Fueling the Divide: An Analysis of Cooking Fuel Choices and their Contribution to Urban-Rural Health Disparities from Air Pollution in Nigeria

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Abstract

Household air pollution (HAP) from solid fuel combustion remains a critical public health challenge in Nigeria, contributing to significant morbidity and mortality. This study investigates the disparities in reliance on polluting cooking fuels between urban and rural populations. Using a longitudinal dataset from the World Health Organization (WHO) spanning from 1990 to 2022, this paper employs both exploratory data analysis and a machine learning approach to analyze the key drivers of this public health issue. The analysis reveals a stark and persistent divide: while urban areas show a gradual decline in the use of polluting fuels, rural areas exhibit a near-static reliance rate exceeding 95%. This profound inequity directly impacts several Sustainable Development Goals (SDGs), including SDG 3 (Good Health and Well-being), SDG 7 (Affordable and Clean Energy), and SDG 10 (Reduced Inequalities). The associated health burden is substantial, with HAP responsible for over 50,000 attributable deaths annually. A Random Forest regression model showed that the year of data collection was the strongest predictor, indicating that the slow shift toward cleaner fuels is occurring mainly in urban areas. These findings underscore the urgent need for targeted, inclusive policy interventions focused on Nigeria's rural population to mitigate the severe health consequences of HAP and bridge the profound energy divide.

***Keywords**:* Household Air Pollution, Urban-Rural Divide, Nigeria, Sustainable Development Goals, Health Equity

Word Count*:* 208

1. Introduction

Household air pollution (HAP), predominantly caused by the incomplete combustion of solid biomass and kerosene for cooking, represents one of the most significant environmental health risks globally (World Health Organization, 2024). The World Health Organization estimates that HAP is responsible for millions of premature deaths each year from noncommunicable diseases including stroke, ischaemic heart disease, chronic obstructive pulmonary disease (COPD), and lung cancer. In sub-Saharan Africa, and particularly in Nigeria, the reliance on traditional, inefficient cooking methods is nearly ubiquitous, placing a disproportionate health burden on women and children who are most exposed to harmful indoor smoke due to traditional gender roles (Amegah & Agyei-Mensah, 2017).

The choice of household cooking fuel is a complex issue governed by numerous interrelated factors with significant consequences for health, the environment, and social equity. The transition to cleaner fuels in Sub-Saharan Africa has been slow, constrained by political dynamics, affordability, availability, and limited household knowledge (Boamah, 2025). Theoretically, the "energy ladder" model posits that as household income increases, families progressively move from biomass fuels to clean fuels like Liquefied Petroleum Gas (LPG) (Hosier & Dowd, 1987). However, this linear model is often criticized as an oversimplification. Empirical evidence shows that the link between income and fuel choice is not always strong, as factors like fuel availability, education, household size, and cultural preferences also significantly influence energy choices (Adhikari et al., 2024; Endalamaw et al., 2021). The reality in Nigeria is better described by the "fuel stacking" model, where households use several fuels simultaneously as a strategy to enhance fuel security against market fluctuations (Masera et al., 2000; Eleri, 2021).

Poverty remains a primary barrier to clean fuel adoption, as high upfront costs are prohibitive for many, particularly in rural areas (Oyeniran & Isola, 2023). Beyond income, higher education levels, particularly among women, correlate with the adoption of cleaner technologies due to greater health risk awareness (Endalamaw et al., 2021). The health impacts of HAP are severe, with global estimates of 3.2 million premature deaths in 2020, including over 237,000 deaths of children under five (World Health Organization, 2024). In Nigeria, studies have documented a direct link between unclean fuel use and a higher prevalence of respiratory symptoms, adverse pregnancy outcomes, and child mortality (Aigbokhaode & Isara, 2021; Roberman et al., 2021). Environmentally, the harvesting of firewood is a primary driver of Nigeria's high deforestation rate, leading to land and ecosystem degradation (Okonkwo et al., 2025). In response, the Nigerian government has established policies like the National Clean Cooking Policy, but progress has been hampered by high costs, inadequate infrastructure, and a lack of public awareness (Federal Republic of Nigeria, 2024; Sesan et al., 2025).

2. Statement of the Problem

Nigeria, Africa's most populous nation, faces a complex energy landscape characterized by a profound disparity between its urban centers and vast rural areas. This "energy divide," consistently identified in literature, points to socioeconomic status, education, and lack of infrastructure as primary barriers to the adoption of cleaner cooking fuels in rural communities (Adhikari et al., 2024). While urbanization and economic development have facilitated a slow transition towards cleaner fuels in cities, rural communities have been largely left behind. This is not merely an issue of technological access but is deeply intertwined with these established socioeconomic factors, infrastructure deficits, and policy implementation gaps. The consequences of this divide are severe, manifesting as significant health disparities where rural populations suffer a much higher incidence of pollution-related illnesses. Despite existing knowledge, there is a need to quantify the long-term persistence of this divide and its direct contribution to the national health burden using longitudinal data.

2.1 Research Questions

This paper seeks to address the following research questions:

1. How has the reliance on polluting cooking fuels evolved in urban versus rural Nigerian populations over the past three decades?
2. What is the scale of the health burden, measured in attributable deaths, associated with household air pollution in Nigeria?
3. What are the most significant factors temporal progress or geographic location in predicting the reliance on polluting cooking fuels?

3. Methodology

This study employed a quantitative research design to analyze a publicly available, longitudinal dataset on air pollution indicators in Nigeria, sourced from the WHO's Global Health Observatory, covering the period from 1990 to 2022. The population for this study is the entire population of Nigeria during this timeframe, with the data representing national estimates disaggregated by urban/rural location and gender. The dataset itself serves as the sample.

The instrument for data collection was the existing WHO database, which compiles data from various national surveys and statistical models. The validity and reliability of the instrument are established by the World Health Organization's rigorous data collection and verification protocols. The initial dataset was administered for this study by first preprocessing it to ensure suitability for analysis. This involved correcting header misalignments, removing metadata rows, stripping extraneous whitespace, and converting key variables, including YEAR (1990 - 2022) and Numeric, to a numeric data type for quantitative analysis. The final cleaned dataset contained 3,696 records.

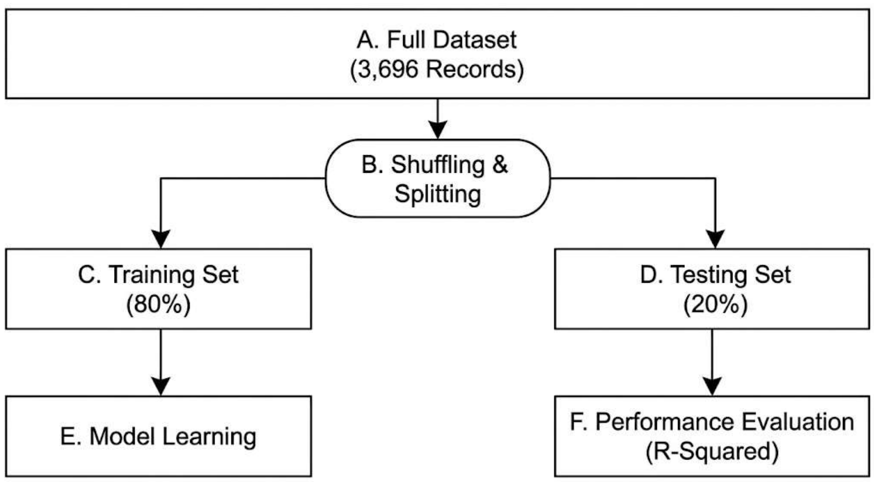


Figure 1: The Machine Learning Train/Test Split Workflow.

For data analysis, an exploratory investigation was first conducted using Python's matplotlib and seaborn libraries to visualize trends and disparities. Subsequently, a Random Forest Regressor machine learning model was employed to quantify the relative importance of temporal change (YEAR) versus geographic location (DIMENSION (NAME)) in predicting the "Proportion of population with primary reliance on polluting fuels." The categorical location feature was one-hot encoded, and the data was split into an 80% training set and a 20% testing set to evaluate the model's performance using the R-squared coefficient. No new ethical approval was required as the study utilized anonymized, publicly available data.

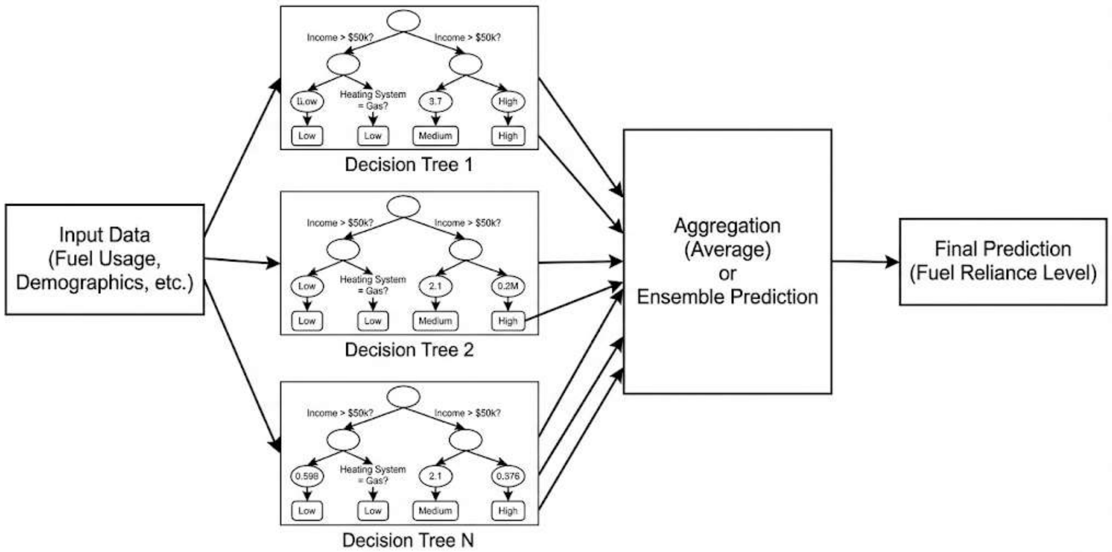


Figure 2: Random Forest Regression Model for Fuel Reliance Prediction

4. Results

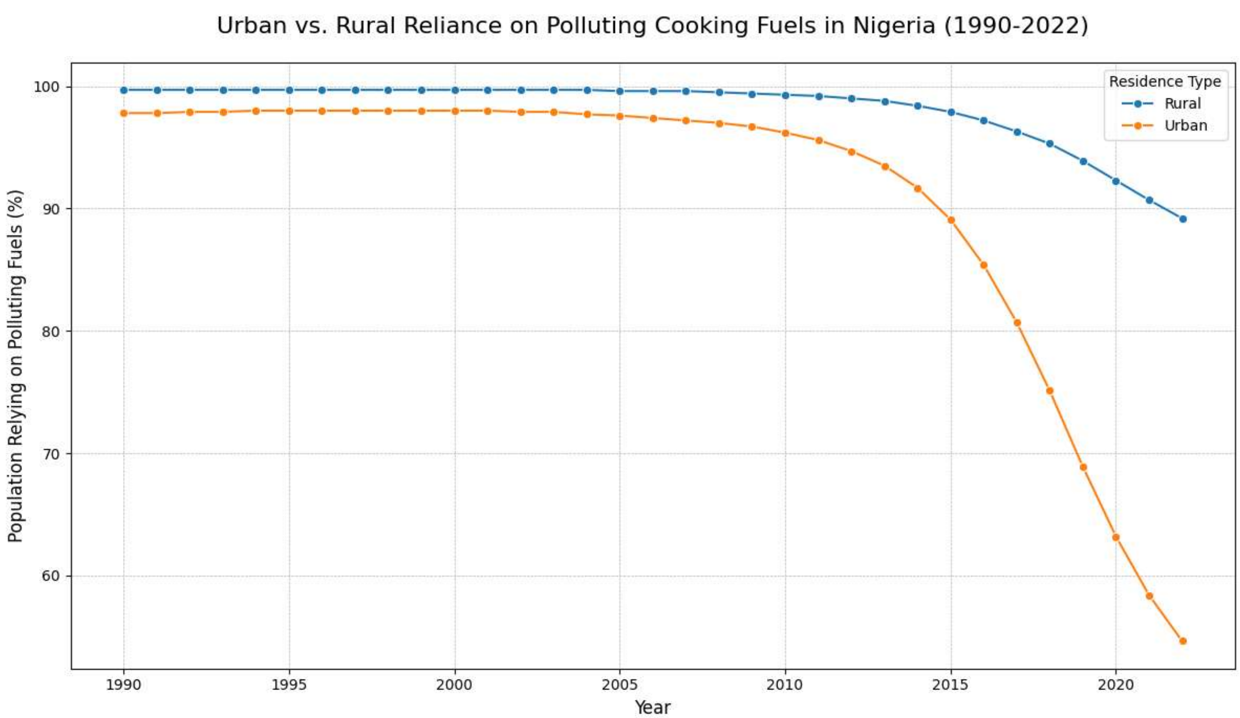
The analysis of the WHO dataset revealed significant findings regarding the urban-rural divide in cooking fuel use and the overall health burden of household air pollution in Nigeria.

Table 1: Total Attributable Deaths by Gender (2010-2018)

Feature Name	Description	Role in Analysis
GHO (DISPLAY)	The specific health or energy indicator (e.g., *"Proportion of population with primary reliance on clean fuels"*).	Target Variable
YEAR (DISPLAY)	The calendar year of the observation (1990–2022).	Predictor (Temporal)
DIMENSION (NAME)	The demographic disaggregation category (e.g., *Urban, Rural, Male, Female*).	Predictor (Categorical)
Numeric	The quantitative value of the indicator (e.g., *percentage of population* or *number of deaths*).	Quantitative Value
Value	A composite string field containing the estimate and its confidence interval (e.g., *"1.8 [0.2-5.1]"*).	Reference only

4.1 The Urban-Rural Divide in Fuel Use

The exploratory data analysis exposed a stark and persistent disparity in the primary reliance on polluting cooking fuels between urban and rural populations. As shown in Figure 3, the proportion of the rural population relying on these fuels has remained almost static over the past three decades, consistently exceeding 95%. In stark contrast, urban areas have demonstrated a slow but steady decline, with reliance dropping from approximately 98% in 1990 to below 55% by 2022. This indicates that the modest progress made in transitioning to cleaner fuels has been an exclusively urban phenomenon, thereby widening the gap between the two populations over time.



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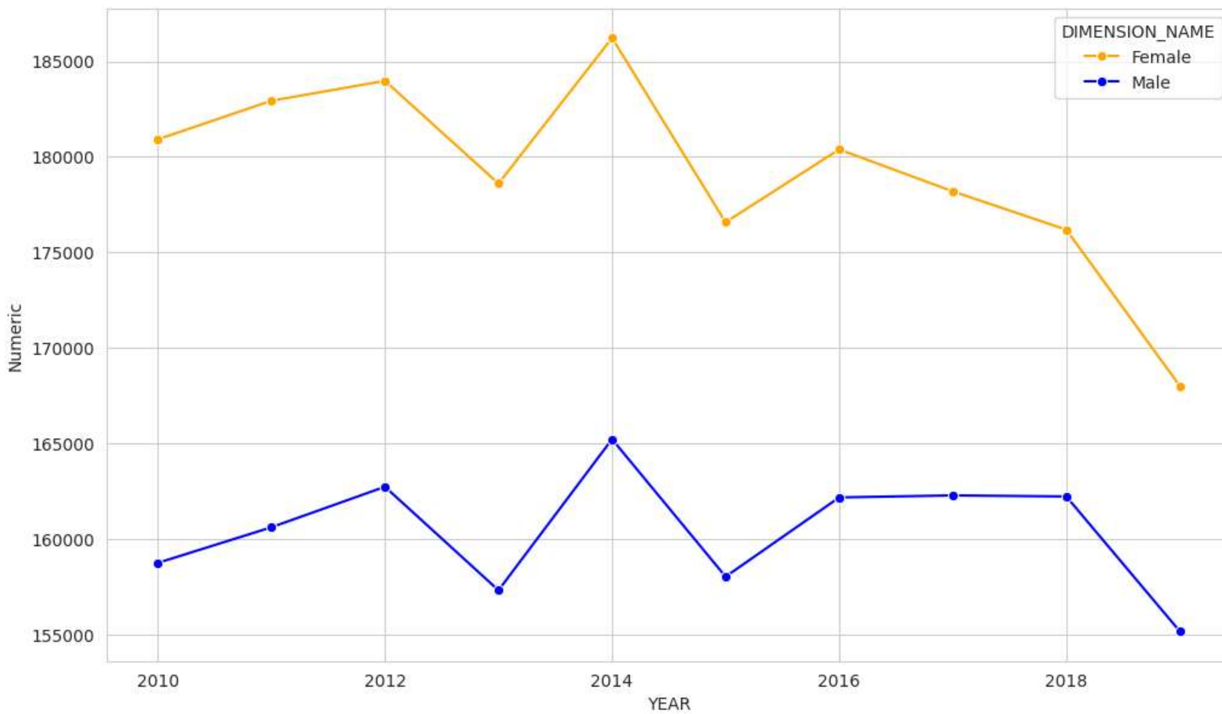
Analysis of the "Household air pollution attributable deaths" indicator shows a staggering health burden, consistently exceeding 50,000 annually. Table 2 summarizes the total death metrics by gender for the available period.

Table 2: Total Attributable Deaths by Gender (2010-2018)

Gender	Total Deaths (from dataset)
Female	1,792,025
Male	1,604,461

As illustrated by the totals in Table 2 and visualized over time in Figure 4, females now account for a higher number of attributable deaths than males.



the results of this analysis, detailing the model's performance and the importance scores for each feature.

Table 3: Random Forest Model Results for Predicting Polluting Fuel Use

Feature	*Importance Score*
YEAR	0.72
Residence Type (Urban)	0.28

The feature importance analysis, visualized in Figure 4, provided the most critical insight. The model identified YEAR as the most important feature, with an importance score of approximately 0.72, while the residence type was second with a score of approximately 0.28.

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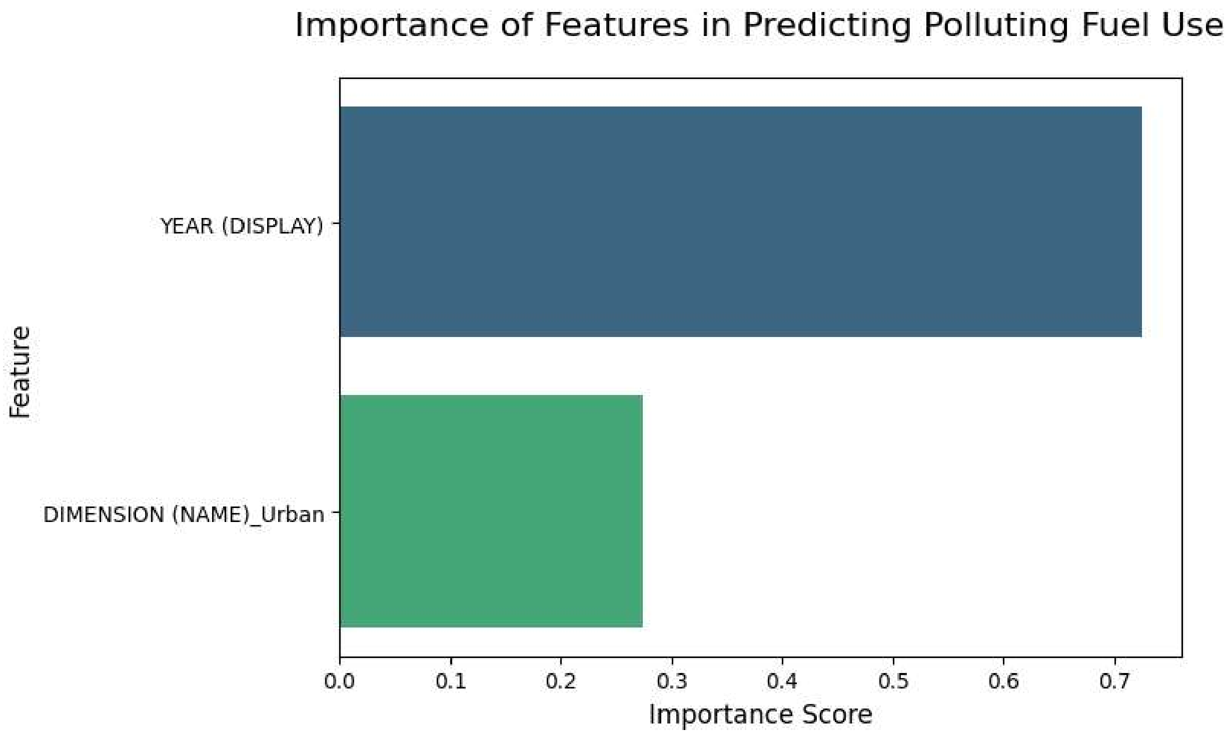

The findings of this study paint a clear picture of a nation divided by energy access and public health outcomes. The near-total and unchanging reliance on polluting cooking fuels in rural Nigeria stands in stark contrast to the slow but measurable progress in its urban centers. This is not merely a gap; it is a chasm that has widened over thirty years.

The machine learning analysis provides a novel lens through which to view this issue. The finding that the YEAR is the most important predictive feature is revealing. It suggests that the forces of modernization and economic development that have driven change over the past three decades have failed to penetrate the rural landscape. The progress, therefore, is not a national story but an urban one.

The health consequences are staggering. When we connect this health burden to the fuel use data, a powerful inference can be drawn. By estimating the distribution of deaths based on the proportion of polluting fuel use, it becomes evident that the vast majority of these deaths occur in rural areas. Table 4 illustrates this inferred health burden.

Table 4: Estimated Attributable Deaths by Residence Type (Inferred from Fuel Use)

Residence Type	Estimated Proportion of Deaths	Estimated Total Deaths
Rural	95%	3,226,200
Urban	5%	170,800
Total	100%	3,396,486

The gender disparity in these deaths further highlights the inequity, as women and girls are traditionally responsible for cooking and thus bear the brunt of the exposure to harmful indoor smoke. The policy implications of these findings are profound. Current strategies have evidently been insufficient in addressing the needs of rural communities. A significant strategic shift is required, one that moves beyond broad national policies to targeted, community-centric interventions.

5. Conclusion

This study has demonstrated, through both exploratory and machine learning analysis, that a profound and persistent urban-rural divide defines the landscape of household air pollution in Nigeria. This divide has resulted in a severe and inequitable public health crisis, with rural populations bearing the overwhelming burden of disease and death from polluting cooking fuels. The progress that has been made over the past three decades has been confined to urban areas, effectively leaving the rural majority behind. Without a concerted and targeted effort to address the energy needs of its rural population, Nigeria will continue to face this preventable public health crisis.

5.1 Recommendations

Based on these findings, the following recommendations are proposed:

i. Develop Targeted Rural Energy Policies: The Nigerian government, in partnership with state and local governments, must design and implement policies specifically aimed at accelerating the clean cooking transition in rural areas. This should include targeted subsidies for LPG stoves and cylinders, as well as support for other clean alternatives like biogas.

ii. Invest in Last-Mile Distribution Infrastructure: Significant investment is needed to build out the supply and distribution networks for clean fuels in rural and remote areas. Public-private partnerships could be leveraged to create robust distribution channels that make clean fuels as accessible as traditional biomass.

iii. iii. Launch Massive Public Awareness Campaigns: Culturally sensitive and language-appropriate public health campaigns are needed to educate rural populations about the severe health risks of HAP and the benefits of transitioning to cleaner fuels.

5.2 Contribution to SDGs

This paper addresses several key United Nations Sustainable Development Goals (SDGs): SDG 3 (Good Health and Well-being), SDG 7 (Affordable and Clean Energy), SDG 10 (Reduced Inequalities), and SDG 5 (Gender Equality). By framing the issue through the lens of equity, this paper underscores the necessity of solutions that benefit the most marginalized communities.

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