Report

Nigeria's fossil fuel subsidy reforms: the welfare effects on households

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Abstract

Understanding the distributional consequences of progressive fossil fuel subsidy reform is critical to the sustainability of reform efforts as well as progress towards more just and inclusive energy transitions. This study examines the welfare effects of fossil fuel subsidy reforms on Nigerian households, focusing on the socio-economic implications of petrol price changes caused by the removal of subsidies. Using the Quadratic Almost Ideal Demand System (QUAIDS) model, the research explores household energy consumption patterns, estimating budget, own-price, and cross-price elasticities for petrol. The study critically evaluates the welfare impacts of petrol price increases and assesses the effectiveness of government redistribution policies targeting economically vulnerable households. It considers the immediate, direct impact of price changes on household budgets (first-order effects) and adjustments households can make (second-order effects), including substitution between goods. By analysing both these effects, the research provides a holistic view of the dynamic interaction between subsidy removal and household welfare, highlighting the varied impacts across different income groups and residential settings. The study finds that the increase in petrol prices following subsidy removal disproportionately affects lower-income households. This is because the average Nigerian household has become dependent on petrol and shows an inelastic response to changes in its price. This means a petrol price hike would not significantly deter petrol consumption but would strain household budgets in the absence of available, accessible, or suitable alternatives to petrol. There is a significant variation in welfare impacts across different household income quintiles and locations, with rural and lower-income households experiencing higher welfare losses. The analysis demonstrates that targeted lump-sum transfers, particularly to bottom 40%, lower bound, and upper bound poverty line households, effectively counteract some of the welfare losses, indicating the progressive nature of these policies. The findings highlight the necessity of carefully designed redistribution policies to mitigate the adverse effects of subsidy reforms, ensuring that lower-income and rural households are adequately supported. Such policies need to consider disparate welfare impacts together with progress on the effectiveness of redistributive, revenue recycling, or palliative policies.

Key messages

- Impact of petrol price changes: the study finds that the increase in petrol prices following subsidy removal is regressive, disproportionately affecting lower-income households.
- Disparate welfare impacts: there is a significant variation in welfare impacts across different household income quintiles and locations, with rural and lower-income households experiencing higher welfare losses.
- Effectiveness of redistribution policies: the analysis demonstrates that targeted lump-sum transfers, particularly to bottom 40%, lower bound, and upper bound poverty line households, effectively counteract some of the welfare losses, indicating the progressive nature of these policies.
- Policy implications: the findings highlight the need of carefully designed redistribution policies to mitigate the adverse effects of subsidy reforms, ensuring that lower-income and rural households are adequately supported.

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Acronyms

AIDS	Almost Ideal Demand System
Bottom-40	bottom forty percent of household income
CO_2	carbon dioxide emissions
CV	compensating variation
GHS	Nigerian General Household Survey
LBPL	lower Bound Poverty Line
LSMS	Living Standards Measurement Study of the World Bank
NBS	National Bureau of Statistics
NDC	Nationally Determined Contribution
NGN	Nigerian Naira
NNPCL	Nigerian National Petroleum Corporation Limited
PMS	premium motor spirit
QUAIDS	Quadratic Almost Ideal Demand System
UBLP	upper Bound Poverty Line
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar

Executive summary

The urgent need to combat climate change calls for a global shift towards decarbonisation, primarily through reducing fossil fuel consumption and encouraging renewable energy adoption. This transition, critical for achieving low-emission societies, aligns with the Paris Agreement's goal to limit temperature increases to below 2 degrees Celsius, requiring that a significant portion of fossil fuel reserves remain untapped and carbon dioxide (CO_2) emissions reach net zero by 2050. The removal of fossil fuel subsidies is a key strategy in this process and is expected to lead to significantly lower CO_2 emissions. However, the implementation of fuel pricing policies is complex, often driven by economic rather than environmental considerations, and has profound social and economic implications. In developing countries, higher fuel prices can severely affect livelihoods by increasing the cost of basic necessities. In oil-producing nations, subsidy removal has led to public unrest, as seen in Nigeria's Occupy protests in 2012, demonstrating the challenges of balancing economic reforms with social stability.

The recent removal of fuel subsidies in Nigeria under new President Bola Ahmed Tinubu marks a significant policy shift, raising concerns about its impact on the socio-economic welfare of vulnerable households. Understanding the distributional consequences of progressive fossil fuel subsidy reforms is critical to the sustainability of the reforms as well as progress towards more just and inclusive energy transitions. This study focuses on understanding how fuel subsidy removal affects household welfare in Nigeria, aiming to inform policymakers and stakeholders about the socio-economic implications of such reforms. The objectives include analysing Nigerian households' energy consumption patterns, calculating the budget, own-price, and cross-price elasticities for petrol, assessing the welfare consequences of petrol price hikes, and evaluating the effectiveness of government redistribution policies aimed at aiding impoverished households. Through this comprehensive analysis, the research offers insights into the repercussions of subsidy reform on household welfare in the hope of contributing to more informed decision-making in post-subsidy Nigeria.

This study investigates the welfare implications of petrol price increases, focusing on whether these increases are regressive or progressive across different household income deciles. It employs a hypothetical scenario where energy prices double (a 100% increase) to understand consumer reactions and the impact on household welfare. The analysis aims to determine the regressive nature of petrol price hikes and examines the disparities in welfare losses between urban and rural households, providing deeper insight into the socioeconomic effects of fuel price adjustments. Additionally, the study evaluates the potential of revenue recycling as a policy measure to offset the negative impacts resulting from the removal of fossil fuel subsidies. Specifically, it explores the effectiveness of redistributing the revenues saved through lump-sum transfers to the poorest households, defined as those within the bottom 40% of the income distribution, and those living below the national poverty line thresholds. This approach aims to assess the capacity of such redistribution policies to alleviate the adverse effects on vulnerable populations, highlighting the importance of targeted support in mitigating the socioeconomic fallout of subsidy removal initiatives.

To empirically assess these impacts, the study employs the Quadratic Almost Ideal Demand System (QUAIDS) model. This approach is especially suited to analysing consumer demand and expenditure patterns, allowing for a nuanced dissection of household responses to price changes. The QUAIDS model is applied in a two-stage analytical framework. it is assumed that in the first stage a household allocates its income or expenditures to energy and non-energy commodities. In the second stage, the expenditures for energy are allocated to specific energy commodities, i.e., as petrol, electricity, kerosene, and other household energy goods like wood, charcoal, diesel, and other fuels. For the second stages, the QUAIDS is applied to gain detailed information on expenditure elasticities, own-price elasticities, and cross-price elasticities of the commodities.

The estimated elasticities are then used to measure the welfare impact of the petrol price changes. This study estimates the change in consumer welfare, measured as compensating variation (CV). The CV measures the total monetary transfer required to compensate (bring the consumer back to the original utility level) after the price change, as a percentage of their initial total expenditure.

The main source of information is the Nigerian General Household Survey (GHS) from the National Bureau of Statistics (NBS). The Nigeria GHS includes a panel survey component implemented in collaboration with the World Bank's Living Standards Measurement Study (LSMS) team. The GHS-Panel is a nationally representative survey, also representing the six geopolitical zones. This study uses the most recent three waves – 2012/13, 2015/16, and 2018/19 – combined into a single cross-sectional dataset. The focus of this study is residential petrol consumption expenditure, but it is necessary to explore the relationship between petrol and other residential energy commodities.

The study highlights several key insights regarding the demand for energy commodities in Nigeria. Notably, the study reveals that all energy commodities are 'normal goods' with positive budget elasticities, indicating demand increases with income in Nigeria. Petrol, electricity, and transport are necessities (elasticity < 1), while kerosene and other energy goods are considered luxuries (elasticity > 1), consistent across different income and location groups. Own-price elasticities show an inelastic response to petrol price changes, suggesting that increases in petrol prices do not significantly reduce demand, underlining petrol's essential role despite the economic strain on households, especially those with lower incomes. Cross-price elasticities indicate a modest shift towards other energy commodities as petrol prices rise, reflecting a search for substitutes. However, the limited magnitude of these elasticities points to the challenges of finding perfect substitutes due to availability, accessibility, and suitability constraints. This is particularly true in rural areas or for lower-income households where alternatives to petrol are less viable, highlighting the complexities in adjusting energy consumption patterns in response to price changes.

The welfare analysis of a 100% petrol price increase caused by subsidy removal reveals significant insights. The study finds that the increase in petrol prices following subsidy removal disproportionately affects lower-income households. This is because the average Nigerian household has become dependent on petrol and shows an inelastic response to changes in its price. This means a petrol price hike would not significantly deter petrol consumption but would strain household budgets in the absence of available, accessible, or suitable alternatives to petrol. There is a significant variation in welfare impacts across different household income quintiles and locations, with rural and lower-income households experiencing higher welfare losses.

The evaluation of revenue recycling via lump-sum transfers demonstrates that targeted lump-sum transfers, particularly to bottom 40%, lower bound, and upper bound poverty line households, effectively counteract some of the welfare losses, indicating the progressive nature of these policies. The findings highlight the necessity of carefully designed redistribution policies to mitigate the adverse effects of subsidy reforms, ensuring that lower-income and rural households are adequately supported. Such policies need to consider disparate welfare impacts together with progress on the effectiveness of redistributive, revenue recycling, or palliative (i.e. relief) policies.

For policymakers, these results highlight the importance of crafting equitable and sensitive strategies in response to economic reforms. The study advocates redistribution policies that balance fiscal objectives with social welfare considerations, ensuring that the economic burden of reforms is not disproportionately borne by the most vulnerable segments of society. Furthermore, appropriate policy targeting should consider variation within rural and urban areas and household demographics. This approach not only fosters a more equitable distribution of economic burdens and benefits but also enhances the public acceptability of such reforms.

1 Introduction

1.1 Background

The unprecedented challenge of climate change necessitates a global pivot towards rapid decarbonisation, which in turn demands a substantial reduction in fossil fuel consumption. Transitioning to low-emission societies involves leveraging policy measures to increase the cost of fossil fuels, thereby promoting a shift to renewable energy sources (Steffen et al., 2018). To meet the ambitious goals of the Paris Agreement, which aims to limit global temperature increases to well below 2 degrees Celsius (UNFCCC, 2015), a considerable portion of known fossil fuel reserves must remain unextracted, and global CO_2 emissions need to reach net zero by around 2050 (IEA, 2021; IPCC, 2021). The removal of fossil fuel subsidies is projected to play an important role in this endeavour, significantly reducing global CO_2 emissions and acting as a catalyst for decarbonisation (Coady et al., 2017; Otto et al., 2020).

However, economic considerations often drive government policies on fuel pricing, though their environmental implications – particularly in terms of influencing consumption patterns and emissions – are significant (Von Uexkull et al., 2024). Public reaction to price changes plays a crucial role in the success or failure of these policies, underscoring the need for a deeper understanding of societal responses to subsidy removal and price increases. The economic and social ramifications of rising fuel prices are profound; increase in fuel prices can adversely impact people's well-being and economic condition by increasing the costs associated with cooking, heating, lighting, and transportation, while also indirectly increasing costs for essential items, such as food – especially in developing countries (Arze del Granado et al., 2012; Von Uexkull et al., 2024).

Moreover, in oil-producing countries, fuel subsidies have served as a means to distribute oil wealth, forming a part of the social contract between governments and citizens. The removal of these subsidies can lead to significant public opposition, as vividly demonstrated by the Occupy Nigeria protests in 2012 (Von Uexkull et al., 2024). These protests, triggered by the government's removal of fuel subsidies, led to widespread public outcry and a doubling of petrol prices. Arguing that subsidies favoured the governing elite and a fuel importers' cartel over national refineries, President Goodluck Jonathan's Administration faced a major strike that halted the nation (Agbonifo, 2023; Houeland, 2020, Mark, 2012). The crisis ended when the government partially reinstated the subsidies. These protests highlight the subsidy removal challenge of balancing economic reforms with social stability (Ross et al., 2017; Skovgaard and van Asselt, 2019).

Against this backdrop, the decision to remove the fuel subsidy announced by President Tinubu on 29 May 2023 signified a fundamental shift in the nation's fiscal policy (Ozili and Obiora, 2023). The immediate aftermath of this announcement saw a sharp increase in the price of petrol – widely called premium motor spirit (PMS) in Nigeria –as reported by the Nigerian National Petroleum Company Limited, with prices ranging from 488 naira per litre in Lagos State to N555 per litre in Maiduguri, Borno State (Adetayo, 2023). This policy change, while crucial for addressing long-standing fiscal imbalances (Gençsü et al., 2022; Ozili and Obiora, 2023), prompted significant concerns regarding its impact on the socio-economic welfare of Nigerian households, particularly for the most vulnerable.

Thus, the dynamics of fossil fuel subsidy policies and their removal are intricately linked to broader issues of economic policy, social welfare, and climate change mitigation. This is the context for examining the welfare and distributional effects of fuel subsidy removal on households, with a focus on Nigerian households' response to these policy changes. Understanding the distributional consequences of progressive fossil fuel subsidy reform is critical to the sustainability of reform as well as to progress towards more just and inclusive energy transitions. This research is predicated on the understanding that the removal of fuel subsidies, a contentious economic support measure, is likely to have varied impacts across different strata of the population. Given the central role of fossil fuels in Nigeria's energy mix, these price changes are expected to affect various aspects of household economics, particularly energy consumption patterns and associated expenditures.

To systematically assess these impacts, the study employs the QUAIDS model developed by Banks et al. (1997).[1] This approach is especially suited to analysing consumer demand and expenditure patterns, allowing for an in-depth analysis of household responses to price changes. The QUAIDS model is applied in a two-stage analytical framework: in the first, household expenditures are categorised into energy and non-energy groups; the second stage delves deeper, decomposing the energy expenditure into specific categories such as petrol, electricity, kerosene, and other household energy goods like wood, charcoal, diesel, and other fuels. This two-stage approach facilitates a comprehensive understanding of how households allocate their budgets in response to changing energy costs.

1.2 Objectives

We aim to provide a comprehensive understanding of the interplay between subsidy removal and household welfare, offering insights that can guide policymakers, stakeholders, and the broader community in navigating the socioeconomic landscape of a post-subsidy Nigeria.

To explore and assess the consequences of fuel subsidy reform, the specific objectives of this study are:

1. to describe the household energy consumption patterns of Nigerian households
2. to estimate the budget, own-price, and cross-price elasticities for petrol consumed by Nigerian households
3. to investigate the welfare impacts of petrol price increases among Nigerian households
4. to examine the welfare impacts of government redistribution policies targeted at poor households in Nigeria.

1.2.1 Welfare analysis description

For the welfare effects exploration, this study asks whether petrol price increases are regressive or progressive. As a scenario, a stylised energy price change of 100% (based on observed price changes) is simulated to determine consumers' responses to these changes. The aim is to determine if the petrol price increases are regressive or not across household income deciles. Furthermore, this study considers

1 Please refer to Section 2 and Appendix 1 for discussion of this approach

households' welfare losses based on settlement type, urban and rural, for additional insights on the effects of petrol price changes.

1.2.2 Redistribution policy

Revenue recycling is one of the support policies to be implemented by the Nigerian government to cushion the adverse effects of the fossil energy subsidy removal policy. The policy scenarios will focus on the effect of a lump-sum transfer of the saved revenues on the poorest households (households in the bottom 40% of the income distribution) and those below the official national poverty line thresholds (the lower bound poverty line and the upper bound poverty line).[2]

The results indicate that the removal of fuel subsidies leads to a rise in petrol prices, which disproportionately impacts households with lower income. This is attributed to the reliance of the average Nigerian household on petrol, coupled with a lack of significant change in petrol consumption in response to price increases. Consequently, without viable alternatives, households face financial strain. The study reveals that the negative effects on welfare vary significantly among households of different income levels and geographic locations, with those in rural areas and in the lower income brackets suffering more. It suggests that direct, targeted cash transfers to the poorest 40% of households can partially offset these negative impacts, showcasing the progressive potential of such interventions. The results underscore the importance of well-crafted redistribution measures to alleviate the negative consequences of subsidy removal, ensuring support for lower-income and rural households by acknowledging the varied impacts and the efficacy of policies aimed at redistribution, revenue recycling, or providing relief. In the following section we give a short overview on the cross-sectional household data. We then specify the model and estimation procedure in section 3. In section 4 we present the results and discussion on elasticities, welfare analysis, and redistribution analysis. The paper closes with conclusion and policy implications.

2 Lower bound poverty line: N124,948 (US$ 347.07) per person per year. Upper bound poverty line: N137,430 (US$ 381.75) per person per year (NBS, 2020).

2 Methodology

2.1 Energy demand analysis

Research in the domain of energy demand is characterised by a diverse range of methodologies, geographic and energy type coverage, and data aggregation levels (Moshiri and Martinez Santillan, 2018). The methodologies employed in these studies divide primarily into macro and micro analyses. Macro analyses typically leverage aggregate time series data to derive price and income elasticities at a national or regional level. This approach is extensively used for trend analysis and forecasting. Micro analyses, by contrast, focus on granular data from households and firms to ascertain energy demand. This approach is twofold, encompassing end-use (or computational) models and theoretical models. End-use models emphasise the role of capital, its application, and technological progress in determining energy demand. These models are predominantly applied for long-range energy demand forecasts and do not directly integrate economic factors like price and income into their framework. Conversely, theoretical models are rooted in microeconomic theories that address consumer and business behaviours. These models used detailed data to deduce energy demand elasticities, focusing on individual and firm-level interactions with the energy market (see Moshiri and Martinez Santillan, 2018).

One of the key strengths of micro-level empirical studies is their ability to harness extensive datasets that encompass several observations about households and firms over time. This enables a detailed analysis of individual characteristics that potentially influence energy demand. The evolution of theoretical frameworks and empirical tools, coupled with the growing accessibility of micro-level data, has significantly contributed to the proliferation of micro-level studies in energy demand analysis. The approach used in this study to assess household petrol demand is the QUAIDS model (Banks et al., 1997). This model aligns well with the structure of household budget data. It is predicated on the assumption that individuals seek to maximise their utility (satisfaction) level by the consumption of different goods (energy and non-energy). The utility maximisation will be subject to a budget constraint determined by the individual's income (or desired expenditure) and the prices of the goods consumed. This alignment, combined with the flexibility QUAIDS provides, allows for a more accurate representation of consumer demand, making it suitable for various applications such as analysing the effects of taxing sugar-sweetened beverages (Segovia et al., 2020), estimating food demand systems for rural households (Naz et al., 2018), and assessing residential energy demand elasticity (Kutortse, 2022). The QUAIDS model has been applied in diverse settings, including studies on consumer demand for alcoholic beverages (Aepli, 2014), household animal-sourced food in West Java (Kharisma et al., 2020), the demand behaviour of consumers in Peru (Molina and Gil, 2005), and to estimate the social welfare cost of taxes on food and non-food items in Pakistan (Iqbal et al., 2019).

The QUAIDS model thus offers a framework for understanding how households allocate their budget across different commodities, factoring in their income and the cost of these commodities.

$$w_i = \alpha_i + \sum_{j=1}^{K} \gamma_{ij} \, lnP_j + \beta_i ln\left\{\frac{m}{a(p)}\right\} + \frac{\lambda_i}{b(p)}\left[ln\left\{\frac{m}{a(p)}\right\}\right]^2 + \sum_{k}^{n} \varphi_{ik} \, z_k + \varepsilon_i \quad (1)$$

where w_i is the budget share of each household for commodity i $(i = 1, \ldots, n)$, m indicates the household income, P_j are the logarithm of prices of the commodities and $ln\{m/(a(p))\}$ is the logarithm of real expenditures. The parameters α_i, β_i, and γ_{ij} have to α_i be estimated, where β_i measures the effect of a real income change to the change in budget share of commodity i and γ_{ij} measures the effect of a price change in commodity j on the budget share of i. The function $\alpha(p)$ is positive, linearly homogenous in prices and convex. See Appendix 1 for a detailed description of the model.

In this study, it is assumed that in the first stage a household allocates its income or expenditures to energy and non-energy commodities. In the second stage, the expenditures for energy are allocated to specific energy commodities, i.e., petrol, electricity, kerosene, and other household energy goods like wood, charcoal, diesel, and other fuels. For the second stage, the QUAIDS is applied to gain detailed information on expenditure elasticities, own-price elasticities, and cross-price elasticities of the commodities.

The approach in this research employs Equation (1) for estimating the budget shares of five residential energy sources consumed by Nigerian households. These are petrol (w_1), electricity (w_2), transport (w_3), kerosene (w_4), and an aggregate category of other household energy items such as wood, charcoal, diesel, and additional fuels (w_5). Following Kutortse (2022), who investigates residential energy demand elasticity in Ghana using the QUAIDS model, the budget share for each energy type is computed by dividing the household's expenditure on a specific energy commodity by its total expenditure on energy. Corresponding prices for these energy sources are labelled from p_i to w_4. In line with the QUAIDS model, the study operates under the assumption that each consumer faces fixed prices for these energy sources. As such, following Kutortse (2022), the study calculates the prices of these energy fuels by dividing the household's expenditure on a specific type of energy by the total number of people in the household.

Moreover, the study incorporates demographic variables (z) as outlined in Equation (1), which include the household's urban or rural location (urban = 1, rural = 0), the gender of the household head (male-headed = 1, female-headed = 0), ownership of a motorbike (yes = 1, no = 0), and the size of the household. While there are other demographic factors that potentially influence a household's energy consumption pattern, the study is mindful of the complexity that arises from including an excessive number of demographic variables. This is particularly pertinent in the QUAIDS model, where the addition of more variables substantially increases the quantity of coefficients to estimate, thus adding to the complexity of the demand system analysis.

2.2 Welfare analysis

The estimated elasticities are used to assess the welfare consequences of the petrol price changes. The study assesses the 'dynamic' household welfare effect, one that jointly considers (static) first-order effects in consumption as well as consumption responses. While the first-order approximation may capture a large part of the impact of price changes on welfare, ignoring household behavioural responses in welfare analysis, the second-order approximation may lead to significant biases and inappropriate inferences (Banks et al., 1997). The first-order approximation of impact of price changes implicitly assumes that households are unable to change their consumption patterns when prices change (equivalent to assuming that all elasticities are zero). Given the substantial observed price changes, substitution effects can be non-trivial, and therefore, first-order approximations can be biased (Banks et al., 1997). Thus, we report results from second-order approximations.

Consistent with the existing literature, we use the estimated elasticities to measure the welfare impact of the petrol price changes. Following empirical literature (Ackah and Appleton, 2007; Moshiri and Martinez Santillan, 2018; Okonkwo, 2021), we estimate the change in consumer welfare, measured as compensating variation (CV).[3] The CV measures the total monetary transfer required to compensate (bring the consumer back to the original utility level) after the price change, as a percentage of their initial total expenditure (Araar and Verme, 2019). For changes from p^a to p^b of petrol, this can be represented as:

$$CV = e(p^a, v^a) - e(p^b, v^a)$$
$$\int_{p^a}^{p^b} h(p, v^a) \, . \, dp$$

where v and e represent generic indirect utility and expenditure functions.

2.3 Data

The main source of information is the Nigerian GHS, which includes a panel survey implemented in collaboration with the World Bank's LSMS team (World Bank, 2019). The objectives of the GHS-Panel include the development of an innovative model for collecting household, agricultural, community data, as well as inter-institutional collaboration, and comprehensive analysis of welfare indicators and socio-economic characteristics. The GHS-Panel is a nationally representative survey of approximately 5,000 households, which are also representative of the six geopolitical zones. This study uses the most recent three waves –2012/13, 2015/16, and 2018/19 – combined into a single cross-sectional dataset. The focus of this study is residential petrol consumption expenditure, but it is necessary to explore the relationship between petrol and other residential energy commodities. Consistent with existing literature, this study uses total expenditures to represent the long-run income for households, as income tends to be understated, particularly by high-income households, and total expenditures does not fluctuate as much as current income over short periods (Moshiri and Martinez Santillan, 2018).

3 We concentrate here on changes in consumer welfare from the change in prices, assuming income effects away. Our model therefore does not account for supply responses through production and labour adjustments. The results must therefore be interpreted with these caveats in mind.

3 Results

3.1 Summary statistics

Table 1 presents the overall sample summary statistics, while Table A2 to Table A4 in Appendix 2 present the sub-sample summary statistics for the years studied.

Petrol expenditure: the summary statistics highlight petrol as a significant energy expenditure for Nigerian households. The average expenditure on petrol for the whole sample (which comprises average expenditure across the three survey waves) stands at N20,968.9, while the value in 2019 is N26,976.[4] This underlines petrol's crucial role in household energy budgets, averaging 18% for the full sample, and its sensitivity to policy changes, such as subsidy removals (see Figure 1 for the budget shares of petrol across household groups and settlement type for the survey waves used in the study). The high standard deviation in petrol expenditure (49,518 for the overall sample) points to a wide disparity among households in petrol use. This disparity is key, particularly in a scenario of subsidy removal, as it could disproportionately impact lower-income households, which dedicate a larger budget share to petrol. Further, considering the substantial share of the household budget spent on petrol, the data suggests that any increase in petrol prices due to subsidy removal could have immediate and significant welfare implications. A year-wise analysis (see Table A2 to Table A4 in Appendix 2) shows that, compared to the first survey wave in 2012/13, the average household energy budget share of petrol increased by 25% and 19% in 2015/16 and 2018/19, respectively. This increase highlights the potential increasing financial pressure on households over the years, likely to be intensified by subsidy removal.

Energy budget shares and welfare implications: the budget share for petrol (18%), emphasises its criticality in household energy expenditures. Other energy expenditure shares are as electricity (13%), transport (40%), and kerosene (15%). See Figure 2 for the budget shares of petrol across household groups and settlement type for the survey waves used in the study.

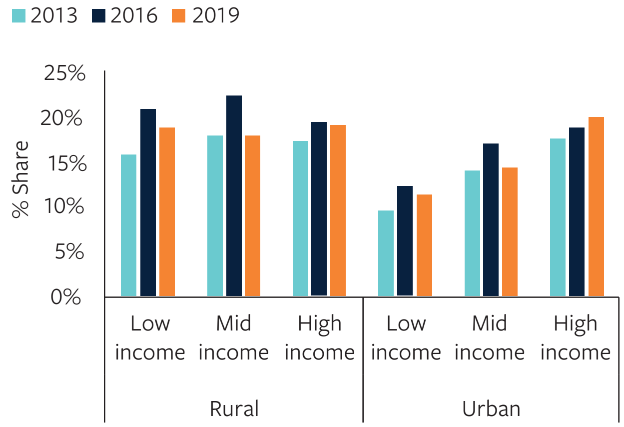
4 Official exchange rate (local currency unit per US$, period average): USD1 = ₦157.31 (2013), ₦253.49 (2016), ₦306.92 (2019). https://data.worldbank.org/indicator/PA.NUS.FCRF?locations=NG.

Table 1 Summary statistics – overall sample

Variable	Obs	Mean	Std. Dev.	Min	Max
Expenditure (naira)					
Petrol	13,496	20,968.90	49,517.67	0	2,190,000.00
Electricity	13,496	10,084.62	17,888.23	0	615,683.31
Transport	13,496	41,629.63	72,194.02	0	3,229,381.00
Kerosene	13,496	7,104.41	9,576.43	0	280,697.16
Other energy	13,496	11,434.02	83,293.31	0	9,125,000.00
Total energy	13,496	91,221.58	139,454.92	24.33	9,154,721.00
Expenditure share					
Petrol	13,496	0.18	0.25	0	1
Electricity	13,496	0.13	0.19	0	1
Transport	13,496	0.40	0.33	0	1
Kerosene	13,496	0.15	0.23	0	1
Other energy	13,496	0.15	0.24	0	1
Log prices					
Petrol	13,496	4.08	4.32	0	12.65
Electricity	13,496	4.09	4.07	0	12.30
Transport	13,496	6.46	4.10	0	13.16
Kerosene	13,496	5.22	3.44	0	11.20
Other energy	13,496	3.87	3.99	0	14.08
Demographic variables					
Location					
Rural	13,496	0.67	0.47	0	1
Urban	13,496	0.34	0.47	0	1
Household head					
Female	13,496	0.05	0.23	0	1
Head	13,496	0.95	0.23	0	1
Ownership if bike					
No	13,496	0.77	0.42	0	1
Yes	13,496	0.23	0.42	0	1
Household size	13,496	5.85	3.33	1	31
Total Expenditure	13,496	916,315.36	1,196,815.60	39,105.31	56,819,180.00

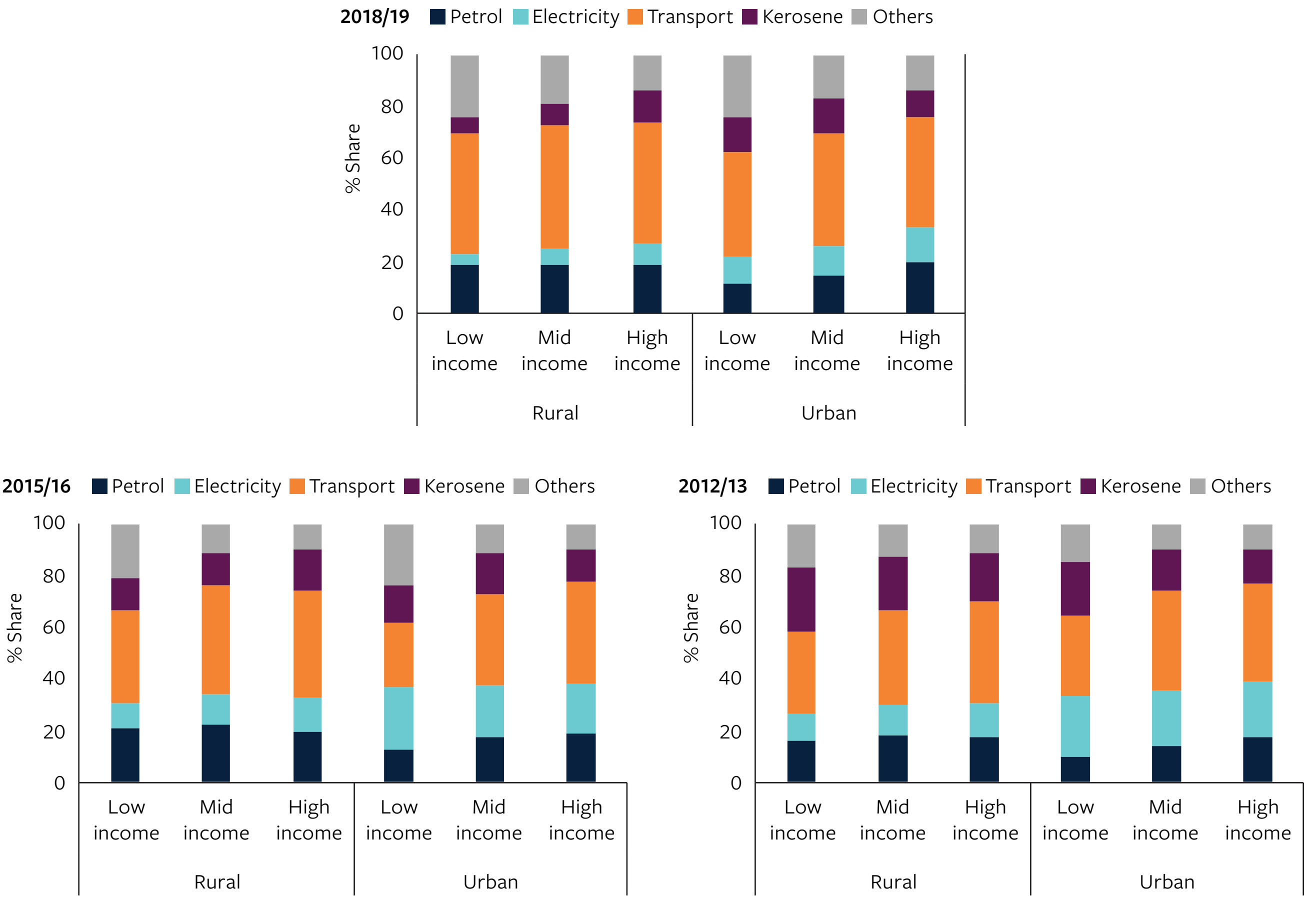
Note: Obs stands for number of observations in the study sample. Transport is total transport expenditure. The 2018/19 wave did not disaggregate household private and public transportation.
Source: Authors' calculations based on Nigeria GHS-LSMS data

Figure 1 Average share of petrol in total household energy expenditure by year, location, and income group



Source: Authors' charts using Nigeria GHS-LSMS data.

Figure 2 Average share of total household expenditure by energy goods, location, and income group



Source: Authors' charts using Nigeria GHS-LSMS data.

3.2 Model parameter estimates

The goal of fitting a demand system is to compute the elasticities, which requires the parameter estimates and data. Usually, empirical studies do not interpret the estimated parameters directly; instead, they are used to compute elasticities by using the incomes, prices, and expenditure shares of the average household. The coefficients (λ) on the non-linear income term for all goods in the system (petrol, electricity, transport and other energy) are all highly significant, justifying the selection of the QUAIDS and not the linear AIDS model in our analysis (see Appendix 1).

Table 2 Demand system estimation results – full sample

		Electricity	Petrol	Transport	Kerosene	Others
α	Constant	0.222*** (0.004)	**0.327*** (0.005)**	0.345*** (0.007)	-0.132*** (0.015)	0.238*** (0.006)
β	Expenditures	-0.014*** (0.002)	**-0.046*** (0.002)**	-0.043*** (0.002)	0.174*** (0.003)	-0.072*** (0.003)
γ	Electricity price	0.036*** (0.000)	**-0.010*** (0.000)**	-0.019*** (0.000)	-0.001* (0.001)	-0.006*** (0.000)
γ	**Petrol price**		**0.043*** (0.000)**	-0.025*** (0.000)	-0.000 (0.001)	-0.007*** (0.000)
γ	Transport price			0.064*** (0.001)	-0.003*** (0.001)	-0.016*** (0.000)
γ	Kerosene price				-0.004*** (0.001)	0.008*** (0.001)
γ	Others price					0.022*** (0.001)
λ	**Expenditure squared**	**-0.002*** (0.000)**	**-0.004*** (0.000)**	**-0.000*** (0.000)**	**-0.014*** (0.001)**	**0.020*** (0.001)**
η	Location (1= Urban)	0.001 (0.001)	**0.001 (0.001)**	0.001 (0.001)	-0.010*** (0.002)	0.007*** (0.001)
η	Male-headed household	0.002 (0.002)	**0.025*** (0.002)**	0.004* (0.002)	-0.023*** (0.004)	-0.009*** (0.001)
η	Motorbike ownership	-0.003** (0.001)	**0.016*** (0.002)**	0.004*** (0.001)	-0.019*** (0.002)	0.002 (0.002)
η	Household size	0.000 (0.000)	**0.000*** (0.000)**	0.001*** (0.000)	-0.001*** (0.000)	-0.001*** (0.000)
ρ	Location (1= Urban)	-0.091*** (0.017)				
ρ	Male-headed household	-0.843*** (0.023)				
ρ	Motorbike ownership	-0.046*** (0.016)				
ρ	Household size	0.029*** (0.005)				

Note: Number of observations is 13,496. Standard errors are in parentheses. *, **, *** stand for statistical significance at the 10%, 5%, and 1% levels, respectively.
Source: Authors' calculations based on Nigeria GHS-LSMS data.

Next, we present our estimates of the elasticity of demand for each household location.

3.3 Demand elasticity estimates for average Nigerian household

We now turn to the discussion of the estimated demand elasticities, which are needed to properly evaluate the welfare consequences of the fuel subsidy reforms.

3.3.1 Budget (income, expenditure) elasticity

The results on budget elasticity in Table 3 show that all goods have positive consumption expenditure elasticities, implying that no energy commodity is classified as 'inferior'; all are 'normal goods'. In other words, demand for all the energy commodities increase with income. As expected, the budget elasticity for petrol is less than one; this indicates that, for the average Nigerian household, petrol is a necessity. Additionally, the results show that electricity and transport are necessities for the average Nigerian household. Conversely, the budget elasticities for kerosene and an aggregate of the other household energy goods are greater than one, which indicates that, for the average Nigerian household, kerosene and the aggregate other energy goods are luxuries. These results are consistent when results are decomposed into household income groups – low income, middle income, and high income – and household location – urban and rural.[5] Consequently, in Nigeria, income is an important factor in determining the demand for petrol use when price changes.

Table 3 Budget (income/expenditure) elasticities

	Petrol	Electricity	Transport	Kerosene	Others
Overall sample	**0.748*** (0.006)**	**0.689*** (0.014)**	**0.926*** (0.003)**	**1.195*** (0.024)**	**1.508*** (0.017)**
Low-income households	0.674*** (0.009)	0.253*** (0.038)	0.932*** (0.004)	0.535*** (0.054)	1.652*** (0.021)
Middle-income households	0.726*** (0.007)	0.652*** (0.016)	0.93*** (0.003)	1.104*** (0.026)	1.525*** (0.016)
High-income households	0.784*** (0.006)	0.773*** (0.011)	0.921*** (0.003)	1.397*** (0.018)	1.407*** (0.019)
Urban households	0.764*** (0.007)	0.816*** (0.011)	0.92*** (0.003)	1.311*** (0.024)	1.414*** (0.018)
Rural households	0.741*** (0.007)	0.57*** (0.019)	0.929*** (0.003)	1.138*** (0.027)	1.539*** (0.018)

Note: Number of observations is 13,496. Standard errors are in parentheses. *, **, *** stand for statistical significance at the 10%, 5%, and 1% level, respectively.
Source: Authors' calculations based on Nigeria GHS-LSMS data.

5 Kerosene, however, has a budget elasticity value less than one for low-income households, which suggests that, for this group, kerosene is a necessity.

3.3.2 Own-price elasticities

As shown in Table 4, the statistically significant compensated and uncompensated own-price elasticities exhibit the expected negative signs. Consistent with consumer demand theory, there exists an inverse relationship between changes in own-price indexes and quantities demanded. This implies that an increase in the price of an energy good would result in a decrease in the demand for that good. The absolute values of the own-price elasticities are smaller than unity (one), meaning that they are not price elastic. In other words, on average, Nigerian families show an inelastic response to changes in the price of petrol.

The own-price elasticity of petrol is -0.571, indicative of its relatively inelastic nature. This suggests that petrol does not experience a proportionate decline in demand despite price increases. Such inelasticity is a common characteristic of essential goods, reflecting petrol's indispensable role in daily life. In practical terms, a subsidy removal leading to a price hike would not significantly deter petrol consumption but would strain household budgets, particularly among lower-income groups. This phenomenon underscores the importance of considering the economic burden on these households in policy planning. Additionally, the results show an inelastic response to electricity and transport price changes, while they show an elastic response to kerosene price changes. As expected, in all cases, the compensated elasticities are lower than the uncompensated elasticities.

Table 4 Own-price elasticity estimates for petrol and other household energy items

Panel A: Compensated elasticity

		Price				
		Petrol	**Electricity**	**Transport**	**Kerosene**	**Others**
Demand	**Petrol**	**-0.571*** (0.002)**				
	Electricity		-0.466*** (0.006)			
	Transport			-0.397*** (0.001)		
	Food				-0.593*** (0.006)	
	Others					-0.573*** (0.003)

Table 4 Own-price elasticity estimates for petrol and other household energy items (continued)

Panel B: Uncompensated elasticity

		Price				
		Petrol	**Electricity**	**Transport**	**Kerosene**	**Others**
Demand	**Petrol**	**−0.709*** (0.002)**				
	Electricity		−0.524*** (0.005)			
	Transport			−0.822*** (0.001)		
	Kerosene				−0.717*** (0.007)	
	Others					−0.829*** (0.002)

Note: Standard errors are in parentheses. *** stands for statistical significance at the 1% level.
Source: Authors' calculations based on Nigeria GHS-LSMS data.

3.3.3 Cross-price elasticities

As shown in Table 5, when we expand our view to include other energy-related commodities such as electricity, transport, kerosene and others, the cross-price elasticities offer insights into the substitutability and complementarity among these goods. The positive cross-price elasticities signify that as petrol becomes more expensive, there is a tendency for households to increase their consumption of other energy commodities like electricity, kerosene, and alternative transportation methods. This shift suggests a search for substitutes to petrol, driven by the need to maintain energy consumption levels while coping with rising petrol costs. However, the relatively modest magnitude of these elasticities suggests that these alternatives are not perfect substitutes, possibly due to constraints in the availability, accessibility, or suitability of these alternatives compared to petrol.

This limited substitutability can be attributed to factors such as the limited availability of alternatives in certain regions – particularly in rural areas, where access to diverse energy sources is often constrained. Additionally, the accessibility and affordability of these alternatives play a critical role. For many households, especially those with lower incomes, the cost of transitioning to alternative energy sources or transportation modes may be prohibitively high. The suitability of these alternatives is another factor; for example, electricity might not be a feasible substitute in areas with frequent power outages, and public transportation may not be a viable option in regions where the infrastructure is underdeveloped or non-existent.

Table 5 Crossprice elasticity estimates for petrol and other household energy items

		Price				
		Petrol	Electricity	Transport	Kerosene	Others
Demand	**Petrol**	**-0.571*** (0.002)**	-0.571*** (0.002)	0.332*** (0.001)	0.086*** (0.002)	0.112*** (0.001)
	Electricity	**0.083*** (0.003)**	-0.466*** (0.006)	0.241*** (0.003)	0.063*** (0.005)	0.080*** (0.002)
	Transport	**0.136*** (0.001)**	0.045*** (0.001)	-0.397*** (0.001)	0.081*** (0.001)	0.136*** (0.000)
	Kerosene	**0.136*** (0.003)**	0.039*** (0.003)	0.346*** (0.003)	-0.593*** (0.006)	0.072*** (0.003)
	Others	**0.133*** (0.001)**	0.038*** (0.001)	0.380*** (0.002)	0.022*** (0.004)	-0.573*** (0.003)

Note: Standard errors are in parentheses. *** stands for statistical significance at the 1% level.
Source: Authors' calculations based on Nigeria GHS-LSMS data.

3.4 Welfare analysis results

As a scenario, we gauge the welfare effects of a 100% price changes due to the petrol subsidy removal. In doing this, we also recognise the importance of determining how different population groups are affected in different ways by these reforms. Thus, to illustrate which groups of households are relatively disadvantaged by the price changes, we disaggregate the compensating variation (CV) measure by income group and household location (Table 6).

First-order effects vs second-order effects (CV) for the whole sample

The comparison between the first-order effects (19%) and the compensating variation (15%) for the full sample indicates that the immediate, direct impact of price changes (first-order effects) overestimates the welfare loss compared to the full adjustment scenario (CV). The first-order effects capture the immediate, direct impact of price changes without accounting for the subsequent adjustments in consumption behaviour and other dynamic market reactions. In contrast, the CV, which considers the full range of adjustments households can make, including substitution between goods, results in a somewhat lower welfare loss estimate. This underscores the importance of calculating the second-order effects, or CV.

Table 6 Compensating variation implied by a 100% price change in petrol

Household category	CV (%)	First-order effects (%)
Panel A: Full sample	**15**	**19**
Location of residence	**CV**	
Rural	16	
Urban	14	
Household income quintiles	**CV**	
1	16	
2	15	
3	14	
4	14	
5	14	
Household income quintiles	**Rural**	**Urban**
1	17	10
2	16	10
3	15	11
4	15	13
5	15	17

Note: CV is measured as a proportion of 2018/19 total household expenditures. Values are approximated to integers.
Source: Authors' calculations based on Nigeria GHS-LSMS data.

The disparity in CV between rural (16%) and urban areas (14%) in response to petrol subsidy removal-induced price change underscores the relative vulnerability of rural households. Across household income quintiles, the results show that a 100% increase in petrol prices is regressive: the lowest-income households experience a higher welfare loss. In other words, the CV shows a higher impact on lower-income quintiles (16% for the lowest quintile) compared to the highest quintile (14%). For instance, a 100% increase in the price of petrol requires a payment of 16% of the household expenditure on petrol to compensate the lowest income households, compared to a relatively lower 14% for the highest income households. Although high-income households will spend more on fuel in total expenditure, this pattern suggests that, as a proportion of household energy budget, lower-income households are relatively more vulnerable to petrol price changes. The limited financial flexibility of lower-income groups means that a rise in petrol prices significantly reduces their welfare, more so than higher-income households.

When considering both income levels and area of residence, the results show that rural households across all income quintiles experience a higher welfare loss compared to urban households. This finding is especially pronounced in the lower income quintiles, highlighting the compounded vulnerability of lower-income, rural households.[6] This could be partly explained by high poverty rates and lack of livelihood diversification options in rural areas. However, in practice, household income varies

6 The analysis is conducted at the cluster level (rural vs urban), thus smoothing out real-world variation among urban households.

within rural and urban areas, which has implications for palliative policy design. The results for the urban area is consistent with those of Ramírez et al. (2021), who find evidence of welfare losses for households due to energy subsidy reforms in Mexico. Moreover, they show that the effects can be progressive in urban areas, where the richest income group experiences the highest welfare losses.

While the compensating variations are higher in rural areas, the sheer number of low-income individuals in urban areas and their specific challenges (such as higher overall living costs and fewer alternatives to petrol-based transportation) cannot be overlooked.

The analysis underlines the significant welfare impact of petrol subsidy removal across different segments of the Nigerian population, with pronounced effects on rural and lower-income households. This calls for carefully crafted policies that cushion these groups from the adverse effects. Targeted support measures, such as direct cash transfers to the most affected households, could make the reform publicly acceptable and progressive.

Gender dynamics

There is a dearth of research focusing on the gender-specific impacts of energy price changes on household welfare. This study does not cover this gap due to the limitations of the Nigeria GHS-LSMS datasets (see Appendix 3 for detailed description); however, gender-specific impacts and these interactions with household income should motivate future research. In this context, the study conducted by Ramírez et al. (2021) emerges as an important piece of research that closely aligns with our own analysis, shedding light on the nuanced effects of energy reforms. Their investigation into Mexico's energy reform offers invaluable insights because Mexico has economic parallels with Nigeria. Both countries are notable oil producers that have historically relied on fossil fuel subsidies to stabilise domestic energy prices. These similarities suggest that the impacts observed in Mexico could offer predictive insights into the potential repercussions of similar reforms in Nigeria, making their findings especially pertinent.

Disproportionate effects on women-led households: the findings from Ramírez et al. (2021) suggest a disproportionately negative effect of energy price reforms on households led by women, both in urban and rural areas. This aligns with our observations and reinforces the concern that women, particularly those heading households, face greater vulnerability to economic shocks such as subsidy removal. Ramírez et al. reveal that female-headed households in urban areas experience a more significant welfare loss compared to their male counterparts, with similar patterns observed in rural settings. This suggests that policy interventions need to be sensitive to the gendered dimensions of energy reforms.

Acknowledging the disproportionate effects of energy reforms on women-led households compels a re-evaluation of policy frameworks to ensure they are inclusive and equitable. It is imperative that policy interventions be designed with a deep understanding of the gendered nuances of energy consumption and expenditure. This means moving beyond generic policy solutions to embrace targeted approaches that directly address the specific needs and challenges faced by female-headed households. For instance:

- Targeted financial assistance: direct financial assistance programmes for women-led households can mitigate the impact of energy price increases, ensuring these programmes are easily accessible and tailored to the needs of this vulnerable group.

- Enhanced social safety nets: social safety nets can be specifically designed to support women-led households affected by energy price reforms, including cash transfers and emergency energy vouchers.
- Gender-inclusive policy design: gender analysis can be incorporated in all stages of energy policy planning and implementation to ensure the unique needs of women-led households are considered and addressed.
- Women's participation in decision-making: mechanisms for the active participation of women, particularly those heading households, can be introduced into energy policy decision-making processes, ensuring women's voices and concerns shape equitable and effective energy policies.

3.5 Revenue recycling

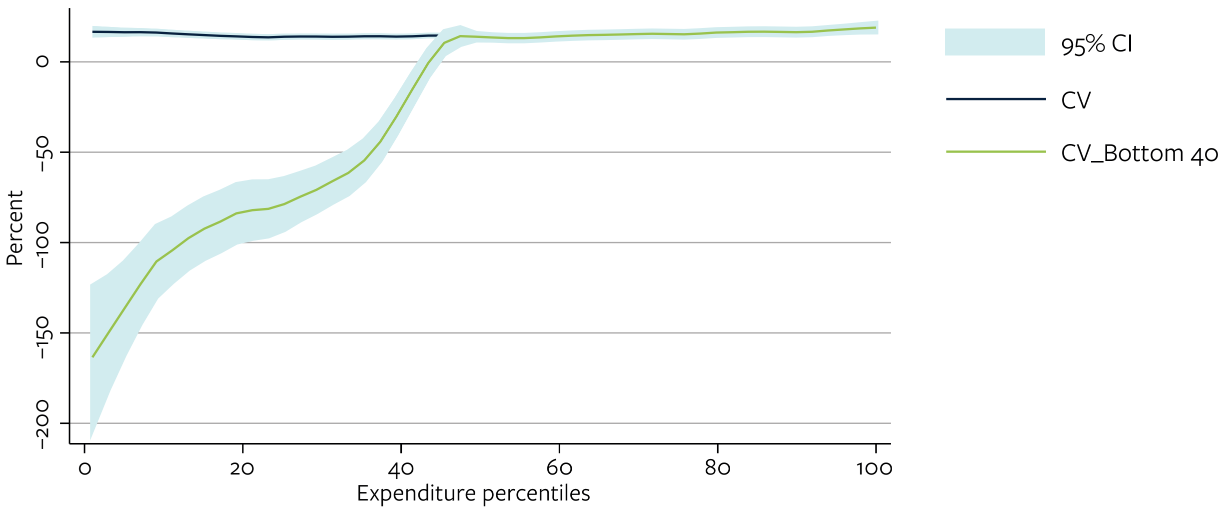
Revenue recycling is one of the support policies planned by the Nigerian government to cushion the adverse effects of the PMS subsidy removal policy. Therefore, this study analyses the effect of a lump-sum transfer of the subsidy saving to the poorest households i.e., households in the bottom 40% of the income distribution and those below the national poverty lines. Nigeria has high income inequality. In 2018 and 2019, the share of income going to the bottom 40% of households in Nigeria was only 9.5% of total income (UNDP, 2022). Hence, the bottom 40% is a worthy representation of the poorest households in Nigeria. This study uses official poverty lines to delineate the different levels of poverty in Nigeria, based on the lower-bound and the upper-bound poverty lines (LBPL and UBPL) defined by the NBS. Individuals at the LBPL are unable to purchase sufficient food and non-food items and are therefore obliged to sacrifice food to obtain essential non-food items. Individuals at the UBPL can purchase both adequate levels of food and non-food items (NBS, 2020).

The scenario shifts when considering the welfare effects of lump-sum transfers. These transfers are targeted at lower-income quintiles under three different schemes: the bottom 40%, LBPL, and UBPL thresholds. The results of the redistribution policy scenarios are presented in Figure 3 and Figure 4. The negative CV values for lower quintiles in all redistribution scenarios suggest welfare gains, indicating that these transfers effectively counter some of the welfare losses caused by fuel price changes.

The effects of the lump-sum transfer of the subsidy savings revenue to the households below the poverty lines and the bottom 40% are similar. The subsidy savings revenue redistribution to the poorest households yields a progressive outcome. For a 100% change in PMS prices and 100% revenue recycling, the poorest households experience significant welfare gains.

Bottom 40% transfer: targeting the bottom 40% of households results in welfare gains for the lower quintiles. The magnitude of these gains is highest for the lowest income quintile, gradually decreasing as income increases. This pattern exhibits the progressive nature of the policy, as it benefits the poorest group the most.

Figure 3 Welfare effects of a lump-sum transfer to the bottom 40%



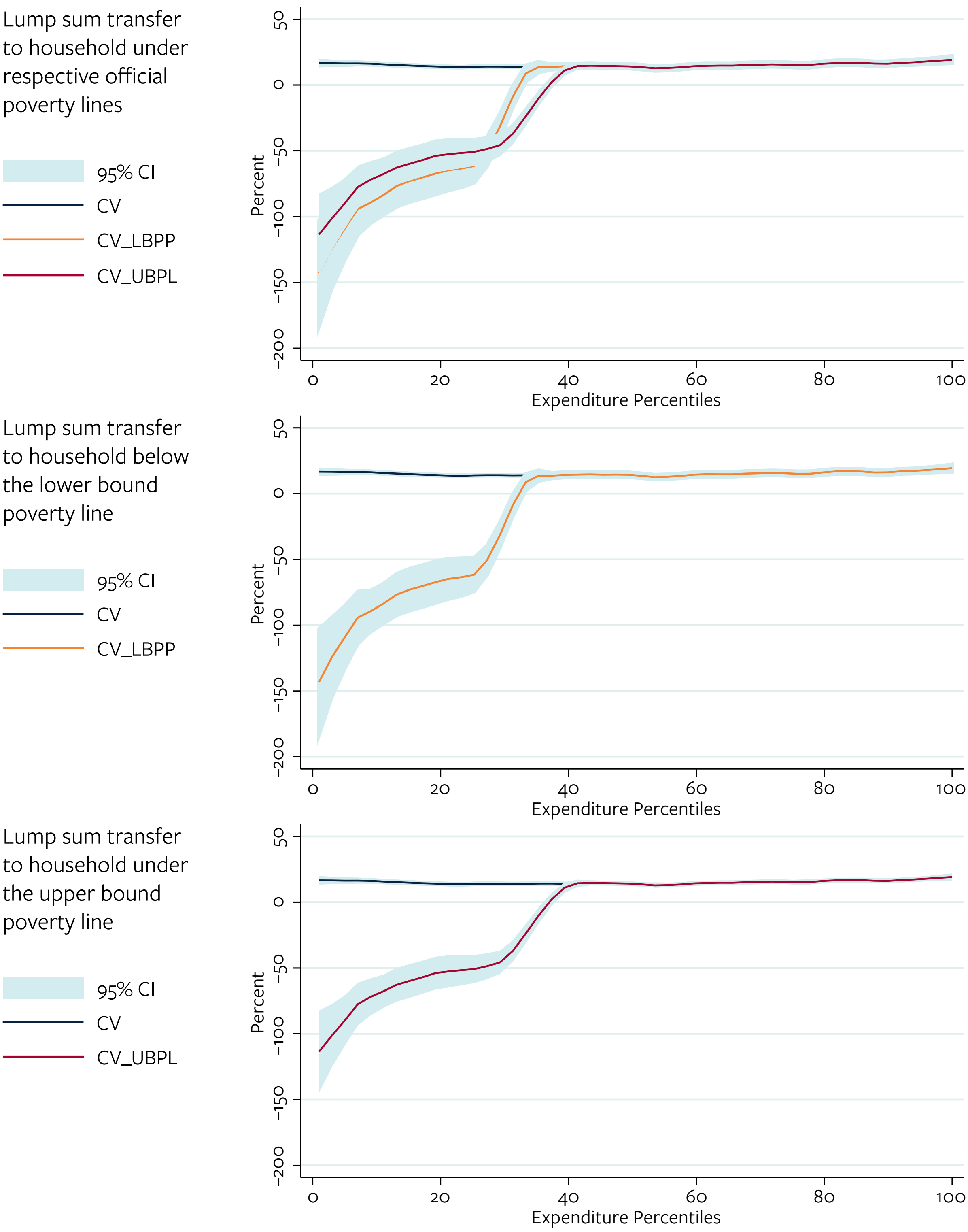
Note: The redistribution of petrol subsidy savings revenue to the bottom 40% of the Nigerian population yields a progressive outcome. For a 100% change in the petrol prices, the poorest households experience up to 100% welfare gains.
Source: Authors' diagram based on Nigeria GHS-LSMS data.

LBPL transfer: expanding the lump-sum transfer to include households below the LBPL further accentuates the welfare gains for the lower quintiles. Additionally, the third quintile, in particular, shows a substantial improvement in welfare, indicating that a slightly broader but still targeted approach can enhance the progressiveness of the policy.

UBPL transfer: extending the redistribution to the UBPL threshold continues to show welfare gains for the lower quintiles, with a more pronounced effect on the middle quintile. This suggests that including a broader segment of low-income households in the redistribution scheme maintains the progressiveness of the policy, as it continues to benefit lower-income groups more significantly than higher-income ones.

The analysis demonstrates that the targeted lump-sum transfers in response to petrol price changes can be progressive. These results show that they can be calibrated to disproportionately benefit lower-income groups, thereby mitigating the regressive impact of the initial fuel price changes. This approach exemplifies how fiscal policies, particularly in developing economies like Nigeria, can be designed to balance economic, energy reform and energy transition objectives with equity considerations. By strategically targeting financial support to lower-income groups, such policies can ensure that the burden of economic reforms does not unduly fall on the most vulnerable sections of society, fostering a more equitable distribution of economic burdens and benefits.

Figure 4 Welfare effects with a lump-sum transfer to households below the official poverty lines



Note: LBPL = lower bound poverty line; UBLP = upper bound poverty line. This figure shows the lump-sum redistribution of petrol subsidy savings revenue to household below different poverty lines. The results are similar to that of the bottom 40%.

Source: Authors' diagram based on Nigeria GHS-LSMS data.

4 Conclusion and policy implications

The Nigerian government's removal of fuel subsidies, initially motivated by fiscal challenges, is a step towards aligning with the country's nationally determined contributions to the Paris Agreement goals and to advancing the true costing of carbon. This measure, while economically driven, paves the way for Nigeria to move beyond outdated fossil fuel subsidies, embracing a sustainable energy transition. It signifies a commitment to environmental sustainability and economic resilience, marking a critical shift towards renewable energy adoption and fulfilling global climate commitments. It not only addresses immediate economic needs but also charts a course for sustainable growth and energy security in Nigeria. As a significant policy shift, it has also ushered in a new era of challenges and opportunities for the nation's socio-economic landscape.

This paper investigated the welfare effects of petrol subsidy removal on Nigerian households in order to provide a deeper understanding of how the newly implemented petrol subsidy removal policy would affect Nigerian households in different income groups. It reveals that the consequent petrol price increases have a regressive impact, particularly burdening lower-income and rural households. These groups experience the highest welfare losses, underscoring the critical need for targeted support measures. The research findings emphasise the effectiveness of redistribution policies, such as lump-sum transfers to the poorest households. By focusing on the bottom 40% and those below national poverty lines, these measures exhibit a progressive outcome, significantly offsetting the welfare losses among the most vulnerable groups. Additionally, there is a lack of evidence on gender-specific impacts, which must also be considered in policy responses. Furthermore, while this study does not empirically consider gender-specific welfare impacts, gender and other demographic factors are important and should be included in policy design/response.

Beyond the empirical focus of this study, the authors note that increasing fuel prices due to subsidy removal in oil-producing nation like Nigeria has the potential for generating dissent. Von Uexkull et al. (2024) find that such increases not only provoke protests over fuel but also trigger broader economic grievances affecting basic needs. The research underscores the critical role of policy design in subsidy and tax reforms to prevent social unrest, advocating for measures that protect vulnerable groups and assessing their effectiveness across various contexts.

For policymakers, the results of this paper highlight the importance of crafting equitable and sensitive strategies in response to economic reforms. The study advocates redistribution policies that balance fiscal objectives with social welfare considerations, ensuring that the economic burden of reforms is not disproportionately borne by the most vulnerable segments of society. Furthermore, appropriate policy targeting should consider variation within rural and urban areas and household demographics. This approach not only fosters a more equitable distribution of economic burdens and benefits but also enhances the public acceptability of such reforms.

To build on these foundational principles, a holistic policy framework is needed. This should include an integrated urban-rural strategy that acknowledges the unique needs of low-income households across Nigeria's diverse regions. Key to this is improving urban public transportation to reduce the financial impact on urban low-income families and introducing a progressive petrol taxation system where wealthier households contribute more. Reinvesting these funds into targeted support for energy assistance, efficient appliances, and renewable energy initiatives for both urban and rural communities could mitigate the reform's negative effects. Moreover, creating data-driven programmes tailored to the socioeconomic realities of urban residents, coupled with sustained support for rural households, would ensure a comprehensive and equitable transition. Such policies could foster a more inclusive and resilient path towards energy sustainability.

While this study attempts to provide insights on the welfare effects of petrol subsidy removal on Nigerian households, the results should be interpreted with caution. The model presented is a short-run analysis which does not reveal the distributional impacts of the petrol subsidy removal in the long run. In addition, the welfare analysis is based on elasticities from the QUAIDS model which would be different for dramatic price changes. Further, we note that explicit and detailed prices for energy goods or price indices are not provided by the surveys or the NBS at the enumeration area level. This study relies instead on a second-best approach to approximate household-level prices for each energy good.

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Appendix 1 Detailed empirical strategy

Demand analysis

In this analysis, we employ the Almost Ideal Demand System (AIDS) model as the foundational framework to assess household energy demand. This model provides a versatile first-order approximation for any demand system that stems from utility-maximisation behaviours. Notably, the AIDS model upholds the axioms of rational choice and enables aggregation across consumers without the need for assuming parallel linear Engel curves (Deaton and Muellbauer, 1980). Its formulation aligns with the structure of household budget data, positing that individuals aim to optimise their satisfaction by consuming a variety of goods, including but not limited to energy, food, and clothing. This optimisation process is constrained by the individual's budget, which is a function of their income (or intended expenditure) and the prices of the consumed goods. By applying Shepard's lemma to the expenditure functions, we derive a set of equations representing the shares of expenditure for different goods:

$$w_i = \alpha_i + \sum_{j=1}^{K} \gamma_{ij} \, lnP_j + \beta_i ln\left\{\frac{m}{a(p)}\right\} \qquad (2)$$

where w_i denotes the budget share allocated to commodity i $(i = 1, \ldots, n)$, m represents the household income, P_j are the logarithms of commodity prices and $ln\{m/(a(p))\}$ is the logarithm of real expenditures. α_i, β_i, and γ_{ij} represent parameters to be estimated, where β_i measures the effect of a real income change to the change in budget share of commodity i and γ_{ij} measures the effect of a price change in commodity j on the budget share of i. The functions $a(p)$ is positive, linearly homogenous in prices and convex, expressed as the Translog Price Index, as follows:

$$lna(p) = \alpha_0 + \sum_i \alpha_i \, lnP_k + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \, lnP_i lnP_j \qquad (3)$$

To ensure theoretical consistency, Equation (1) is estimated under the restrictions of additivity [Equation (4), homogeneity [Equation (5), and symmetry [Equation (6)]:

$$\sum_{i=1}^{K} \alpha_i = 1; \sum_{i=1}^{K} \beta_i = \sum_{i=1}^{K} \lambda_i = \sum_{i=1}^{K} \gamma_{ij} = 0, \qquad (4)$$

Zero homogeneity in prices is the absence of money illusion.

$$\sum_{j=1}^{K} \gamma_{ij} = 0, \qquad (5)$$

The adding up property means that the expenditure among the different commodities is equal to the budget constraint.

$$\gamma_{ij} = \gamma_{ji} \quad \forall \, i \neq j. \qquad (6)$$

Symmetry denotes that the cross-partial price derivatives are equal.

The AIDS model assumes that Engel curves, the relationship between budget shares and total expenditures, are linear, whereas the budget shares might change nonlinearly with income. Thus, the Quadratic Almost Ideal Demand System (QUAIDS) derived by Banks et al. (1997) accommodates non-linear Engel curves by including a quadratic term for expenditure, which varies with prices. This specification implies that goods can be luxuries or necessities at different expenditure levels. AIDS is also a demand system of rank 2 while QUAIDS is a rank 3 model

(Lewbel, 1991). The rank of a demand system is the dimension of space defined by its Engel Curves holding fixed every consumer characteristic except for income. The rank shows the maximum number of linearly independent vectors of price functions (LaFrance and Pope, 2006). Such space is defined by a matrix of 3 columns, therefore, 3 is the maximum rank an exactly aggregable demand system can have (Gorman, 1981). Intuitively, models with higher rank allow for more flexibility and can better approximate non-linear Engel curves. The implications of the rank involve aggregation across goods and individuals, separability, and the functional form of the demands. To derive the budget shares in QUAIDS, the same procedure used for AIDS can be applied. However, an alternative method is to apply the Roy's identity to the indirect utility function (Banks et al., 1997), which yields the following expenditure share equations:

$$w_i = \alpha_i + \sum_{j=1}^{K} \gamma_{ij}\, lnP_j + \beta_i ln\left\{\frac{m}{a(p)}\right\} + \frac{\lambda_i}{b(p)}\left[ln\left\{\frac{m}{a(p)}\right\}\right]^2 \quad (7)$$

In addition to price and income, the socio-demographic characteristics also alter spending in different ways. For instance, it is expected that a larger family increases its overall expenditure in energy compared to a smaller family with the same preferences. We assume that the constant term in Equation (7) varies across households and is a linear function of demographic variables. That is, Equation (7) is modified to allow socio-demographic characteristics to become taste shifters as follows:

$$a_i = a + \sum_{k} \varphi_{ik}\, z_k \quad (8)$$

where z_k represents the K socio-demographic variable and φ represents the shift of the budget share because of the household characteristic. The socio-demographic variables included in the model are the size of the household, state and rural/urban location of the household, and ownership of motorbike. These variables are often shown to have effects on energy expenditures (see Okonkwo, 2021). To preserve the adding up condition, the following restriction is also added to the system: $\sum_k \varphi_{ik} = 0$

For prices, we use the price index proposed by (Moschini, 1995), which, unlike the Stone Price Index commonly used in the literature, is invariant to changes in the units of measurement of prices. In this index, prices are scaled by their sample mean as follows:

$$lna^*(p) = a + \sum_{i}^{n} \bar{w}_i\, lnp_i \quad (9)$$

where $\bar{w}_i$ is the mean of budget share for good i. The estimation equations of expenditure shares based on Equations (7) – (9) can thus be written as follows:

$$w_i = \alpha_i + \sum_{j=1}^{K} \gamma_{ij}\, lnP_j + \beta_i ln\left\{\frac{m}{a(p)}\right\} + \frac{\lambda_i}{b(p)}\left[ln\left\{\frac{m}{a(p)}\right\}\right]^2 + \sum_{k}^{n} \varphi_{ik}\, z_k + \varepsilon_i \quad (10)$$

Where $i = 1, \dots, N$ denotes each household and ε_i is the independent and identically distributed (iid) error term with covariance matrix Σ. The rest of the variables are as previously defined. The requirement for the adding-up condition results in a singular covariance matrix, necessitating the exclusion of one of the demand share equations. The parameter's estimates for the final equation are recovered using the constraints. The estimation process utilises the nonlinear seemingly unrelated regressions (NLSUR) technique, which accounts for inter-equation correlations, thereby yielding estimates that are both consistent and efficient (Poi, 2012).[7]

7 The model is implemented in Stata software using the quaids command.

Appendix 2 Descriptive statistics

Table A1 Sample size and number of households represented in each GHS-LSMS Wave

Year	Original Obs	Households represented	Obs after depuration	Households represented
2019	4,976	198,387,623	4,806	193,296,311
2016	4,581	181,137,448	4,251	177,147,391
2013	4,716	167,228,767	4,439	166,228,924

Source: Authors' calculations based on 2012/13, 2015/16, and 2018/19 Nigeria GHS-LSMS data.

Table A2 2019 Sub-sample descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Expenditure					
Petrol	4806	26975.819	54472.562	0	973333.38
Electricity	4806	10184.173	17458.059	0	243333.34
Transport	4806	52469.814	63943.145	0	1251428.5
Kerosene	4806	7996.969	11634.89	0	170333.33
Other energy	4806	17009.138	134485.09	0	9125000
Total energy	4806	114635.91	172117.33	608.333	9154721
Expenditure share					
Petrol	4806	0.19	0.25	0	1
Electricity	4806	0.08	0.14	0	1
Transport	4806	0.46	0.32	0	1
Kerosene	4806	0.10	0.18	0	1
Other energy	4806	0.17	0.24	0	1
Log prices					
Petrol	4806	4.4	4.49	0	12.63
Electricity	4806	3.79	4.18	0	11.71
Transport	4806	7.46	3.75	0	12.65
Kerosene	4806	4.45	3.98	0	11.20
Other energy	4806	4.97	4.05	0	14.08
Demographic variables					
Location					
Rural	4806	0.67	0.47	0	1
Urban	4806	0.33	0.47	0	1
Household head					
Female	4806	0.07	0.25	0	1
Head	4806	0.93	0.25	0	1
Ownership if bike					
No	4806	0.69	0.46	0	1
Yes	4806	0.31	0.46	0	1
Household size	4806	5.47	3.38	1	29
Total Expenditure	4806	997247.69	841275.31	85002.37	33648572

Note: Obs stands for number of observations in the study sample. Transport is total transport expenditure. The 2018/19 wave did not disaggregate household private and public transportation.

Source: Authors' calculations based on 2012/13, 2015/16, and 2018/19 Nigeria GHS-LSMS data.

Table A3 2016 Descriptive statistics sub-sample descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Expenditure					
Petrol	4,251	21,366.10	57,239.72	0	2,190,000.00
Electricity	4,251	11,405.35	20,367.85	0	615,683.31
Transport	4,251	40,693.83	89,056.38	0	3,229,381.00
Kerosene	4,251	6,893.74	9,325.45	0	280,697.16
Other energy	4,251	9,158.74	21,607.52	0	511,000.00
Total energy	4,251	89,517.75	131,792.64	24.33	3,434,389.30
Expenditure share					
Petrol	4,251	0.20	0.26	0	1
Electricity	4,251	0.14	0.20	0	1
Transport	4,251	0.38	0.33	0	1
Kerosene	4,251	0.14	0.21	0	1
Other energy	4,251	0.14	0.24	0	1
Log prices					
Petrol	4,251	4.39	4.26	0	12.65
Electricity	4,251	4.45	4.05	0	12.12
Transport	4,251	6.25	4.12	0	13.16
Kerosene	4,251	5.42	3.30	0	11.04
Other energy	4,251	3.46	3.89	0	12.45
Demographic variables					
Location					
Rural	4,251	0.66	0.48	0	1
Urban	4,251	0.34	0.48	0	1
Household head					
Female	4,251	0.04	0.19	0	1
Head	4,251	0.96	0.19	0	1
Ownership if bike					
No	4,251	0.65	0.48	0	1
Yes	4,251	0.35	0.48	0	1
Household size	4,251	6.04	3.37	1	31
Total Expenditure	4,251	952,613.25	898,249.04	83,391.30	14,702,299.00

Note: Obs stands for number of observations in the study sample. Transport is total transport expenditure. The 2018/19 wave did not disaggregate household private and public transportation.
Source: Authors' calculations based on 2012/13, 2015/16, and 2018/19 Nigeria GHS-LSMS data.

Table A4 2013 Sub-sample descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Expenditure					
Petrol	4,439	14,084.97	31,924.05	0	547,500.00
Electricity	4,439	8,712.05	15,562.38	0	292,000.00
Transport	4,439	30,789.40	59,841.07	0	1,626,857.10
Kerosene	4,439	6,339.79	6,894.11	0	73,000.00
Other energy	4,439	7,576.88	31,840.13	0	1,191,116.60
Total energy	4,439	67,503.10	96,277.43	121.67	1,980,973.30
Expenditure share					
Petrol	4,439	0.16	0.24	0	1
Electricity	4,439	0.15	0.22	0	1
Transport	4,439	0.35	0.33	0	1
Kerosene	4,439	0.21	0.27	0	1
Other energy	4,439	0.14	0.24	0	1
Log prices					
Petrol	4,439	3.43	4.11	0	12.12
Electricity	4,439	4.06	3.94	0	12.30
Transport	4,439	5.57	4.20	0	13.16
Kerosene	4,439	5.87	2.71	0	9.74
Other energy	4,439	3.07	3.74	0	12.48
Demographic variables					
Location					
Rural	4,439	0.67	0.47	0	1
Urban	4,439	0.33	0.47	0	1
Household head					
Female	4,439	0.05	0.22	0	1
Head	4,439	0.95	0.22	0	1
Ownership if bike					
No	4,439	0.98	0.13	0	1
Yes	4,439	0.02	0.13	0	1
Household size	4,439	6.09	3.21	1	31
Total Expenditure	4,439	793,931.24	1,671,299.30	39,105.31	56,819,180.00

Note: Obs stands for number of observations in the study sample. Transport is total transport expenditure. The 2018/19 wave did not disaggregate household private and public transportation.
Source: Authors' calculations based on 2012/13, 2015/16, and 2018/19 Nigeria GHS-LSMS data.

Appendix 3 Gender-disaggregated welfare loss dynamics

In this Appendix, we rationalise why an in-depth gender-disaggregated analysis was not carried out, the approach used to obtain insights, and suggestion for future studies in this area.

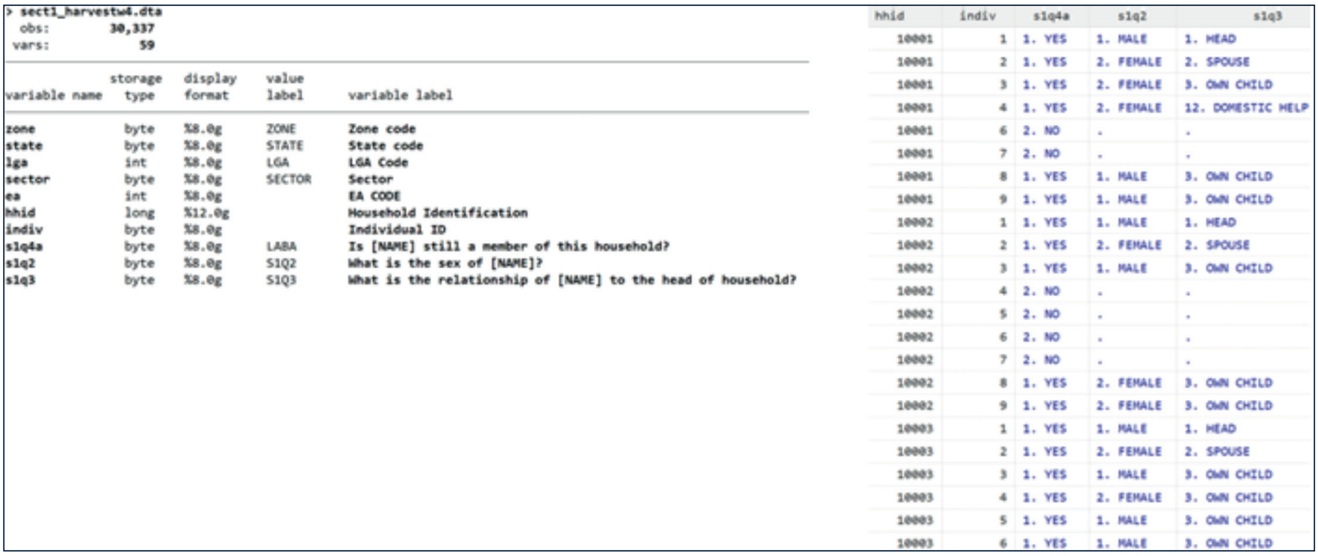
Methodological considerations and data limitations: the QUAIDS model is renowned for its robustness in analysing expenditure patterns and deriving price and income elasticities across different commodities, making it particularly suitable for evaluating policy impacts on household welfare. A crucial prerequisite for the application of QUAIDS is the availability of a large and representative dataset that allows for reliable estimation of parameters. Our overall sample, characterised by 95% male-headed and 5% female-headed households, presented a significant challenge for conducting a gender-disaggregated analysis. This is latter group is further reduced if the focus is on female-headed households who reported expenditure on petrol—a low share. The disproportionally small representation of female-headed households raises concerns about the statistical validity and reliability of separate estimates for this group. Thus, the limited sample size of female-headed households could lead to unstable estimates, potentially distorting the interpretation of gender-specific impacts.

Future research opportunities: we recognise the critical importance of examining the differential impacts of energy policy reforms on male-headed versus female-headed households. The current study lays the groundwork for future research that could specifically address this aspect, using datasets that offer a more balanced representation of household types or employing methodologies designed to explore intra-household disparities. This direction not only complements the findings of our study but also enriches the literature on the socio-economic effects of energy policies.

Below, we detail key characteristics of the data (and sample) used for the analysis.

Regarding household interviewees, there are different practices used in LSMS-type household surveys:

1. the household head is interviewed
2. whoever is available when the enumerator shows up is interviewed
3. multiple members of the household are interviewed, with the most knowledgeable respondents providing different pieces of information wherever possible.

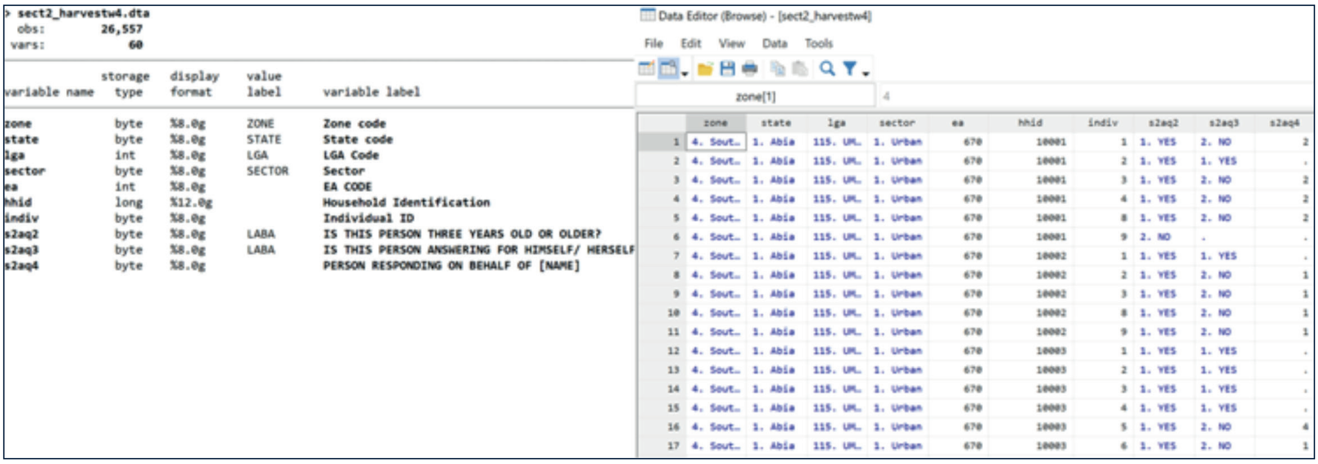


> sect1_harvestw4.dta
obs: 30,337
vars: 59

variable name	storage type	display format	value label	variable label
zone	byte	%8.0g	ZONE	Zone code
state	byte	%8.0g	STATE	State code
lga	int	%8.0g	LGA	LGA Code
sector	byte	%8.0g	SECTOR	Sector
ea	int	%8.0g		EA CODE
hhid	long	%12.0g		Household Identification
indiv	byte	%8.0g		Individual ID
s1q4a	byte	%8.0g	LABA	Is [NAME] still a member of this household?
s1q2	byte	%8.0g	S1Q2	What is the sex of [NAME]?
s1q3	byte	%8.0g	S1Q3	What is the relationship of [NAME] to the head of household?

hhid	indiv	s1q4a	s1q2	s1q3
10001	1	1. YES	1. MALE	1. HEAD
10001	2	1. YES	2. FEMALE	2. SPOUSE
10001	3	1. YES	2. FEMALE	3. OWN CHILD
10001	4	1. YES	2. FEMALE	12. DOMESTIC HELP
10001	6	2. NO	.	.
10001	7	2. NO	.	.
10001	8	1. YES	1. MALE	3. OWN CHILD
10001	9	1. YES	1. MALE	3. OWN CHILD
10002	1	1. YES	1. MALE	1. HEAD
10002	2	1. YES	2. FEMALE	2. SPOUSE
10002	3	1. YES	1. MALE	3. OWN CHILD
10002	4	2. NO	.	.
10002	5	2. NO	.	.
10002	6	2. NO	.	.
10002	7	2. NO	.	.
10002	8	1. YES	2. FEMALE	3. OWN CHILD
10002	9	1. YES	2. FEMALE	3. OWN CHILD
10003	1	1. YES	1. MALE	1. HEAD
10003	2	1. YES	2. FEMALE	2. SPOUSE
10003	3	1. YES	1. MALE	3. OWN CHILD
10003	4	1. YES	2. FEMALE	3. OWN CHILD
10003	5	1. YES	1. MALE	3. OWN CHILD
10003	6	1. YES	1. MALE	3. OWN CHILD

In Nigeria's case and in practice, it is mostly **Option 2** – whoever is around when the enumerator shows up is interviewed (NBS, 2020). This can be seen in the individual survey data files provided by the National Bureau of Statistics (NBS) and the World Bank, as shown in the screenshots. Here, the interviewers meet with available household members. The variable **'indiv'** stands for represents each household member's code in ascending order, starting from the household **head (code 1)** to **spouse (code 2)**, and others.



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vars: 60

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sector	byte	%8.0g	SECTOR	Sector
ea	int	%8.0g		EA CODE
hhid	long	%12.0g		Household Identification
indiv	byte	%8.0g		Individual ID
s2aq2	byte	%8.0g	LABA	IS THIS PERSON THREE YEARS OLD OR OLDER?
s2aq3	byte	%8.0g	LABA	IS THIS PERSON ANSWERING FOR HIMSELF/ HERSELF
s2aq4	byte	%8.0g		PERSON RESPONDING ON BEHALF OF [NAME]

Data Editor (Browse) - [sect2_harvestw4]
File Edit View Data Tools
zone[1] 4

	zone	state	lga	sector	ea	hhid	indiv	s2aq2	s2aq3	s2aq4
1	4. Sout..	1. Abia	115. UM..	1. Urban	670	10001	1	1. YES	2. NO	2
2	4. Sout..	1. Abia	115. UM..	1. Urban	670	10001	2	1. YES	1. YES	.
3	4. Sout..	1. Abia	115. UM..	1. Urban	670	10001	3	1. YES	2. NO	2
4	4. Sout..	1. Abia	115. UM..	1. Urban	670	10001	4	1. YES	2. NO	2
5	4. Sout..	1. Abia	115. UM..	1. Urban	670	10001	8	1. YES	2. NO	2
6	4. Sout..	1. Abia	115. UM..	1. Urban	670	10001	9	2. NO	.	.
7	4. Sout..	1. Abia	115. UM..	1. Urban	670	10002	1	1. YES	1. YES	.
8	4. Sout..	1. Abia	115. UM..	1. Urban	670	10002	2	1. YES	2. NO	1
9	4. Sout..	1. Abia	115. UM..	1. Urban	670	10002	3	1. YES	2. NO	1
10	4. Sout..	1. Abia	115. UM..	1. Urban	670	10002	8	1. YES	2. NO	1
11	4. Sout..	1. Abia	115. UM..	1. Urban	670	10002	9	1. YES	2. NO	1
12	4. Sout..	1. Abia	115. UM..	1. Urban	670	10003	1	1. YES	1. YES	.
13	4. Sout..	1. Abia	115. UM..	1. Urban	670	10003	2	1. YES	1. YES	.
14	4. Sout..	1. Abia	115. UM..	1. Urban	670	10003	3	1. YES	1. YES	.
15	4. Sout..	1. Abia	115. UM..	1. Urban	670	10003	4	1. YES	1. YES	.
16	4. Sout..	1. Abia	115. UM..	1. Urban	670	10003	5	1. YES	2. NO	4
17	4. Sout..	1. Abia	115. UM..	1. Urban	670	10003	6	1. YES	2. NO	1

In the screenshot below, in household id (**hhid**) **10001** for example, the **spouse** (**code 2**) is responding on behalf of the household, whereas the **head** (**code 1**) is responding on behalf of the household in **hhid 10002**.

With respect to the gender shares of household heads, male-headed households dominate, accounting for more than 93% in each of the survey waves. The table below presents an overview of the most recent wave – the 2018/19 wave in the welfare effects simulation.

Table A5 Distribution of male- and female-headed households by income group for the 2018/19 sample

	Percentage of total households	
Income class	**Female-headed**	**Male-headed**
1	0.04%	7.45%
2	0.19%	15.21%
3	0.52%	20.24%
4	1.11%	25.42%
5	3.14%	26.68%

Note: 2018/19 survey round is the most-recent survey for simulation.

The comparatively lower proportion of female-headed households (to male-headed households) across the income groups in the national survey constrains an in-depth gender-decomposed analysis in the current study. We note here that the data cleaning process is a common practice in applied research. Importantly this study considers only households for which there are at least one expenditure on each of the energy goods considered in this study, as well as observation for the demographic variables.

Further, this report refers to the existing literature for evidence of the potential heterogenous welfare effects of energy price changes across household headship – male and female. One key observation is striking; there is a dearth of literature investigating detailed gender-decomposed impacts of energy price changes on household welfare. However, a recent study (Ramírez et al., 2021) investigates the impact of Mexico's energy reform on consumer welfare in Mexico. The study closely aligns with the current analysis, shedding light on the nuanced effects of energy reforms. The study offers key insights, particularly because Mexico shares several economic parallels with Nigeria. Both countries are notable oil producers that have historically relied on fossil fuel subsidies to stabilise domestic energy prices. These similarities suggest that the impacts observed in Mexico could offer predictive insights into the potential repercussions of similar reforms in Nigeria, making their findings especially pertinent.

Overall, the study finds that variations in consumer surplus associated with the increased petrol prices are negative. Further, their results show that welfare loss occurs for all households in the country regardless of urban and rural settlement types, and gender of household heads. Consistent with our estimates, the study finds that price changes due to subsidy reforms are progressive in the urban areas.

However, comparatively, the results show varying welfare loss dynamics across urban-rural areas and head of household types:

Urban sector analysis:

1. **Overall impact**: the complete urban sample shows a more significant welfare loss in female-headed households (-0.0531) compared to male-headed households (-0.0448). This suggests that energy price reforms have a disproportionately negative effect on households led by women in urban areas.

2. **Income stratification**: when broken down by income level, the result indicates that the highest welfare loss for both genders is in the 'High' income category (-0.0652 for males and -0.0556 for females). This could imply that higher-income households consume more energy and thus are more affected by subsidy removal.
3. **Comparative gender impact**: interestingly, in the 'Medium' income bracket, female-headed households (-0.0498) experience a slightly greater welfare loss than male-headed households (-0.0494), aligning with the overall trend of a greater burden on female-led households.

Rural sector analysis:

1. **Overall impact**: in the rural sector, female-headed households also generally exhibit a greater welfare loss (-0.0458) compared to male-headed households (-0.0377) when subsidies are removed. This consistent pattern across both urban and rural sectors emphasises the greater vulnerability of female-headed households to energy price reforms.
2. **Income stratification**: the pattern in rural areas somewhat mirrors that of the urban sector with the 'High' income category facing the largest welfare loss. However, the differential between male (-0.0601) and female (-0.0525) headed households in the 'High' category is less pronounced than in urban areas.
3. **Equivalence across genders in the middle bracket**: a notable insight in the rural data is the equal welfare loss for male and female-headed households in the 'Medium' income bracket (-0.0442 for both), which contrasts with the urban data where female-headed households were slightly worse off.

Cross-sectoral insights:

1. **Gender sensitivity**: across both urban and rural samples, female-headed households tend to incur a larger welfare loss due to energy price reforms than male-headed households. This could reflect differences in energy consumption patterns, income elasticity of demand for energy, or a combination of both.
2. **Influence of income levels**: high-income households experience the most significant welfare loss in both sectors, which could be indicative of a higher marginal propensity to consume energy. However, it also suggests that energy price reforms may be progressive, impacting higher-income households more severely in absolute terms, although the relative impact on lower-income households' welfare could be greater.
3. **Rural vs. urban differential**: comparing the complete samples of both sectors, it appears that the urban sector experiences a slightly higher welfare loss than the rural sector. This might be due to a greater dependency on subsidised energy in urban settings or a more substantial change in prices relative to income levels in these areas.

Policy implications:

1. **Targeted financial assistance:** implement direct financial assistance programs for women-led households to mitigate the impact of energy price increases, ensuring these programmes are easily accessible and tailored to the needs of this vulnerable group.
2. **Enhanced social safety nets:** strengthen social safety nets specifically designed to support women-led households affected by energy price reforms, including cash transfers and emergency energy vouchers.

3. **Gender-inclusive policy design:** incorporate gender analysis in all stages of energy policy planning and implementation to ensure the unique needs of women-led households are considered and addressed.
4. **Women's participation in decision-making:** establish mechanisms for the active participation of women, particularly those heading households, in energy policy decision-making processes, ensuring their voices and concerns shape equitable and effective energy policies.
5. **Progressive pricing structures**: the higher impact on wealthier households suggests that a progressive pricing system, where higher consumption leads to higher prices, may help address equity concerns while maintaining the incentives for reduced energy consumption.

Comprehensive welfare support: the welfare loss across all income categories signals that energy price reforms should be accompanied by broader welfare support programmes to cushion the adverse effects on household welfare.