bonan & Pareglio, 2017). However, recent literature reframes clean cooking as a critical nature-based climate solution. UNDP and FAO (2025) argue that integrating clean cooking into Nationally Determined Contributions (NDCs) is essential to close the global agrifood mitigation action gap. This is supported by Khan et al. (2024), who found that economic growth in South Asia is insufficient to drive transition without climate-conscious policies. Similarly, the OPEC Fund (2024) warns that without a shift toward renewables-based electric cooking, population growth in Sub-Saharan Africa threatens to reverse recent gains.

Energy Poverty and Cooking Fuel

Energy poverty is primarily caused by a lack of access to electricity and clean cooking fuel, and is closely linked to economic underdevelopment (Eguino, 2015). Many developing countries rely on solid fuels, such as wood, coal, and dung, for cooking, which causes high levels of indoor air pollution (World Bank, 2023b; WHO, 2018). Approximately 2.1 billion people worldwide rely on solid biofuels, while the majority of the global population relies on fossil fuels, including coal, natural gas, kerosene, LPG, and electricity (WHO, 2024). The use of solid fuel not only causes air pollution but also increases the health risk of people involved in cooking, especially women (Parikh, 2011).

Energy and Health Risk

The theoretical connection between energy consumption is explained by Gary’s production theory, where health is considered as an output that enters the utility function and, on the other hand, acts as an input to the production function (Hartwig & Sturm, 2018). Burning fuels during cooking releases carbon monoxide, nitrogen oxides, and other harmful gases that cause respiratory problems (Fullerton et al., 2008). Around 4 million people die prematurely worldwide each year (WHO, 2021). Household pollution during cooking increases the risk of lung cancer, pneumonia, cardiovascular disease, and other health problems.

Gendered Health Synergies and Maternal Outcomes

The health burden of traditional fuels exhibits a distinct gender and generational bias. Recent epidemiological studies highlight the intergenerational cycle of risk, where maternal exposure to household air pollution during pregnancy is strongly correlated with adverse birth outcomes, including low birth weight and cognitive development delays in neonates (Daba et al., 2024). Furthermore, the synergy between energy poverty and gender inequality is stark; women and children, who spend the most time near the hearth, account for nearly 60% of the disease burden related to household air pollution. Consequently, the transition to clean cooking acts as a double-dividend intervention, simultaneously reducing child mortality from pneumonia while liberating women’s time for economic empowerment (WHO, 2024).

Adoption of clean Fuels

Although the use of clean energy is essential from both health and environmental perspectives, its adoption is still relatively slow. Research indicates that the definition of energy poverty remains a matter of debate, with no

consensus having been reached (Eguino, 2015). The benefits of using clean fuels for cooking include lower carbon emissions, reduced health risks, and decreased reliance on fossil fuels (Rosenthal et al., 2018).
Many countries have successfully increased the acceptance of LPG and clean fuels. For example:

- LPG usage has increased tremendously in countries like Brazil, Ecuador, Ghana, Indonesia, and India (Wright et al., 2020; Martínez-Gomez et al., 2016; Thoday et al., 2018)

- The use of clean energy not only provides health benefits but also reduces greenhouse gas emissions (Rosenthal et al., 2018).

Research Gap

However, there is a dearth of research on the regional disparities in the adoption of clean cooking fuels, particularly in low-income and South Asian countries (IEA, 2023d; World Bank, 2023a). Despite the extensive examination of environmental impacts, the majority of studies concentrate on high-income regions or global averages, neglecting the distinctive socio-economic and infrastructural challenges that South Asia and Sub-Saharan Africa encounter.
Critically, existing literature often treats developing nations as a monolith, failing to distinguish between the urgent need for subsidy-driven financial interventions in South Asia (where markets exist but affordability is low) versus the fundamental infrastructure-first approaches required in Sub-Saharan Africa (where supply chains are frequently non-existent). Consequently, there is a lack of comprehensive analysis regarding the efficacy of these targeted policy interventions in reversing declining adoption rates (Ravindra, Kaur-Sidhu, & Mor, 2021). Additionally, the potential of gender-inclusive methodologies (WHO, 2022a) and digital technologies (Dai et al., 2025) to encourage clean culinary practices remains incompletely investigated. The objective of this study is to address these deficiencies by providing a comprehensive regional comparison, evaluating the effectiveness of policies, and proposing innovative solutions to accelerate the transition to clean culinary fuels.

Conceptual Framework

This section develops a conceptual framework to organize the key factors, challenges, and impacts related to cooking fuel choice, drawing from established global literature. This framework provides the theoretical underpinning for the present study by structuring the complex variables and relationships that define the problem. The framework is built upon three core pillars: the negative impacts of traditional fuels, the reasons for their continued use, and the challenges hindering the adoption of clean alternatives.

The Effects of Traditional Fuel Use

A primary component of this framework is understanding the significant and well-documented negative consequences of relying on traditional cooking fuels. As illustrated in Figure 2, these impacts are extensive. Environmentally, traditional cooking contributes to global CO_2 emissions, black carbon emissions, deforestation, and land degradation (IEA, 2023b; Vohra et al., 2021; World Bank, 2020). Economically, the global cost of air pollution from fossil fuels is estimated at $2.9 trillion annually, or 3.3% of global GDP

(CREA, 2020). These effects are compounded by severe air pollution, which causes millions of premature deaths, and other environmental damages such as oil spills and ocean acidification.

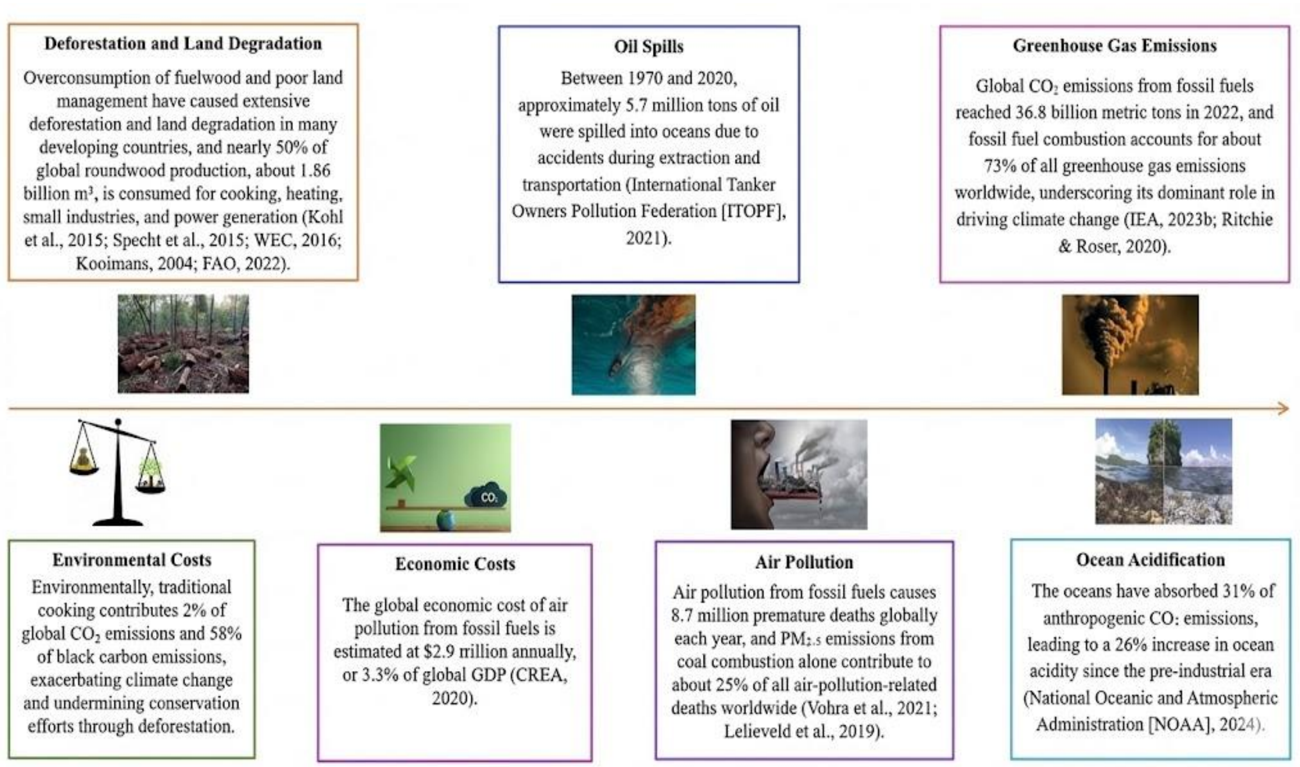

Figure 2. Effect of Traditional Fuel on the Environment

Drivers of Traditional Fuel Reliance

Despite the clear dangers, billions of people, particularly in Sub-Saharan Africa and Asia, continue to use traditional fuels. Table 2 summarizes the primary drivers identified in the literature for this persistent reliance. These factors include:

Table 2. Summarizes the Primary Drivers Identified in the Literature for this Persistent Reliance

Actors	Explanation (Global Context)
Lack of Access to Modern Energy	Globally, 2.4 billion people still rely on traditional fuels like wood, charcoal, and animal dung for cooking, with the majority concentrated in Sub-Saharan Africa and Asia (IEA, 2023d).
High Cost of Clean Cooking Technologies	The upfront cost of clean cooking solutions, such as LPG stoves, can exceed $50, which is unaffordable for low-income households (World Bank, 2022b).
Cultural Preferences and Habits	In many parts of the world, particularly in Sub-Saharan Africa and South Asia, traditional fuels are preferred because food cooked over wood or charcoal fires is considered tastier and more authentic (WHO, 2022b).

Table 2 Continued . . .

Limited Infrastructure for Clean Energy	Globally, 759 million people lack access to electricity, and in rural areas, this figure rises to 80% in Sub-Saharan Africa, forcing reliance on traditional fuels (IEA, 2023a).
Reliance on Subsistence Farming	In low-income countries, 60% of rural households use biomass for cooking because crop residues and animal dung are readily available and free (World Bank, 2022b).
Lack of Awareness About Health Risk	Household air pollution from traditional fuels causes 2.9 million premature deaths annually, with the highest burden in low- and middle-income countries (WHO, 2023).
Inconsistent Supply of Clean Energy	In many developing countries, unreliable electricity supply and frequent LPG shortages force households to revert to traditional fuels. For example, in Nigeria, 70% of households rely on firewood due to inconsistent LPG supply (IEA, 2023a).
Lack of Government Support and Policies	Only 10% of countries globally have national policies to promote clean cooking, leaving millions without access to modern energy solutions (World Bank, 2022b).
Urbanization and Informal Settlements	In rapidly urbanizing areas, approximately 1 billion people reside in informal settlements (UN-Habitat, 2022), often without access to clean energy infrastructure and relying on charcoal and firewood (IEA, 2023d)
Gender Inequality and Household Roles	Globally, women are disproportionately affected by the use of traditional fuels, as they are primarily responsible for cooking. In South Asia, only 20% of women have decision-making power over household energy choices (WHO, 2022a).

Source: Author's Compilation**,** 2025

The study reveals that economic barriers, a lack of infrastructure, and cultural practices are key reasons why people continue to rely on traditional fuels, such as wood, charcoal, and dung. In low-income regions, such as South Asia and Sub-Saharan Africa**,** the high upfront costs of clean cooking technologies and limited access to modern energy sources perpetuate the use of traditional fuels (Adams, Jumpah, & Dramani, 2023; Kariuki, 2021).

Additionally, lack of awareness about the health and environmental benefits of clean fuels further hinders adoption (Akintan, Jewitt, & Clifford, 2018). These challenges highlight the need for targeted policies and financial incentives to accelerate the transition to clean cooking solutions.

Challenges to Adopting Clean Cooking Fuels

Finally, the framework identifies the specific, multifaceted challenges that actively hinder the transition to clean cooking technologies, even when they are available. As detailed in Figure 2, these barriers are interconnected and span economic, infrastructural, and socio-political domains.

Key challenges include high upfront and recurring operating costs, a lack of supporting infrastructure, and inconsistent supplies of clean fuels like LPG (IEA, 2023c). These are exacerbated by limited government support, environmental and supply chain issues, and deep-rooted cultural habits. Furthermore, social factors like gender inequality, a lack of awareness of the benefits, and the specific challenges of urbanization and informal settlements create significant obstacles to adoption (WHO, 2022b; IEA, 2023d).

Figure 3. Challenges of Adopting Clean Cooking Fuels

This complete framework synthesizing the effects of traditional fuels, the reasons for their use, and the challenges to adopting cleaner alternatives identifies the key variables and complex interactions that the present study aims to investigate.

Methodology

This study employs a quantitative, comparative descriptive design to analyze global, regional, and national disparities in Clean Cooking Fuel (CCF) adoption. The research is based on a secondary analysis of publicly available longitudinal data.

Data Collection and Sources

A comprehensive panel dataset was compiled for the period 2000-2022. All data were sourced from authoritative international organizations to ensure reliability and comparability. As detailed in Table 3, these sources include:

- **The International Energy Agency (IEA)** and **The World Bank:** For primary data on Access to Clean Cooking Fuels (% of Population).

- **The International Renewable Energy Agency (IRENA):** For contextual data on renewable energy deployment.

- **The United Nations Statistics Division (UNSD):** For core demographic and economic indicators.

Table 3. Description of Data Variables, Sources, and Time Coverage

Data Name	Data Source/Sources	Obtained Year
Clean Cooking Adoption in South Asia (% of Population)	IEA, IRENA, UNSD, World Bank, 2023	2000-2022
Global Clean Cooking Adoption by Region (% of Population)	IEA, IRENA, UNSD, World Bank, 2023	2000-2022
Clean Cooking Adoption in High-Income Countries (% of Population)	IEA, IRENA, UNSD, World Bank, 2023	2000-2022
Clean Cooking Adoption in Low-Income Countries (% of Population)	IEA, IRENA, UNSD, World Bank, 2023	2000-2022
List of Highest Income Countries in the world (GNI per Capita)	World Bank	2024
List of Lowest Income Countries in the world (GNI per Capita)	World Bank	2024

Source: IEA (2023b), IRENA, UNSD, World Bank (2023b)

The primary variables for analysis include Clean Cooking Adoption by Region (% of Population), Clean Cooking Adoption in High-Income Countries, and Clean Cooking Adoption in Low-Income Countries.

Analytical Approach

The analysis was conducted in two stages: first to identify trends and then to test their statistical significance.

1. **Descriptive and Trend Analysis:** A longitudinal descriptive analysis was conducted to illustrate the trajectories of Clean Cooking Fuel (CCF) adoption from 2000 to 2022. This is visualized in Figure 2, which plots the diverging paths of high-income countries against the global average.

2. **Statistical Significance Testing:** To move beyond simple observation, paired t-tests were employed to statistically validate the observed disparities. This approach quantifies the access gap by comparing the mean Clean Cooking Fuel access rates of specific groups against the global mean over the 22 years. Specifically:

   - **Table 4** presents t-test results comparing regional access rates (e.g., Sub-Saharan Africa, South Asia) against the global mean.

- **Table 5** presents t-test results comparing South Asian countries' access rates (e.g., Afghanistan, Bangladesh, India) against the global mean.

- **Table 6** presents t-test results comparing access rates in selected low-income countries against the global mean.

This two-stage approach allows the study to not only describe the problem but also to provide statistical evidence for the depth and persistence of global inequalities in clean cooking access.

Results and Discussion

Disparities in Clean Cooking Adoption Across Global Regions

Table 4. Paired t-test results comparing regional access to clean fuels and technologies for cooking (% of population) against the global mean (2000–2022)

Region	Mean (%)	Global Mean (%)	t-Statistic	df	p-Value (two-tailed)	Significance	Interpretation
Asia-Pacific	51.46	60.42	-6.957	22	p < 0.001	***	Significantly lower than the global mean
Central & South America	85.70	60.42	25.455	22	p < 0.001	***	Significantly higher than the global mean
Europe	99.99	60.42	24.670	22	p < 0.001	***	Significantly higher than the global mean
Middle East	91.57	60.42	21.721	22	p < 0.001	***	Significantly higher than the global mean
North Africa	97.33	60.42	30.930	22	p < 0.001	***	Significantly higher than the global mean
North America	96.23	60.42	22.368	22	p < 0.001	***	Significantly higher than the global mean
Sub-Saharan Africa	9.82	60.42	-60.444	22	p < 0.001	***	Significantly lower than the global mean

Note: *** indicates statistical significance at p < 0.001 (two-tailed).

A regional analysis further clarifies the global disparities in clean cooking access. Paired t-tests (Table 5) reveal that Europe, North America, North Africa, and the Middle East have achieved universal or near-universal access, each displaying extremely high mean values (≥ 90%) and statistically significant positive deviations from the global mean ($p < 0.001$).

Similarly, Central and South America surpass the global average significantly ($t = 25.46$, $p < 0.001$), reflecting strong policy frameworks and regional cooperation in clean energy dissemination. Conversely, Asia-Pacific countries fall notably below the global average ($t = –6.96$, $p < 0.001$), while Sub-Saharan Africa shows the lowest mean access (Mean = 9.82%) and an exceptionally large negative *t*-statistic ($t = -60.44$, $p < 0.001$), indicating a severe and persistent access deficit.

This statistical gradient highlights a clear North-South divide, where access to clean cooking fuels remains overwhelmingly concentrated in developed regions, while developing and least-developed areas, particularly in Asia and Africa, remain disproportionately energy-poor.

Clean Cooking Adoption in South Asia

Table 5. Paired t-test results comparing national access to clean fuels and technologies for cooking (% of population) against the global mean (2000-2022)

Country	Mean (Country)	Global Mean (%)	t-Statistic	df	p-Value (Two-Tailed)	Significance	Interpretation
Afghanistan	21.08	60.42	-72.48	22	p < 0.001	***	Access is significantly lower than the global average.
Bangladesh	15.24	60.42	-146.24	22	p < 0.001	***	Access is significantly lower than the global average.
Bhutan	63.91	60.42	1.31	22	0.204		No significant difference from the global average.
India	41.81	60.42	-10.61	22	p < 0.001	***	Access is significantly lower than the global average.
Maldives	82.30	60.42	5.57	22	p < 0.001	***	Access is significantly higher than the global average.
Nepal	22.85	60.42	-51.60	22	p < 0.001	***	Access is significantly lower than the global average.
Pakistan	37.07	60.42	-76.83	22	p < 0.001	***	Access is significantly lower than the global average.
Sri Lanka	23.98	60.42	-81.35	22	p < 0.001	***	Access is significantly lower than the global average.

Note: *** indicates statistical significance at $p < 0.001$ (two-tailed).

To quantitatively benchmark the scale of clean cooking access disparities, a series of paired two-sample *t*-tests was conducted comparing the mean access to clean cooking fuels for eight South Asian countries against the global average (Mean = 60.42%) over the period 2000-2022 (Table 4). The findings reveal a pronounced and statistically significant divide across the region.

Within South Asia, a clear divergence in energy adoption emerges. High-performing outliers like the Maldives (Mean = 82.30%) demonstrate significantly higher access than the global average ($t = 5.57$, $p < 0.001$), aligning closer to developed economies. In stark contrast, the region's largest populations, like India, Bangladesh, and Pakistan, remain statistically entrenched in a deficit trajectory. Notably, Bangladesh exhibits the most severe deficit ($t = -146.24$), confirming substantial lags in clean energy equity. Interestingly, Bhutan occupies a middle ground (t = 1.31, p = 0.204), indicating a unique equilibrium where adoption rates have converged with the global mean.

Conversely, the majority of South Asian countries remain statistically entrenched in a deficit trajectory. India, Pakistan, Sri Lanka, Nepal, and Afghanistan (average Mean ≈ 29.77%) all show access levels significantly lower than the global mean ($p < 0.001$ for all). The most severe deficit is observed in Bangladesh, which records the lowest mean access (Mean = 15.24%) and the largest negative *t*-statistic ($t = -146.24$, $p < 0.001$), confirming its substantial lag in achieving clean energy equity.

This stark empirical pattern highlights the persistence of intra-regional inequality. It underscores the urgent need for targeted, country-specific interventions, particularly in Bangladesh and other low-performing economies, to accelerate the transition toward clean cooking fuels and fulfill Sustainable Development Goal 7 (Affordable and Clean Energy for All).

The sheer magnitude of the negative t-statistics for South Asia (t < -100) indicates that these deficits are structural, not merely cyclical. Consequently, statistical improvements in 'access' metrics may mask underlying behavioral barriers. The Access vs. Usage Paradox, while the statistical data indicates improved physical access, the observed stagnation (and in some low-income pockets, decline) in effective adoption rates across South Asia is driven by distinct socio-political dynamics. A critical factor is the volatility of fossil fuel subsidies. In nations like Pakistan and Bangladesh, recent fiscal austerity measures driven by macroeconomic pressure have led to the reduction of LPG subsidies, causing a sharp spike in retail prices. This phenomenon creates a backsliding effect where households retain their clean cooking connections but revert to biomass for daily meals due to recurring costs. Furthermore, political instability in the region has frequently disrupted energy import supply chains, making biomass the only reliable, inflation-proof fuel source for the rural poor (Kar, 2019; World Bank, 2023a).

Clean Cooking Adoption Across National Income Levels

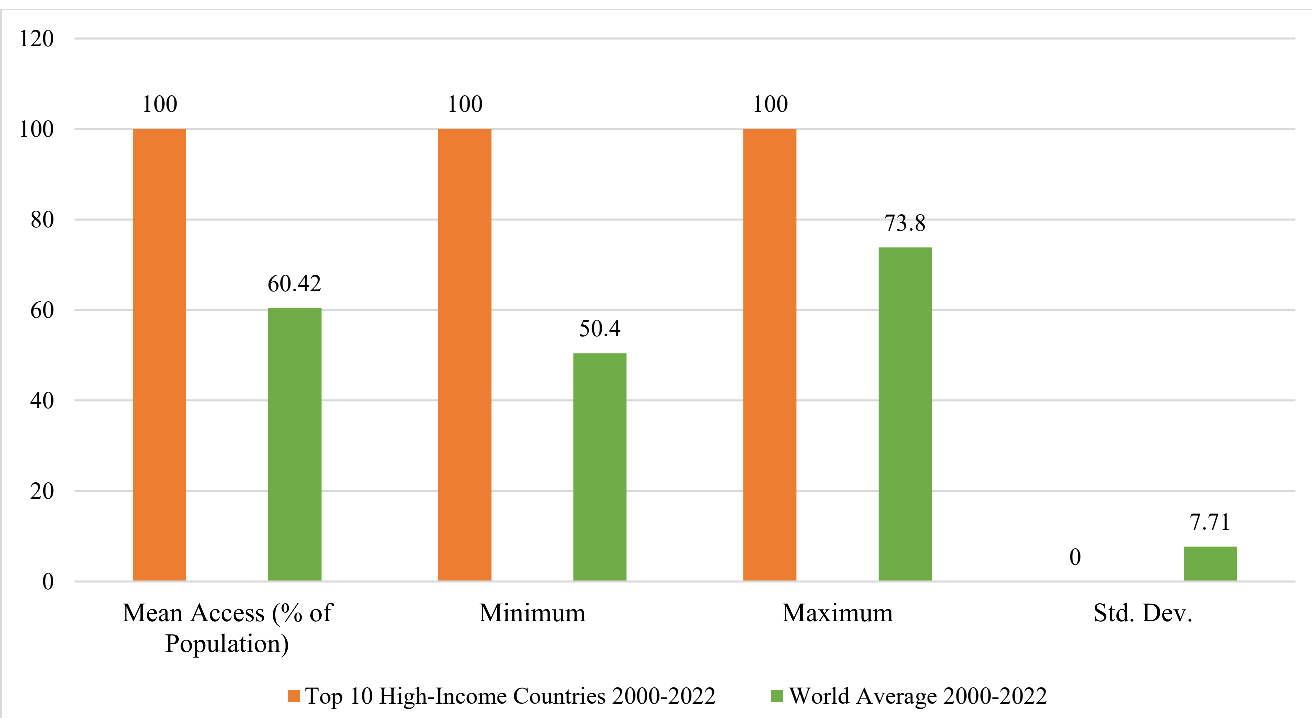

Figure 2. Access to Clean Cooking Fuels: High-Income Countries Compared with Global Average (2000–2022)

Table 6. Access to Clean Cooking Fuels in Lowest GNI Per Capita Countries

Country	Mean Access (%)	Global Mean (%)	t-Statistic	df	p-Value (two-tailed)	Significance	Interpretation
Burundi	0.07	60.42	-37.14	22	p < 0.001	***	Significantly lower than the global mean
South Sudan	1.70	60.42	-44.02	22	p < 0.001	***	Significantly lower than the global mean
Somalia	3.49	60.42	-41.76	22	p < 0.001	***	Significantly lower than the global mean
Mozambique	0.61	60.42	-37.92	22	p < 0.001	***	Significantly lower than the global mean
Central African Republic	0.61	60.42	-37.92	22	p < 0.001	***	Significantly lower than the global mean
Madagascar	1.12	60.42	-37.18	22	p < 0.001	***	Significantly lower than the global mean
Sierra Leone	0.45	60.42	-38.61	22	p < 0.001	***	Significantly lower than the global mean
Congo Dem. Rep.	3.01	60.42	-41.00	22	p < 0.001	***	Significantly lower than the global mean
Niger	2.08	60.42	-35.57	22	p < 0.001	***	Significantly lower than the global mean

Note: *** indicates statistical significance at $p < 0.001$ (two-tailed).

A country-level analysis of the lowest GNI per capita nations highlights an extreme deficit in access to clean cooking fuels. Paired t-tests reveal that all nine countries: Burundi, South Sudan, Somalia, Mozambique, Central African Republic, Madagascar, Sierra Leone, Congo Dem. Rep., and Niger exhibit mean access well below the global average (60.42%), with t-statistics ranging from –35.57 to –44.02 and p-values < 0.001.

This demonstrates a severe and statistically significant energy poverty problem, indicating that households in these nations primarily rely on traditional fuels, with minimal penetration of clean cooking technologies. The findings underscore the urgent need for targeted policy interventions, international support, and sustainable energy programs to bridge this stark gap.

Statistical Justification for Targeted Intervention

The magnitude of the t-statistics (ranging from -60.44 to -146.24) and the consistent statistical significance ($p < 0.001$) carry profound policy implications. These results confirm that the energy poverty observed in South Asia and Sub-Saharan Africa is structural rather than transient. The statistical rejection of the null hypothesis that these regions are on par with global standards provides the empirical basis for rejecting one-size-fits-all global energy policies. Instead, the data mandates a shift toward asymmetric policy interventions. Specifically, the extreme negative deviations suggest that without significant external shocks in the form of heavy subsidization, infrastructure investment, and technology transfer, these regions will not statistically converge with the global mean in the near future.

Suggestions for Promoting Clean Cooking Adoption based on Case Study

Table 7: Strategies for Promoting Clean Cooking Fuel Adoption

Strategy	Description	Data Example
Countering High Upfront Costs	Reducing the upfront costs of clean cooking technologies through financial aid.	The Pradhan Mantri Ujjwala Yojana (PMUY) program in India provided 80 million LPG connections, leading to a 30% increase in LPG adoption.
Solving Infrastructure Gaps	Investing in clean fuel distribution networks, especially in rural areas, is crucial.	In Sub-Saharan Africa, only 15% of the rural population has access to electricity.
Mitigating Lack of Awareness	Educating the public about the health and environmental benefits of clean fuels.	Awareness campaigns in Bangladesh led to a 20% increase in adoption over five years.
Policy Interventions	Implementing policies like tax exemptions and clean energy mandates can help reduce environmental impact.	Only 10% of countries have national policies promoting clean cooking.
Carbon Financing	Using carbon credits to make clean cooking solutions more affordable.	Carbon financing in Kenya reduced emissions by 1.5 million tons of CO_2 annually.
Public-Private Partnerships	Collaboration between governments and private companies for large-scale adoption.	Ghana's partnerships increased LPG adoption by 25% over three years.
Renewable Energy Integration	Promoting alternative cooking solutions, such as solar cookstoves and biogas, can help reduce emissions.	In Nepal, 400,000 households adopted biogas systems.

Table 7 continued . . .

Gender-Inclusive Approaches	Empowering women through education and decision-making opportunities.	In South Asia, only 20% of women have decision-making power over household energy choices.
Monitoring and Evaluation	Establishing frameworks to track clean cooking adoption.	The Clean Cooking Alliance tracks progress in 50 countries.
Global Cooperation	Strengthening international collaboration for knowledge-sharing and funding.	The Summit on Clean Cooking in Africa, organized by the International Energy Agency (IEA) and supported by the Clean Cooking Alliance, mobilized $2.2 billion for clean cooking initiatives (IEA, 2024)

Sources: Author's Compilation**,** 2025

Conclusion

Achieving universal access to clean cooking fuels is central to the realization of Sustainable Development Goal 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). This study shows that adoption rates remain highly uneven across regions. While high-income countries have achieved near-universal access, South Asia and Sub-Saharan Africa continue to face critical deficits, with adoption rates as low as 4.8% in Somalia. Alarmingly, some countries are even experiencing declining adoption trends, threatening progress toward global sustainability commitments. Traditional fuels, including wood, charcoal, and animal dung, remain widespread, contributing to household air pollution, greenhouse gas emissions, deforestation, and premature mortality. The persistence of these fuels reflects not only economic constraints but also infrastructural gaps, cultural practices, and limited awareness of health and environmental risks. This study underscores that advancing clean cooking adoption requires coordinated, multi-level action. Governments, international organizations, and private actors must work together to reduce costs, strengthen infrastructure, promote awareness, and design gender-inclusive policies. Without large-scale interventions, low- and middle-income countries risk perpetuating energy poverty, environmental degradation, and public health crises. Conversely, targeted strategies can accelerate the transition to sustainable cooking solutions, offering substantial benefits for health, equity, and climate resilience.

Discussion

To contextualize the regional disparities observed in the statistical analysis, it is instructive to compare the distinct policy pathways of India and South Africa. These two nations represent the divergent strategies often employed in the Global South: demand-side financial support versus supply-side infrastructure expansion.

India's approach, driven by the Pradhan Mantri Ujjwala Yojana (PMUY), focused on a subsidy-led model, successfully providing over 96 million initial LPG connections to low-income women. While this solved the access barrier, the lack of ongoing refill subsidies meant that usage dropped significantly when global gas prices rose (Kar et al., 2023). This highlights that access does not guarantee sustained adoption if fuel affordability remains volatile.

In contrast, South Africa pursued an infrastructure-led model, aggressively expanding the national electricity grid to rural areas to promote electric cooking. However, this strategy faces a unique challenge: despite having physical access to electricity, the recent energy crisis and frequent load-shedding (power outages) have forced households to maintain wood-burning stoves as a backup security measure (Wiese & Westhuizen, 2024).
This comparison highlights a critical lesson for global policy: neither subsidies nor grid connections alone are sufficient. Sustainable adoption requires a dual approach, ensuring both financial affordability (the lesson from India) and supply reliability (the lesson from South Africa).

1. **Regional Disparities:** High-income countries have achieved universal adoption of clean cooking fuels, while South Asia and Sub-Saharan Africa remain far behind, with averages well below global benchmarks.

2. **Health Burden:** Household air pollution from traditional fuels continues to cause millions of premature deaths annually, disproportionately affecting women and children.

3. **Environmental Costs:** Reliance on traditional fuels drives deforestation, black carbon emissions, and climate change, undermining global environmental sustainability.

4. **Economic Barriers:** High upfront and recurring costs of clean fuels restrict access for low-income households, sustaining dependence on traditional energy sources.

5. **Policy Gaps:** Weak infrastructure, limited government support, and inconsistent supply chains hinder clean cooking adoption, while successful interventions (e.g., India's PMUY program) demonstrate the transformative potential of targeted policies.

Policy Recommendations Based on Adoption Case Studies: This study suggests the following evidence-based solutions:

1. **Financial Incentives and Targeted Subsidies:** Governments must scale targeted subsidies to bridge the affordability gap for the lowest income quintiles. The efficacy of this approach is demonstrated by India's Pradhan Mantri Ujjwala Yojana (PMUY), which connected over 96 million households to LPG by subsidizing the initial connection cost (Gaikwad, 2025). However, to ensure sustainability, subsidies must be smart and reliable to prevent backsliding during global fuel price spikes.

2. **Infrastructure Development and Last-Mile Delivery:** Infrastructure Development and Last-Mile Delivery: The last-mile distribution challenge remains a critical bottleneck. Investments must prioritize extending electricity grids and LPG supply chains into underserved rural regions. Research indicates that without reliable supply chains, rural households inevitably revert to traditional fuels (IEA, 2023c). Furthermore, empirical evidence from Bangladesh confirms that expanding electricity access is statistically significant in mitigating long-term CO_2 emissions, reinforcing the need for grid modernization alongside stove distribution (Pande, 2025).

3. **Awareness and Behavioral Campaigns:** Public education campaigns are necessary to dismantle myths regarding the cost and safety of clean fuels. Evidence from Bangladesh suggests that health-focused awareness initiatives can increase the probability of clean cooking adoption by approximately 20%,

particularly when messages are delivered through trusted local community leaders rather than distant government officials (Clean Cooking Alliance, 2024).

4. **Carbon Financing and Market-Based Mechanisms:** Carbon credits are essential for making clean cooking projects economically viable by offsetting high initial costs. A leading example is Kenya's BURN Manufacturing, which utilizes Gold Standard carbon credits to subsidize the retail cost of high-efficiency Jikokoa stoves. This mechanism has enabled the distribution of over 5 million stoves, effectively reducing 26 million tons of CO_2 to date (Jeuland, 2020).

5. **Gender-Inclusive Approaches:** Since women are the primary energy managers, policy frameworks must center on their agency (Tornel-Vázquez et al., 2024). Successful interventions link clean energy access with female entrepreneurship. For instance, the Solar Sister initiative in Nigeria trains women to sell clean energy products using a micro-consignment model. Data shows these women entrepreneurs sell significantly more units in rural areas than men due to stronger peer trust networks (Solar Sister, 2023).

6. **Global Cooperation and Knowledge Sharing:** Fragmented national efforts are insufficient to lower technology costs. International collaborations are pivotal for mobilizing the estimated $8 billion annual investment required to achieve SDG 7 (IEA, 2023). Platforms like the Clean Cooking Alliance facilitate standardized technology testing and knowledge transfer, ensuring that countries do not replicate failed pilot programs (Clean Cooking Alliance, 2024).

7. **Addressing Cultural and Regional Nuances:** Policies must account for deep-seated cultural preferences. Recent studies highlight that in many communities, the specific taste of food cooked on traditional wood fires, such as *Roti* in India or *Ugali* in East Africa, remains a barrier (Jagadish & Dwivedi, 2018). Successful interventions employ participatory design, involving local women in the engineering phase to ensure stoves accommodate traditional cookware and habits (Oparaocha & Dutta, 2011).

8. **Leveraging Digital Ecosystems and Smart Monitoring:** Integrating digital technologies is crucial for scaling adoption. Pay-As-You-Go (PAYG) models, enabled by mobile money platforms (like M-PESA in East Africa), allow households to purchase cooking services in small, affordable daily increments, removing the barrier of high upfront costs (Shupler et al., 2021). Furthermore, Internet of Things (IoT) sensors on modern stoves allow policymakers to track actual usage rates in real-time, ensuring subsidies target active users (Stritzke et al., 2023).

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