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What Goes Along with the Energy Ladder? Regression Analysis and Crisp-Set Qualitative Comparative Analysis

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ABSTRACT

The study reveals that, while economic variables, such as income, remain central to explaining clean energy adoption in the selected 20 African countries, other non-economic elements, like access to infrastructure and social demographics, can exert notable influence under certain circumstances. To enable comparison, two analyses were employed: regression analysis and crisp-set qualitative comparative analysis (cs-QCS). The trend findings show higher adoption rates of clean cooking fuels in West and Central Africa, particularly under certain socioeconomic and infrastructure conditions (high rates of female household heads and access to electricity). Conversely, East Africa has made limited progress due to specific socioeconomic and infrastructure constraints (low rates of improved water and access to electricity). These results reinforce the primary relevance of the Energy Ladder theory for African nations but also indicate that certain combinations of social factors modulate clean energy utilization. Thus, the study highlights the need for a more nuanced understanding of how economic and non-economic determinants interact and shape household fuel choices across diverse regional settings in Africa, which goes beyond energy stacking.

Keywords: Improved Cookstoves, Clean Cooking, Energy Ladder Theory, Energy Stack, cs-QCA
JEL Classifications: D10, D12

1. INTRODUCTION

The world population in 2024 is estimated to reach 8.2 billion, reaching a peak of around 10.3 billion people in the mid-2080s (United Nations, 2024). Approximately 2.1 billion people would have limited options and rely on traditional solid biomass without access to clean cooking fuels. The number decreased from 2.7 billion in 2015 to 2.1 billion in 2022, representing a decline of 0.6 billion people globally (Tracking SDG 7, The Energy Progress Report, 2024, p. 10). The improvement may be partially due to carbon credit projects, where project proponents distribute cookstoves for free or at a subsidized price to community members, recouping their investment by selling carbon credits. Two main types of cookstoves are commonly recognized: Improved Cookstoves (ICS) and Clean Cooking Solutions (CCS). The energy sources for the ICS are biomass fuels such as firewood, charcoal, crop waste, and animal dung. In contrast, the energy sources for the CCS are ethanol, methanol, biogas, LPG, natural gas, and electricity. The shift of energy sources from the ICS to the CCS is often explained by the Energy Ladder Theory, which posits that energy sources progress up the ladder from biomass to clean energy as GDP per capita in purchasing power parity (PPP) increases. Compared to traditional cooking systems, such as Triple Stone Stoves or Tripods, the ICS can cook food quickly because the chamber system creates a higher temperature, which reduces the volume of firewood and charcoal, ultimately protecting the forests (Beyene et al., 2015). However, those courses of action for protecting forests through cookstoves have been exposed to various challenges, including financial ones and a lack of understanding in communities (Parker et al., 2015).

Carbon pricing, "a cost-effective policy tool that governments can use as part of their broader climate strategies" (World Bank, 2022, p. 12), can be a critical enabler of improved and clean cookstove (ICS/CCS) diffusion when paired with carbon credits. By monetizing verified emission reductions, credits help unlock distribution and after-sales financing while also underpinning a bundle of co-benefits: wider ICS/CCS uptake (Bumpus, 2011; Freeman and Zerriffi, 2012; Lambe et al., 2015a; Wang and Corson, 2015), household income gains (Negash et al., 2021), health improvements from reduced household air pollution (Gadgil et al., 2013; Jürisoo et al., 2018), climate change mitigation (Onyekuru et al., 2021), and ancillary social and environmental benefits (Freeman and Zerriffi, 2014; Rosenthal et al., 2018).

Realizing these benefits, however, depends on navigating implementation frictions. Technology performance and monitoring requirements can be demanding (Lovell and Liverman, 2010); user perceptions and practices shape sustained adoption (Simon et al., 2012); business models must bridge upfront and recurring costs (Simon et al., 2014); and project integrity hinges on complex accounting tests such as additionality, which requires showing that emissions cuts would not have occurred absent the crediting intervention (Purdon, 2015). Thoughtful program design that links finance, technology, and user behavior is therefore essential to convert carbon pricing potential into durable ICS/CCS outcomes.

The project developers can develop carbon credit projects based on the cash inflow from selling carbon credits from ICS and CCS. According to Ecosystem Marketplace (2025), the carbon credit volume from household and community devices[1] was 10.2 million tons of CO2 in 2023, amounting to a transactional value of US$78.3 million, and 5.1 million tons of CO2 in 2024, amounting to a transactional value of US$37.4 million. These figures were considered a significant drop, considering a transactional value of US$77.6 million and 9.1 million tons of CO2 in 2022 (Ecosystem Marketplace, 2024). One of the reasons for the significant drop is the lack of confidence in the quality of carbon credits from cookstoves. Gill-Wiehl et al. (2024) found that cookstove projects generated the majority of carbon credits in 15 countries. Further, Gill-Wiehl et al. (2024) noted that the carbon credit volume from their sampled cookstove projects is over-credited 9.2 times higher than it actually is. Thus, their view is that the carbon credit volume is overly issued, which means that the transactional value is also overstated. They found that (1) Inappropriate Methodology: the leading causes are the lack of flexibility in methodologies and inconsistencies in the assessment methods for the fraction of non-renewable biomass (fNRB), adoption rates, usage rates, and fuel consumption. These factors collectively contribute to the issuance of excessive credits, (2) Overestimation of Fuel Conversion Efficiency: Fuel conversion efficiency, which depends on specific regions and charcoal production practices, is overestimated, (3) Rebound Effect: The introduction of improved stoves can lower the "cost" of cooking, which leads to increased fuel consumption by households. This is not captured by some projects, resulting in excessive evaluations of emission reductions, and (4) Poor Tracking: The tracking of carbon reductions and their co-benefits is inadequate, remaining at a superficial level. These project development companies tend to inflate the amount of carbon credits as much as they can get away with, since their income increases with the volume of credits. It is important to maintain project integrity to avoid criticism of over-issuing.

Before these project companies begin their projects, when considering where to develop carbon credit projects through cooking stoves, the Energy Ladder theory, introduced at the outset, requires examination. However, when project development relies solely on this theory, many project development companies likely find that the resulting carbon credits do not meet expectations later on. In other words, project selection based solely on the Energy Ladder theory may be prompting project development companies to inflate credit volumes. When selecting project sites for carbon credits generated from cooking stoves, I would like to explore whether there is any information other than the Energy Ladder theory that project developers can rely on.

2. LITERATURE REVIEW

The Energy Ladder Theory has received several criticisms. According to the theory, households gradually transition to using cleaner fuels as their income increases. Nevertheless, some reviews highlight that this theory does not always reflect the actual situation. In reality, households may not entirely switch to cleaner fuels; instead, they often make a partial transition, moving from fuels like animal dung and crop residues to cleaner options such as wood, charcoal, kerosene, LPG, and electricity. This suggests that the progression is not as straightforward as the energy ladder theory implies, with variations occurring based on the specific conditions of each region and household (Lewis and Pattanayak, 2012). The transition to energy sources is not a linear movement but is often layered due to the oversimplification of the fuel hierarchy (Kroon et al., 2013).

Socioeconomic and demographic household characteristics, such as size, income, education, and gender dynamics, can influence decisions (Shankar et al., 2014; Karanja and Gasparatos, 2019). The fuel for cookstoves and fuel stacking has traditionally been gender driven (Gordon and Hyman, 2012; Gill-Wiehl et al., 2021), relying on the education level of the wife in a household (Pundo and Fraser, 2006). When it comes to the Energy Ladder from ICS to CCF, especially LPG, it requires modernization in household dynamics, such as the construction of new kitchens and the purchase of new cookware, reflecting a more Western-style living (Masera et al., 2000), and overcoming the financial issues associated with LPG (Agbokey et al., 2019; Hsu et al., 2021).

Household energy and water access are closely intertwined, and treating them as a single service bundle often yields more durable benefits than addressing them in isolation. Integrated programs that pair improved cookstoves with safe drinking-water solutions have achieved greater uptake and measurable health benefits by simultaneously lowering indoor air pollution and improving water quality (Barstow et al., 2014; Nagel et al., 2016), yet sustained use still hinges on behavior change and routine practices (Thomas et al., 2013). These user-side dynamics intersect with supply- and policy-side conditions: the feasibility of transitioning to cleaner cooking fuels (e.g., LPG, natural gas) depends not only on

1 Household and community devices include water purification filter projects and drilling boreholes for clean water in the community, so it is not entirely cookstoves.

household preferences but also on national resource endowments, energy pricing, market reliability, and governance, those factors shaped by whether a country is an oil and gas producer and by the broader rule-of-law and resource-curse context (Burke, 2013).

Empirical papers on the incompleteness of the Energy Ladder theory and Energy Stacking exist across countries in Africa. Seen through this integrated lens, the classic Energy Ladder's linear progression is too narrow. Across African settings, empirical studies have documented the practice of fuel stacking and the simultaneous use of multiple stoves as households navigate constraints related to cost, availability, cultural preferences, and reliability. Those findings were reported for Kenya (Fingleton-Smith, 2022), Botswana (Horst and Hovorka, 2008), Nigeria (Jewitt et al., 2020), and Southern Africa, including Mozambique, Malawi, and Zambia (Pailman et al., 2018). All studies cast doubt and criticized the linear movement of the Energy Ladder Theory, as their findings encountered fuel stacking and the use of multi-cookstoves in specific countries.

3. COUNTRY DATA SUMMARY

Numerous studies have revealed that the Energy Ladder theory has a flaw known as Energy Stacking. The adaptation requires technical support (Jürisoo et al., 2018), but the adaptation ratio differs between urban and non-urban areas (Kapfudzaruwa et al., 2017). However, even considering this flaw, the theory remains well-constructed and is likely to continue playing a significant role in cooking stove research. The question is how to reinforce this theory. Figure 1 presents the utilization of clean cooking fuels and GDP per capita (PPP) for several African countries. Although it resembles Figure 1 in Matsubara (2024, p.112), some countries and data time points differ. The author chose 20 countries on the African continent as a sample because data newer than 2019 are available on the Demographic and Health Data website. I chose these 20 countries because the data may be outdated, which could cause them to inaccurately reflect the current situation.

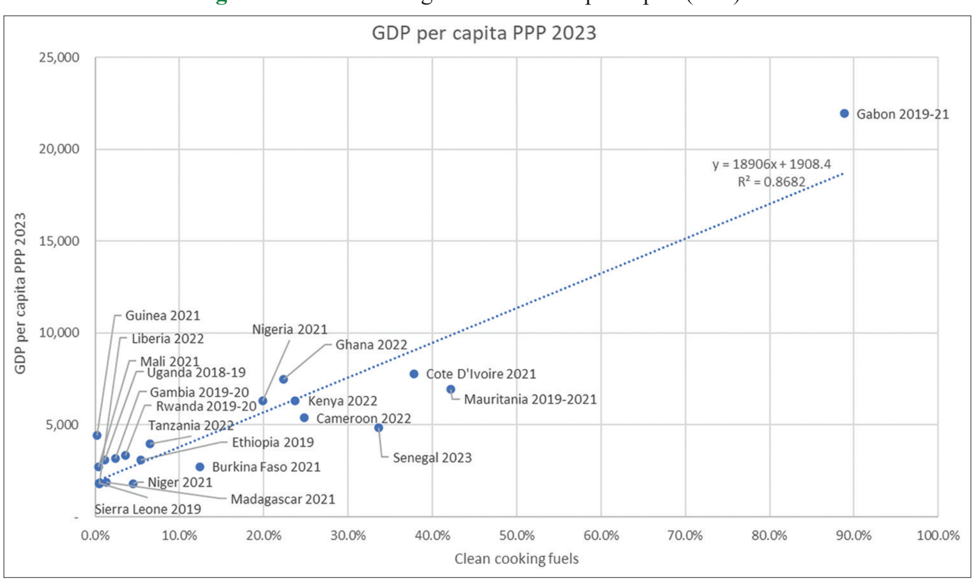
Figure 2 reports access rates for electricity and for clean cooking fuels. Although it resembles Figure 3 in Matsubara (2024, p.112), the country sample and some observation years differ. The R-squared value in Figure 2 is 0.509, which is lower than the 0.8682 shown in Figure 1 for 2023 GDP per capita (PPP). Thus, across 20 African countries, the 2023 GDP per capita (PPP) is more strongly associated with the use of clean cooking fuels than with access to electricity.

Figure 4 illustrates the relationship between the increased water access rate and access to clean cooking fuels. Although it appears similar to Figure 6 in Matsubara (2024, p.112), the country coverage and some observation years differ. The R-squared value in Figure 4 is 0.1949, which is lower than the values for 2023 GDP per capita (PPP) and electricity access. While we expected a close linkage between access to clean cooking fuels and improved water, the observed correlation offers little support for such a relationship.

Figure 3 illustrates the relationship between the share of female-headed households and the share with access to clean cooking fuels. Although it may appear similar to Figure 3 in Matsubara (2024, p.112), the set of countries and observation years differs in part. The R-squared in Figure 3 declines to 0.1212, which is even lower than for access to improved water. While female household heads might be expected to have greater control over spending priorities, the observed correlation provides little evidence that clean cooking fuels are being prioritized as a result.

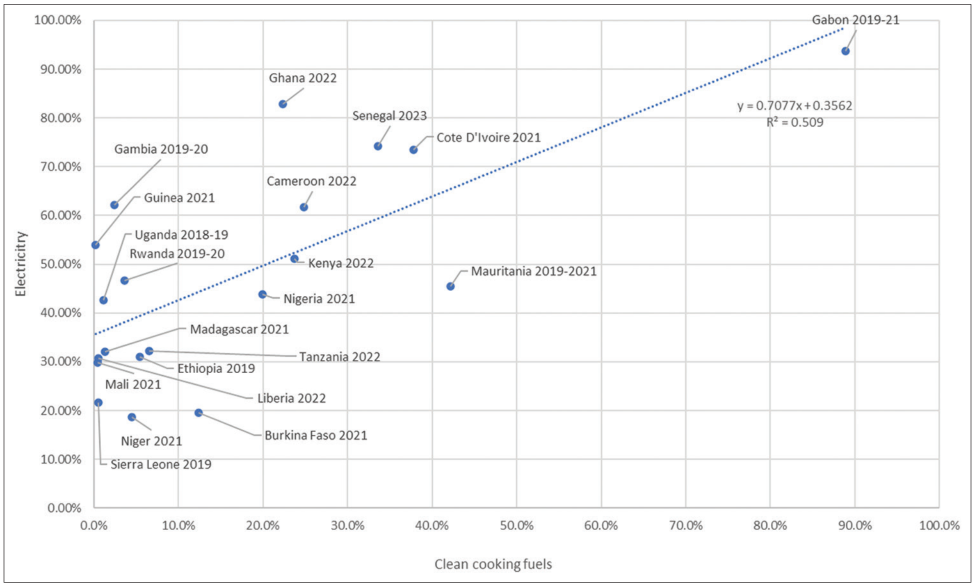
Figure 5 shows the correlation between the mean family size and the access ratio to clean cooking fuels. R-squared in Figure 5 dropped to 0.0536, the lowest among the five Figures. If more

Figure 1: Clean cooking fuels and GDP per capita (PPP) in Africa



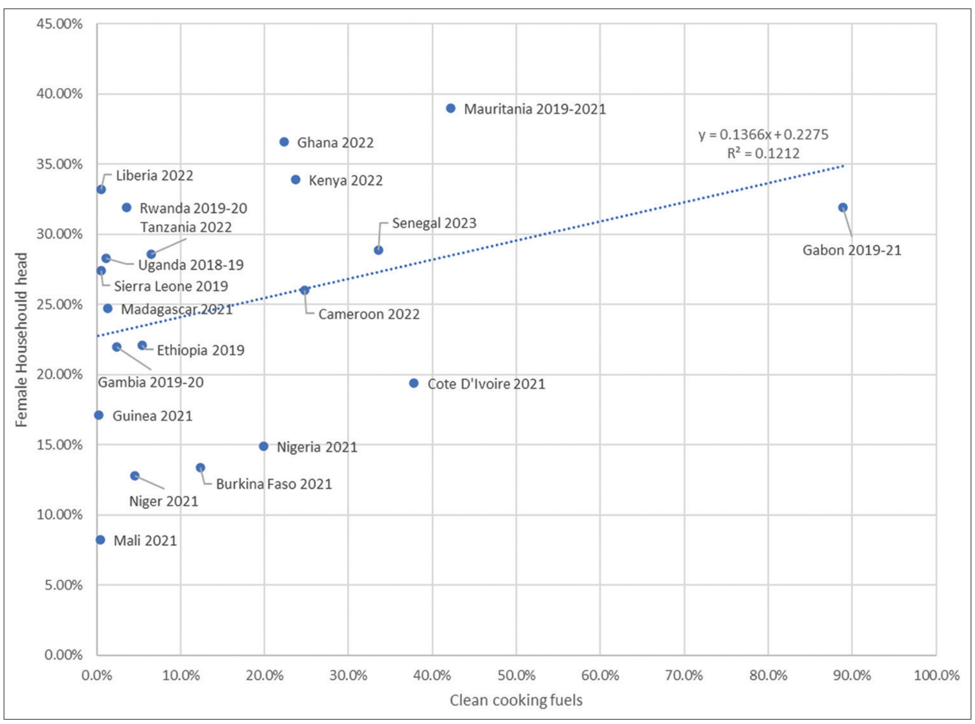
Source: Burkina Faso DHS (2021), Cameroon MIS (2022), Cote D'Ivoire DHS (2021), Ethiopia DHS (2019), Gabon DHS (2019-2021), Gambia DHS (2019-2020), Ghana DHS (2022), Guinea DHS (2021), Kenya DHS (2022), Liberia MIS (2022), Madagascar DHS (2021), Mali MIS (2021), Mauritania DHS (2019-2021), Niger MIS (2021), Nigeria MIS (2021), Rwanda DHS (2019-2020), Senegal MIS (2023), Sierra Leone DHS (2019), Tanzania TDHS-MIS (2022), Uganda MIS (2018-2019), The World Bank

Figure 2: Electricity access and clean cooking fuels



Source: Burkina Faso DHS (2021), Cameroon MIS (2022), Cote D'Ivoire DHS (2021), Ethiopia DHS (2019), Gabon DHS (2019-2021), Gambia DHS (2019-2020), Ghana DHS (2022), Guinea DHS (2021), Kenya DHS (2022), Liberia MIS (2022), Madagascar DHS (2021), Mali MIS (2021), Mauritania DHS (2019-2021), Niger MIS (2021), Nigeria MIS (2021), Rwanda DHS (2019-2020), Senegal MIS (2023), Sierra Leone DHS (2019), Tanzania TDHS-MIS (2022), Uganda MIS (2018-2019)

Figure 3: Female household head and clean cooking fuels

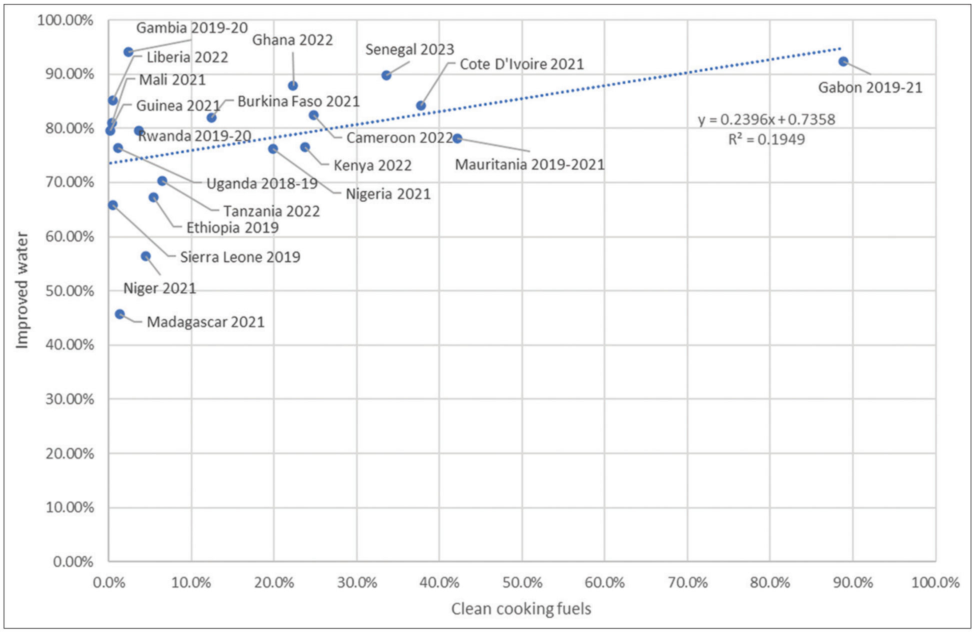


Source: Burkina Faso DHS (2021), Cameroon MIS (2022), Cote D'Ivoire DHS (2021), Ethiopia DHS (2019), Gabon DHS (2019-2021), Gambia DHS (2019-2020), Ghana DHS (2022), Guinea DHS (2021), Kenya DHS (2022), Liberia MIS (2022), Madagascar DHS (2021), Mali MIS (2021), Mauritania DHS (2019-2021), Niger MIS (2021), Nigeria MIS (2021), Rwanda DHS (2019-2020), Senegal MIS (2023), Sierra Leone DHS (2019), Tanzania TDHS-MIS (2022), Uganda MIS (2018-2019)

family members are in the household, the amount of cooked food would need to increase, and the need to cook in a shorter time would also increase; however, this has no bearing on the usage ratio of clean cooking fuels. All Figures 1-5 above were created based on the information described in Table 1 below.

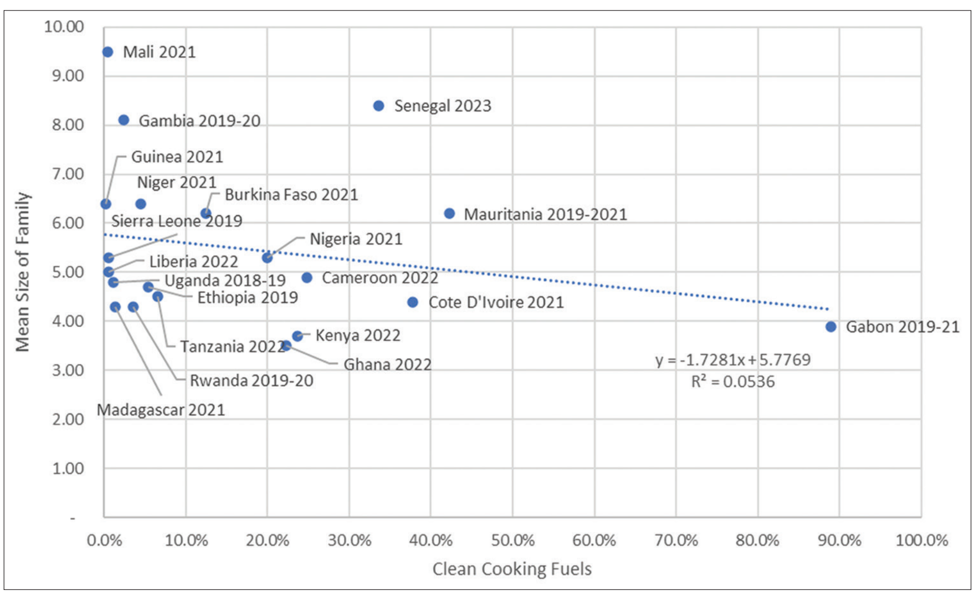
Table 2 below shows the correlation analysis. The mean size of a family is the only negative number, while others are positive numbers, which means the number of children will decrease by the elevation of GDP per capita (PPP). GDP per capita (PPP) and access to electricity are the two most significant factors influencing the use of clean cooking fuels.

Figure 4: Improved water and clean cooking fuels



Source: Burkina Faso DHS (2021), Cameroon MIS (2022), Cote D'Ivoire DHS (2021), Ethiopia DHS (2019), Gabon DHS (2019-2021), Gambia DHS (2019-2020), Ghana DHS (2022), Guinea DHS (2021), Kenya DHS (2022), Liberia MIS (2022), Madagascar DHS (2021), Mali MIS (2021), Mauritania DHS (2019-2021), Niger MIS (2021), Nigeria MIS (2021), Rwanda DHS (2019-2020), Senegal MIS (2023), Sierra Leone DHS (2019), Tanzania TDHS-MIS (2022), Uganda MIS (2018-2019)

Figure 5: Mean size of family and clean cooking fuels



Source: Burkina Faso DHS (2021), Cameroon MIS (2022), Cote D'Ivoire DHS (2021), Ethiopia DHS (2019), Gabon DHS (2019-2021), Gambia DHS (2019-2020), Ghana DHS (2022), Guinea DHS (2021), Kenya DHS (2022), Liberia MIS (2022), Madagascar DHS (2021), Mali MIS (2021), Mauritania DHS (2019-2021), Niger MIS (2021), Nigeria MIS (2021), Rwanda DHS (2019-2020), Senegal MIS (2023), Sierra Leone DHS (2019), Tanzania TDHS-MIS (2022), Uganda MIS (2018-2019)

4. RESEARCH QUESTIONS AND METHODOLOGIES

Burke (2003) attempted to capture environmental issues using the Environmental Kuznets Curve by recording the Energy Ladder with data from 134 countries from 1960 to 2010. Nevertheless, how can the Energy Ladder be reinforced? In Matsubara (2024), the influence of policies and culture was examined using empirical methods; however, this study attempts to quantify the degree of each influence using statistical methods. In Africa, some biomass and clean cooking fuels are used, but what factors determine the energy used for cooking stoves? Why is this factor believed to influence the choice of cookstove fuel?

Table 1: Data sets for analysis

Country	Clean Cooking Fuels	GDP per capita PPP 2023	Electricity access	Female Household head	Mean Size of Family (persons)	Improved Water
Burkina Faso 2021	12.40%	$2,726.94	19.50%	13.40%	6.20	82.00%
Cameroon 2022	24.80%	$5,380.16	61.70%	26.00%	4.90	82.50%
Cote D'Ivoire 2021	37.80%	$7,790.86	73.50%	19.40%	4.40	84.20%
Ethiopia 2019	5.40%	$3,109.28	31.00%	22.10%	4.70	67.30%
Gabon 2019-21	88.90%	$21,946.99	93.80%	31.90%	3.90	92.40%
Gambia 2019-20	2.40%	$3,162.51	62.10%	22.00%	8.10	94.10%
Ghana 2022	22.30%	$7,466.37	82.90%	36.60%	3.50	87.90%
Guinea 2021	0.20%	$4,429.34	54.00%	17.10%	6.40	79.50%
Kenya 2022	23.70%	$6,323.53	51.10%	33.90%	3.70	76.50%
Liberia 2022	0.50%	$1,819.05	30.80%	33.20%	5.00	85.10%
Madagascar 2021	1.30%	$1,875.11	32.00%	24.70%	4.30	45.80%
Mali 2021	0.40%	$2,725.96	29.90%	8.20%	9.50	81.00%
Mauritania 2019-2021	42.20%	$6,934.28	45.40%	39.00%	6.20	78.20%
Niger 2021	4.50%	$1,817.34	18.60%	12.80%	6.40	56.40%
Nigeria 2021	19.90%	$6,318.16	43.80%	14.90%	5.30	76.20%
Rwanda 2019-20	3.60%	$3,361.11	46.60%	31.90%	4.30	79.60%
Senegal 2023	33.60%	$4,833.03	74.20%	28.90%	8.40	89.80%
Sierra Leone 2019	0.50%	$1,846.68	21.60%	27.40%	5.30	65.90%
Tanzania 2022	6.50%	$3,972.61	32.20%	28.60%	4.50	70.30%
Uganda 2018-19	1.10%	$3,098.11	42.70%	28.30%	4.80	76.40%

Source: Burkina Faso DHS (2021), Cameroon MIS (2022), Cote D'Ivoire DHS (2021), Ethiopia DHS (2019), Gabon DHS (2019-2021), Gambia DHS (2019-2020), Ghana DHS (2022), Guinea DHS (2021), Kenya DHS (2022), Liberia MIS (2022), Madagascar DHS (2021), Mali MIS (2021), Mauritania DHS (2019-2021), Niger MIS (2021), Nigeria MIS (2021), Rwanda DHS (2019-2020), Senegal MIS (2023), Sierra Leone DHS (2019), Tanzania TDHS-MIS (2022), Uganda MIS (2018-19), The World Bank

Table 2: Correlation analysis

	Clean Cooking Fuels	GDP per capita PPP 2023	Electricity access	Female Household head	Mean Size of Family	Improved Water
Clean Cooking Fuels	1					
GDP per capita PPP 2023	0.931773558	1				
Electricity access	0.713415125	0.738145611	1			
Female Household head	0.348076012	0.304738718	0.395711588	1		
Mean Size of Family	-0.231622011	-0.321574484	-0.177221338	-0.52294395	1	
Improved Water	0.441476697	0.449754784	0.666988511	0.203081672	0.208391799	1

The study employs a mixed-methods approach, combining quantitative and qualitative analysis, to investigate the determinants of clean cooking fuel adoption in African countries, examining the validity and limitations of the Energy Ladder theory. Data were collected for 20 African countries using publicly available statistics, including GDP per capita (PPP), electricity access rates, and household sociodemographic variables. Quantitative analysis was conducted using multiple linear regression to assess the correlation and predictive power of these variables on the ratio of clean cooking fuel usage. In addition, Crisp-Set Qualitative Comparative Analysis (cs-QCA) was employed to qualitatively identify combinations of conditions associated with high usage of clean cooking fuels. The cs-QCA enabled the identification of potential causal pathways that cannot be captured through regression analysis alone.

The study draws on recent data available from the Demographic and Health Survey website, focusing on data updated after 2019 to reflect the current situation as accurately as possible. Sampling was limited to 20 African nations to ensure data quality and consistency across key variables. Following the regression and cs-QCA, both statistical significance and practical implications were evaluated. The chosen methods provide a robust framework for evaluating not only the effect of GDP per capita (PPP) as postulated by the Energy Ladder theory, but also the influence of other variables such as electricity access, female-headed households, mean family size, and access to improved water sources.

Several assumptions were made, such as (1) a higher electricity utilization ratio is likely to enhance the overall utilization ratio of electric cookstoves, (2) a higher "female household head" is likely to increase the ratio of clean cooking solutions because women are more likely to appreciate better cooking system, and (3) a large family members is likely to put a higher priority for a better cooking system, which all do not have meaningful impact more than the GDP per capita (PPP). In Matsubara (2024), the influence of policies was examined using empirical methods; however, this study attempts to quantify the degree of each influence using mathematical statistical methods.

4.1. Regression Analysis

Multiple linear regression analysis was applied to determine the extent to which various socioeconomic factors can predict the ratio of households using clean cooking systems in 20 African countries.

The regression analysis was performed using Microsoft Excel. The fitted model can be expressed as follows: Ratio of clean cooking system = −0.2046 + (GDP per capita PPP 2023 × 0.000047) + (Electricity access × 0.032) + (Female household head × 0.389)

+ (Mean size of family × 0.024) + (Improved water × −0.139). In addition to regression analysis, the study employed cs-QCA to investigate how various combinations of socioeconomic and infrastructural conditions influence the high adoption of clean cooking fuels across African countries.

4.2. cs-QCA Analysis

The cs-QCA is a comparative analytical technique that allows for the identification of multiple causal pathways leading to an outcome. In this study, countries were coded as “1” (presence) or “0” (absence) for each condition and outcome based on the threshold criteria established for each variable: GDP per capita (PPP), access to electricity, share of female-headed households, family size, and access to improved water. The outcome (high share of clean cooking technology use) was also coded as “1” for countries above the sample median and “0” for those below.

The cs-QCA was conducted by constructing a truth table that lists all logically possible combinations of the five conditions and their observed outcomes. This table was used to identify configurations as unique sets of conditions are consistently associated with high levels of clean cooking fuel use. Through logical minimization, necessary and sufficient conditions, as well as alternative causal pathways, were identified. This method enables the consideration of complex, combinatorial causality that cannot be fully captured by regression analysis, thereby providing additional insights into how different factors may interact in promoting clean energy adoption.

The cs-QCA analysis is conducted by including female household head, mean family size, improved water and electric cookstoves, GDP per capita (PPP), and electricity access. The data on GDP per capita (PPP) is from the World Bank. Except for the data on GDP per capita (PPP), all information is from the DHS report. Table 3 below shows the data set table for analysis. The cs-QCA model (Table 3) is configured with the following thresholds for each respective category. The 13% or more for clean cooking fuel usage, US$4,500 or more for GDP per capita (PPP) in 2023, 43% or more for electricity access, 25% or more for female household heads, and a mean family size of five or more people. Table 4 indicates that less than the thresholds input “0” and more than the thresholds input “1.” When all four columns are aligned with either “1” or “0”, no combination that results in more than six countries can be found in the dataset.

Unlike the regression analysis, the cs-QCA analysis (Table 5) found that the female household head corresponds with the ratio of clean cooking fuels in countries such as Cameroon, Gabon, Ghana, Kenya, Mauritania, and Senegal. Except for Kenya, they are all in West and Central African countries. Gabon stood out in terms of the usage ratio of clean cooking fuels and GDP per capita (PPP). The data also indicated that Gabon has a high electricity access ratio. The mean size of the family and access to improved water did not influence the ratio of clean cooking fuels in selected African countries.

Another cs-QCA analysis (Table 6) indicated that lower electricity access and lower improved water lead to countries with lower levels of usage of clean cooking fuels, such as Ethiopia, Madagascar, Niger, Sierra Leone, Tanzania, and Uganda. Except for Niger and Sierra Leone, they are all in East African countries. The cs-QCA analysis also indicated a lower GDP per capita (PPP). The female household head and the mean family size did not influence the access ratio of clean cooking fuels in the selected African countries.

5. FINDINGS AND DISCUSSION

The multiple regression analysis showed that GDP per capita (PPP) was the most significant predictor of the adoption ratio of clean cooking technology among the selected African countries

Table 3: Regression statistics

Regression Statistics								
Multiple R	0.942901965							
R Square	0.889064116							
Adjusted R Square	0.849444157							
Standard Error	0.084769148							
Observations	20							
ANOVA								
	df	**SS**	**MS**	**F**	**Significance F**			
Regression	5	0.806240681	0.161248136	22.4398042	0.000003159			
Residual	14	0.100601319	0.007185809					
Total	19	0.906842						
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**	**Lower 95.0%**	**Upper 95.0%**
Intercept	-0.204649036	0.160939751	-1.271587871	0.224238752	-0.549830472	0.1405324	-0.549830472	0.1405324
GDP per capita PPP 2023	0.000046947	0.000006887	6.816998361	0.000008365	0.000032177	0.000061718	0.000032177	0.000061718
Electricity access	0.031666774	0.166284521	0.190437292	0.851700308	-0.324978054	0.388311602	-0.324978054	0.388311602
Female Household head	0.388951554	0.293530686	1.325079705	0.206365365	-0.240609153	1.018512261	-0.240609153	1.018512261
Mean Size of Family	0.023570499	0.016695335	1.411801513	0.179847255	-0.012237433	0.059378431	-0.012237433	0.059378431
Improved Water	-0.13923973	0.250445349	-0.555968521	0.587008524	-0.67639158	0.39791212	-0.67639158	0.39791212

Table 4: cs-QCA data sets

Country	Clean Cooking Fuels	13% or more	GDP per capita PPP 2023	US$4.5k or more	Electricity access	43% or more	Female Household head	25% or more	Mean Size of Family (persons)	5 people or more	Improved Water	80% or more
Burkina Faso 2021	12.40%	0	$2,726.94	0	19.50%	0	13.40%	0	6.20	1	82.00%	1
Cameroon 2022	24.80%	1	$5,380.16	1	61.70%	1	26.00%	1	4.90	0	82.50%	1
Cote D'Ivoire 2021	37.80%	1	$7,790.86	1	73.50%	1	19.40%	0	4.40	0	84.20%	1
Ethiopia 2019	5.40%	0	$3,109.28	0	31.00%	0	22.10%	0	4.70	0	67.30%	0
Gabon 2019-21	88.90%	1	$21,946.99	1	93.80%	1	31.90%	1	3.90	0	92.40%	1
Gambia 2019-20	2.40%	0	$3,162.51	0	62.10%	1	22.00%	0	8.10	1	94.10%	1
Ghana 2022	22.30%	1	$7,466.37	1	82.90%	1	36.60%	1	3.50	0	87.90%	1
Guinea 2021	0.20%	0	$4,429.34	0	54.00%	1	17.10%	0	6.40	1	79.50%	0
Kenya 2022	23.70%	1	$6,323.53	1	51.10%	1	33.90%	1	3.70	0	76.50%	0
Liberia 2022	0.50%	0	$1,819.05	0	30.80%	0	33.20%	1	5.00	1	85.10%	1
Madagascar 2021	1.30%	0	$1,875.11	0	32.00%	0	24.70%	0	4.30	0	45.80%	0
Mali 2021	0.40%	0	$2,725.96	0	29.90%	0	8.20%	0	9.50	1	81.00%	1
Mauritania 2019-2021	42.20%	1	$6,934.28	1	45.40%	1	39.00%	1	6.20	1	78.20%	0
Niger 2021	4.50%	0	$1,817.34	0	18.60%	0	12.80%	0	6.40	1	56.40%	0
Nigeria 2021	19.90%	1	$6,318.16	1	43.80%	1	14.90%	0	5.30	1	76.20%	0
Rwanda 2019-20	3.60%	0	$3,361.11	0	46.60%	1	31.90%	1	4.30	0	79.60%	0
Senegal 2023	33.60%	1	$4,833.03	1	74.20%	1	28.90%	1	8.40	1	89.80%	1
Sierra Leone 2019	0.50%	0	$1,846.68	0	21.60%	0	27.40%	1	5.30	1	65.90%	0
Tanzania 2022	6.50%	0	$3,972.61	0	32.20%	0	28.60%	1	4.50	0	70.30%	0
Uganda 2018-19	1.10%	0	$3,098.11	0	42.70%	0	28.30%	1	4.80	0	76.40%	0

Source: Burkina Faso DHS (2021), Cameroon MIS (2022), Cote D'Ivoire DHS (2021), Ethiopia DHS (2019), Gabon DHS (2019-2021), Gambia DHS (2019-2020), Ghana DHS (2022), Guinea DHS (2021), Kenya DHS (2022), Liberia MIS (2022), Madagascar DHS (2021), Mali MIS (2021), Mauritania DHS (2019-2021), Niger MIS (2021), Nigeria MIS (2021), Rwanda DHS (2019-2020), Senegal MIS (2023), Sierra Leone DHS (2019), Tanzania TDHS-MIS (2022), Uganda MIS (2018-19), The World Bank

Table 5: cs-QCA analysis (Choice "1")

Country	Clean Cooking Fuels	13% or more	GDP per capita PPP 2023	US$4.5k or more	Electricity access	43% or more	Female Household head	25% or more	Mean Size of Family (persons)	5 people or more	Improved Water	80% or more
Cameroon 2022	24.80%	1	$5,380.16	1	61.70%	1	26.00%	1	4.90	0	82.50%	1
Gabon 2019-21	88.90%	1	$21,946.99	1	93.80%	1	31.90%	1	3.90	0	92.40%	1
Ghana 2022	22.30%	1	$7,466.37	1	82.90%	1	36.60%	1	3.50	0	87.90%	1
Kenya 2022	23.70%	1	$6,323.53	1	51.10%	1	33.90%	1	3.70	0	76.50%	0
Mauritania 2019-2021	42.20%	1	$6,934.28	1	45.40%	1	39.00%	1	6.20	1	78.20%	0
Senegal 2023	33.60%	1	$4,833.03	1	74.20%	1	28.90%	1	8.40	1	89.80%	1

Source: Table 4

Table 6: cs-QCA analysis (Choice "0")

Country	Clean Cooking Fuels	13% or more	GDP per capita PPP 2023	US$4.5k or more	Electricity access	43% or more	Female Household head	25% or more	Mean Size of Family (persons)	5 people or more	Improved Water	80% or more
Ethiopia 2019	5.40%	0	$3,109.28	0	31.00%	0	22.10%	0	4.70	0	67.30%	0
Madagascar 2021	1.30%	0	$1,875.11	0	32.00%	0	24.70%	0	4.30	0	45.80%	0
Niger 2021	4.50%	0	$1,817.34	0	18.60%	0	12.80%	0	6.40	1	56.40%	0
Sierra Leone 2019	0.50%	0	$1,846.68	0	21.60%	0	27.40%	1	5.30	1	65.90%	0
Tanzania 2022	6.50%	0	$3,972.61	0	32.20%	0	28.60%	1	4.50	0	70.30%	0
Uganda 2018-19	1.10%	0	$3,098.11	0	42.70%	0	28.30%	1	4.80	0	76.40%	0

Source: Table 4

($\beta = 0.78$, $P < 0.001$). This supports the central hypothesis of the Energy Ladder theory. Other factors, such as the electrification rate, proportion of female-headed households, and access to improved water sources, had a minimal or statistically insignificant influence on the outcome. The model's overall fit was statistically significant ($R^2 = 0.889$,\$F(5,14) = 22.44$,\$P < 0.000$), indicating that approximately 89% of the variance in the ratio of clean cooking systems could be explained by these variables. Among the predictors, GDP per capita (PPP) showed the strongest correlation with clean fuel adoption, consistent with the Energy Ladder theory. In contrast, electricity access, female household head, mean family size, and improved water had comparatively weaker or statistically insignificant impacts. The regression provides a quantifiable assessment of the relative influence of each factor, supplementing previous qualitative findings (Matsubara, 2024). The results support the claim that economic development remains the most critical driver of clean cooking fuel adoption in African countries, even when other social variables are considered.

The cs-QCA results (Table 4) identified two conditions associated with a high share of clean cooking fuel usage: (1) high GDP per capita (PPP) combined with a high electrification rate, and (2) high GDP per capita (PPP) combined with a high proportion of female-headed households. Every country that exhibited a high share of clean cooking fuel usage had a high GDP per capita (PPP), which was a necessary condition, confirming the central role of economic development in achieving this goal. Another cs-QCA results (Table 5) identified two conditions associated with a low share of clean cooking fuel usage: low GDP per capita (PPP) combined with a low electrification rate, and (2) low GDP per capita (PPP) combined with a low rate of access to clean water.

These results suggest that while economic factors remain the primary driver, other social and infrastructural factors can play a complementary role under specific conditions (high rates for access to electricity and female-headed households), especially for the positive side of usage rate in West and Central African countries, and the opposing side in East African countries (low rates for access to improved water and electricity). Overall, the findings demonstrate that the Energy Ladder theory largely explains current patterns of clean energy use in African countries, while also suggesting circumstances in which combinations of social variables play a supporting role.

6. CONCLUSION

The multiple regression analysis showed that GDP per capita (PPP) was the most significant predictor of the adoption ratio of clean cooking technology among the selected African countries ($\beta = 0.78$, $P < 0.001$). This supports the central hypothesis of the Energy Ladder theory. However, other factors, such as the electrification rate, proportion of female-headed households, and access to improved water sources, had a minimal or statistically insignificant influence on the outcome.

The results of the crisp-set Qualitative Comparative Analysis (cs-QCA) conducted in this study revealed that countries with a higher proportion of female-headed households and greater access to electricity tend to have particularly high rates of clean cooking fuel usage. Notably, five of the six such countries are located in West and Central Africa. In contrast, countries with limited access to safe water and electricity tend to exhibit lower adoption rates of clean cooking fuels; four of these countries are located in East Africa and also have relatively low GDP per capita (PPP). These findings suggest that while the energy ladder theory largely explains patterns of clean energy use in African countries, specific social and infrastructural factors also play a supplementary role in influencing the adoption of clean cooking fuels.

By combining regression analysis and cs-QCA, the study was able to examine the influence of not only GDP per capita (PPP) as a variable emphasized by the energy ladder theory, but also access to electricity, the proportion of female-headed households, average household size, and access to safe water. However, several limitations should be acknowledged. First, the data tables created by the author in this paper utilize data from years newer than 2019, as more recent data is available. In contrast, the information on GDP per capita (PPP) for each country is for the year 2023. The timing difference might influence the analysis. Second, other social and infrastructural factors should also be considered, such as a woman's education level, as previous studies suggested, and whether a nation is an oil and gas-producing country, which may influence the hydrocarbon utilization rate, including LPG and natural gas. Third, although data availability poses challenges, future studies should consider the panel data approach. Lastly, owing to the author's limited language skills, it was not possible to fully utilize data available only in French and Portuguese for some African countries.

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