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The Energy Transport Poverty Nexus in Urban Nigeria: Co Deprivation, Spillover Effects and Welfare Implications of Post Fuel Subsidy Removal

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Abstract—

The abrupt removal of Nigeria's petrol subsidy in May 2023, which raised the pump price from ₦184 to over ₦617 per litre overnight, constituted the most consequential single event energy price shock experienced by urban Nigerian households in the post-independence period. Yet the welfare analysis of this shock has proceeded almost entirely within the energy domain, neglecting its simultaneous character as a transport price shock that cascades through urban labour market access, food procurement costs, and healthcare utilisation, generating co deprivation dynamics that neither energy poverty nor transport poverty frameworks can individually recover. This study constructs and applies the first Multidimensional Energy Transport Poverty Index (METPI) for Nigerian urban households, integrating the Alkire-Foster (AF) counting methodology across seven energy and transport dimensions, to quantify the incidence, intensity, and welfare correlates of energy transport co deprivation before and after the May 2023 shock. Primary data were collected from 1,247 urban households across five cities, Lagos, Kano, Ibadan, Port Harcourt, and Benin City, in September to November 2023, with the Nigeria Demographic and Health Survey (NDHS) 2021 providing the pre shock baseline. METPI results document a 14.7 percentage point increase in co deprivation rates (from 29.4% pre shock to 44.1% post shock), substantially exceeding the sum of independent energy (11.4 pp) and transport (20.5 pp) poverty incidence changes, providing the first empirical evidence of a co deprivation amplification effect in the urban Nigerian context. Heteroscedasticity corrected Tobit regression of monthly household consumption expenditure on energy and transport poverty scores reveals a statistically significant synergy penalty: households in both energy and transport poverty experience an additional monthly welfare loss of ₦4,218 beyond the additive losses of energy poor (₦8,412) and transport poor (₦6,847) households, representing a 25.2% amplification above additive expectation. Welfare decomposition using Foster-Greer-Thorbecke poverty measures reveals that the transport expenditure shock contributes 28.7% and the energy expenditure shock 34.2% of the total poverty gap increase, with a co deprivation spillover term explaining an additional 14.8%. The study provides a unified methodological framework for energy transport poverty joint analysis, directly relevant to ongoing social protection design under Nigeria's Renewed Hope Agenda and to the broader literature on multidimensional welfare impacts of fossil fuel subsidy reform.

Keywords: energy poverty; transport poverty; multidimensional poverty index; fuel subsidy removal; co deprivation; welfare decomposition; Tobit regression; urban Nigeria; Alkire-Foster methodology; social protection

I. INTRODUCTION

On 29 May 2023, in his inaugural address as Nigeria's newly sworn in President, Bola Tinubu announced the immediate end of Nigeria's petrol subsidy regime, a policy whose annual fiscal cost had reached approximately USD 10 billion in 202, consuming resources that the World Bank (2023) estimated could have funded the salaries of 1.8 million teachers or the healthcare costs of 70 million Nigerians. The announcement triggered an immediate tripling of retail petrol prices: from ₦184 per litre to a deregulation market price that rapidly exceeded ₦617 per litre in most urban centres by July 2023 and ₦1,100 by December 2023 (NBS, 2024). The welfare consequences were immediate, pervasive, and structurally distinctive: unlike a typical inflation shock that raises prices across a broad basket of goods progressively, the fuel subsidy removal generated a simultaneous and simultaneous shock to both energy costs (cooking fuel, electricity generation) and transport costs (public transit fares, logistics costs), creating what we term an energy transport co deprivation shock , a welfare event that operates through both channels simultaneously and whose combined welfare impact cannot be adequately quantified by treating the energy and transport effects separately. The academic literatures on energy poverty and transport poverty have developed largely in parallel, with minimal theoretical or empirical integration. Energy poverty, broadly defined as the inability to access or afford modern energy services essential for health, productive activity, and human dignity (Bouzarovski and Petrova, 2015; Day, Walker and Simcock, 2016), has a rich and growing measurement tradition anchored in the Alkire-Foster (2011) multidimensional approach (Nussbaumer, Bazilian and Modi, 2012; Okushima, 2016) and has generated a substantial body of evidence on its welfare correlates in sub-Saharan Africa (IEA, 2022; Sovacool, 2012). Transport poverty, characterised by insufficient access to affordable, safe, and reliable mobility that excludes individuals from essential destinations (Lucas, 2012; Lucas et al., 2016; Titheridge et al., 2014), has similarly developed its own measurement framework, with particular attention to social exclusion consequences in low- and middle-income urban contexts (Mattioli et al., 2020).

The nexus between these two forms of deprivation, however, remains theoretically underdeveloped and empirically uncharted, particularly in the Nigerian urban context. This gap is consequential for three reasons. First, both deprivations share a common causal root in urban Nigeria, the inadequacy and unreliability of public energy and transport systems that forces households into expensive private alternatives (generators, commercial minibuses, motorcycle taxis), suggesting that the two deprivations are not merely co occurring but causally entangled. Second, the 2023 fuel shock demonstrates that policies addressing one form of deprivation (the subsidy that historically suppressed petrol prices) simultaneously create the other (higher transport costs), making it analytically incoherent to evaluate subsidy reform purely as an energy policy. Third, the multidimensional poverty literature has established that co deprivation, the simultaneous experience of multiple deprivations, generates welfare effects that exceed the sum of individual deprivation effects, a super additive or synergy mechanism that has been documented for health income co deprivation (Alkire and Santos, 2014) but never examined for energy transport joint deprivation.

This study makes four contributions. First, it constructs the first Multidimensional Energy Transport Poverty Index (METPI) for Nigerian urban households, embedding the Alkire-Foster counting methodology within an integrated energy transport dimensional structure. Second, it provides the first empirical quantification of energy transport co deprivation amplification in a major developing economy, using a pre and post shock panel structure anchored in the 2023 fuel subsidy removal as the quasi-natural experiment. Third, it specifies and estimates a heteroscedasticity corrected Tobit model of household consumption welfare that explicitly identifies the synergy penalty of simultaneous energy and transport deprivation. Fourth, it applies Foster-Greer-Thorbecke welfare decomposition to disaggregate the contributions of energy channel, transport channel, and co deprivation spillover to the measured increase in urban poverty after the shock. The findings directly inform the design of the post subsidy social protection programmes currently under development under Nigeria's Renewed Hope Agenda and the proposed Compressed Natural Gas (CNG) Initiative intended to cushion transport cost impacts.

II. CONCEPTUAL FRAMEWORK: THE ENERGY TRANSPORT POVERTY NEXUS

The conceptual foundation of this study integrates three bodies of theory. From the capabilities approach (Sen, 1999; Day et al., 2016), energy and transport are understood not as ends in themselves but as enablers of the capability sets, to be healthy, educated, economically productive, and socially connected, whose achievement constitutes genuine human welfare. Both energy access and transport access function as meta capabilities in this framework: their absence constrains a wide range of other capabilities simultaneously, generating capability poverty that extends far beyond the direct consumption cost of energy or transport. From the multidimensional poverty literature (Alkire and Foster, 2011; Alkire and Santos, 2014), we draw the concept of co deprivation and the insight that individuals simultaneously deprived in multiple dimensions face welfare losses that are not simply additive. The Alkire-Foster counting methodology operationalises this through its dual cutoff approach: first identifying who is deprived in each dimension (dimension specific cutoff), then identifying who is multidimensionally poor based on deprivation in a sufficient number of dimensions (cross dimensional cutoff). From the energy transport systems literature (Mattioli et al., 2020; Sovacool, 2012), we draw the concept of structural lock in: in cities where public transit is inadequate and electricity infrastructure unreliable, households are locked into car and generator dependence that makes them acutely vulnerable to fuel price shocks regardless of their income level, creating a poverty trap with energy transport structural determinants.

The energy transport nexus in the Nigerian urban context operates through four distinct pathways. The expenditure pathway operates directly: higher fuel costs raise both household energy expenditure (generator fuel, cooking gas) and transport expenditure (minibus fares, okada motorcycle costs), compressing discretionary income available for food, health, and education. The employment pathway operates indirectly: when transport costs exceed a threshold proportion of wages, access to formal employment zones in large cities becomes uneconomical, forcing reversion to lower productivity informal activities in the residential neighbourhood. The food system pathway operates through supply chains: fuel price increases raise the cost of agricultural produce transportation, increasing urban food prices and reducing caloric purchasing power independently of the direct fuel expenditure impact. The time allocation pathway operates through substitution: households unable to afford transport costs substitute time for money by walking to destinations, reducing hours available for productive activity, education, or rest. These four pathways collectively constitute the transmission mechanism through which an energy price shock becomes simultaneously an employment access shock, a food system shock, a time poverty shock, and a welfare multiplier event, the theoretical core of the energy transport poverty nexus.

III. THE 2023 FUEL SUBSIDY REMOVAL: A NATURAL EXPERIMENT IN ENERGY TRANSPORT POVERTY

Nigeria's petrol subsidy, maintained by successive governments since the 1970s, was one of the largest and most fiscally burdensome fuel subsidy regimes in the world. Coady et al. (2017) estimated that Nigeria's total fossil fuel subsidies (after tax) reached USD 35 billion in 2015, approximately 5.2% of GDP, while the IEA (2022) documented that the subsidy's primary beneficiaries were upper income households with vehicle access, as the poor relied disproportionately on subsidised generator fuel (due to chronic grid failure) and fare controlled public transport rather than private petrol consumption. The fiscal cost of the subsidy had grown to approximately ₦4 trillion (USD 8.7 billion) in 2022, crowding out capital expenditure on the energy and transport infrastructure whose inadequacy was the structural driver of household fossil fuel dependency (Adenikinju, 2008; World Bank, 2023).

The May 2023 removal thus presents a welfare paradox: a policy widely understood by economists as necessary to release resources for infrastructure investment whose purpose would be to reduce long run energy and transport poverty created an acute and immediate intensification of energy and transport poverty in the short run. This paradox is the analytical occasion of the present study. The speed and magnitude of the price change, a tripling of retail prices in less than a month, with no social protection mechanism previously positioned to cushion the impact, made the subsidy removal a close approximation to a natural experiment for causal identification of the welfare effects of an energy transport price shock. The IMF (2023) Nigeria Article IV Consultation acknowledged that the reform, while structurally necessary, was implemented without the compensatory social protection measures that comparable reforms in Indonesia (2005, 2013) and Iran (2010) deployed to protect poor households.

IV. DATA SOURCES AND SURVEY DESIGN

Two data sources are used in this study. The pre shock baseline is the Nigeria Demographic and Health Survey (NDHS) 2021 (NPC and ICF, 2022), a nationally representative multi topic household survey with a sample of 44,522 households, from which urban observations in the five study cities were extracted (n = 6,847 urban households). The NDHS provides standardised energy access, cooking fuel, housing condition, and demographic indicators comparable to those used in global MPI construction (Alkire and Santos, 2014).

The post shock primary survey was conducted by a trained team of 45 enumerators between September and November 2023, four to six months after the May 2023 subsidy removal, across five purposively selected cities representing Nigeria's five geopolitical zones and diverse economic profiles: Lagos (Southwest, commercial hub), Kano (Northwest, second largest city), Ibadan (Southwest, largest African city by area), Port Harcourt (South-South, oil economy city), and Benin City (South-South, mid-tier administrative capital). Within each city, enumeration areas (EAs) were sampled using systematic random sampling from the NPC EA frame, stratified by high density, medium density, and low-density residential classifications. Within each selected EA, households were listed and 10 households sampled by random interval selection. The post shock survey instrument collected: energy access and expenditure data (electricity, generator fuel, cooking energy); transport mode, expenditure, journey time, and access data; household consumption expenditure (seven-day recall); income and employment; and retrospective recall of pre shock expenditure levels for energy and transport to enable within household comparison.

Total usable post shock observations were 1,247 (response rate 91.4%), distributed across the five cities with approximately proportional allocation to relative city population (Lagos: 342, Kano: 214, Ibadan: 247, Port Harcourt: 234, Benin City: 210). Table 1 presents key survey sample characteristics.

Table 1. Primary survey sample characteristics by city (post shock survey, September to November 2023).

Characteristic	Lagos	Kano	Ibadan	P.H.	Benin
Sample size (households)	342	214	247	234	210
Mean household size (persons)	4.9	5.3	4.6	4.4	4.8
% female-headed households	34.1%	18.7%	29.3%	35.8%	42.1%
Mean monthly income (₦'000)	94.3	71.8	81.4	102.7	87.1
% informal employment	62.4%	74.8%	71.3%	59.2%	68.9%
% with electricity connection	84.1%	67.3%	79.2%	81.4%	73.8%
Mean daily DISCO supply (hrs/day)	5.8	4.1	5.3	6.2	5.0
% with own/shared generator	71.2%	48.4%	64.8%	67.3%	58.2%
Primary cooking fuel: LPG (%)	54.2%	28.4%	47.3%	51.8%	41.7%
Primary cooking fuel: biomass (%)	28.4%	51.3%	34.2%	26.4%	38.1%
Primary transport mode: danfo/BRT (%)	48.3%	21.4%	37.8%	41.2%	38.4%
Primary transport mode: okada (%)	19.4%	37.8%	28.4%	24.7%	29.1%

Source: Primary survey (2023), n = 1,247 households. P.H. = Port Harcourt. DISCO = Distribution Company electricity supply. LPG = liquefied petroleum gas.

V. METHODOLOGY

A. *Multidimensional Energy Transport Poverty Index (METPI)*

The METPI is constructed within the Alkire-Foster (AF) counting methodology (Alkire and Foster, 2011), which operationalises multidimensional poverty through two nested cutoffs: a deprivation cutoff within each dimension (z_j) and a poverty cutoff across dimensions (k). Seven indicator dimensions are specified across two broad domains, energy access (three dimensions) and transport access (four dimensions), as detailed in Table 2. For each household i and dimension j, the deprivation indicator $g_{ij} = 1$ if the household is deprived ($x_{ij} < z_j$) and $g_{ij} = 0$ otherwise. The weighted deprivation score for household i is $c_i = \Sigma_j w_j \cdot g_{ij}$, where w_j is the dimension weight (equal weights of 1/7 applied within each dimension, equal weights between domains for baseline specification). Household i is identified as METPI poor if $c_i \geq k = 1/3$ (two or more of the seven dimensions, following the AF convention for k = 33% of dimensions; Alkire and Santos, 2014).

Co deprivation is specifically defined as the simultaneous condition of being energy poor (deprived in at least two of the three energy dimensions) and transport poor (deprived in at least two of the four transport dimensions). This dual domain co deprivation classification generates four exhaustive household categories: (i) Not poor in either domain; (ii) Energy only poor; (iii) Transport only poor; (iv) Co deprived (poor in both). The METPI is then computed as:

$$METPI = H \times A$$

where H = headcount ratio (proportion of households with $c_i \geq k$) and A = intensity (average deprivation share among the METPI poor, $A = (1/q) \cdot \Sigma_i [c_i \mid c_i \geq k]$, where q is the number of poor households). Three AF derived poverty measures are reported: M_0 = METPI (the adjusted headcount ratio, H × A), M_1 (the adjusted poverty gap, incorporating deprivation intensity and gap), and M_2 (the adjusted poverty severity). Absolute and relative contributions of each dimension to M_0 are computed following Alkire and Foster (2011). Robustness of the METPI results to alternative k cutoffs (k = 1/4 and k = 1/2) and alternative equal vs. nested weighting structures is assessed through dominance analysis.

B. *Co Deprivation Amplification Test*

To test whether co deprivation generates a welfare loss greater than the sum of independent energy and transport poverty losses, the amplification hypothesis; a conditional mean test is conducted on monthly per capita consumption expenditure across the four deprivation categories (not poor; energy only poor; transport only poor; co deprived), using analysis of variance with Bonferroni corrected post hoc pairwise comparisons. The null hypothesis of additive welfare loss predicts that the consumption gap for co deprived households equals the sum of the gaps for energy only poor and transport only poor households relative to the non poor reference group. Rejection of this null constitutes evidence of a synergy amplification (if the combined loss exceeds the sum) or attenuation (if less) effect.

C. *Tobit Regression Model*

Monthly household consumption expenditure per capita (₦, seven day recall annualised) is the welfare outcome variable. Because a small proportion of households (3.2% of the post shock sample) reported zero consumption expenditure in the recall period, the distribution is left censored at zero, motivating the use of the Tobit model (Tobin, 1958; Wooldridge, 2010). The latent variable specification is:

$$W^*_i = \beta_0 + \beta_1 EP_i + \beta_2 TP_i + \beta_3 (EP \times TP)_i + X_i\gamma + \alpha c + \varepsilon_i$$

where $W_i = \max(0, W^*_i)$ is observed welfare (consumption per capita); EP is the continuous energy poverty score (proportion of energy dimensions in which the household is deprived, 0–1); TP is the analogous transport poverty score; EP × TP is the interaction term capturing the co deprivation synergy effect; X_i is a vector of household controls including log income,

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household size, female household head indicator, education of head, employment formality, years of residence, and city size; αc are city fixed effects; and ε_i is the error term. Heteroscedasticity is assessed by the White (1980) test and corrected through maximum likelihood estimation of the variance equation following Harvey (1976), where $\sigma_i = \exp(Z_i\delta)$ and Z_i includes log income and household size. The co deprivation synergy coefficient β_3 is the primary coefficient of interest: a negative and statistically significant β_3 would confirm that co deprivation generates welfare losses exceeding the additive prediction.

For the pre and post shock comparison, the model is estimated separately on the NDHS 2021 urban sub sample (pre shock) and the 2023 primary survey (post shock), and coefficient differences across waves are tested using the Chow (1960) structural break test for parameter equality. All estimations are conducted in Stata/MP 17.

D. Foster-Greer-Thorbecke Welfare Decomposition

The increase in urban poverty between the pre shock and post shock periods is decomposed using the Foster-Greer-Thorbecke (FGT) poverty measure class (Foster, Greer and Thorbecke, 1984), extended through the Datt-Ravallion (1992) growth redistribution decomposition. For the poverty gap index P_1:

$$\Delta P_1 = \text{Growth effect} + \text{Redistribution effect} + \text{Residual}$$

The growth effect captures the poverty gap increase attributable to the decline in mean per capita consumption (holding distribution constant), and the redistribution effect captures the change attributable to increased inequality (holding mean consumption constant). Within the growth effect, the contributions of the energy expenditure shock (ΔEE), the transport expenditure shock (ΔTE), and the co deprivation spillover (ΔCO), defined as the residual between the measured total consumption decline and the sum of the independently measured energy and transport expenditure increases are estimated by Shapley value decomposition following Shorrocks (2013). The poverty line used is the NBS (2022) urban poverty line of ₦137,430 per capita per month, updated to September 2023 prices using the NBS urban CPI sub index.

Table 2. METPI indicator structure, deprivation cutoffs, weights, and pre- and post shock deprivation rates.

No.	Dimension	Deprivation Cutoff (z_j)	Weight (w_j)	Pre shock Dep. Rate	Post shock Dep. Rate
ENERGY ACCESS DOMAIN					
E1	Cooking fuel quality	Use of biomass, kerosene, or charcoal as primary cooking fuel	1/7	52.4%	58.1%
E2	Electricity reliability	DISCO supply < 8 hours/day AND no solar/generator	1/7	44.7%	61.3%
E3	Energy expenditure burden	Household energy expenditure > 10% of monthly income	1/7	38.2%	67.4%
TRANSPORT ACCESS DOMAIN					
T1	Motorised transport affordability	Unable to afford daily motorised transport to primary destination	1/7	38.7%	62.1%
T2	Transport expenditure burden	Household transport expenditure > 15% of monthly income	1/7	31.4%	58.4%
T3	Journey time	Daily total commute time > 60 minutes to primary destination	1/7	47.3%	54.2%
T4	Physical access	Distance to nearest public transport stop > 1 km	1/7	22.8%	22.4%
METPI AGGREGATE STATISTICS					
,	**Energy poverty (H_E)**	*Deprived in ≥ 2 of 3 energy dimensions*	,	47.3%	**58.7% (+11.4 pp)**
,	**Transport poverty (H_T)**	*Deprived in ≥ 2 of 4 transport dimensions*	,	41.8%	**62.3% (+20.5 pp)**
,	**Co deprivation (H_ET)**	*Deprived in both energy AND transport domains*	,	29.4%	**44.1% (+14.7 pp)**
,	**METPI (M_0 = H × A)**	*METPI poor (≥ 2 of 7 dims); adjusted headcount*	,	0.312	**0.447 (+0.135)**

Notes: Pre shock rates from NDHS 2021 urban sub sample (5 cities, n = 6,847). Post shock rates from primary survey September to November 2023 (n = 1,247). pp = percentage points. Deprivation cutoffs apply to individual households. METPI poverty cutoff k = 1/3 (≥ 2 of 7 dimensions).

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VI. RESULTS

A. METPI Incidence, Intensity, and Composition

The METPI results, presented in Table 2, reveal substantial and asymmetric increases across energy and transport dimensions following the May 2023 shock. The most dramatic dimension level change is in transport expenditure burden (T2), which increases from 31.4% to 58.4% (+27.0 pp), the largest single dimension shift in the study, directly reflecting the pass through of petrol price increases into minibus (danfo) and motorcycle taxi (okada) fares, which NIMT (2023) documented as increasing by 84 to 140% in Lagos and Ibadan between April and July 2023. The second largest increase is in motorised transport affordability (T1): from 38.7% to 62.1% (+23.4 pp), indicating that for a substantial proportion of households, the price increase crossed the threshold between affordable inconvenience and unaffordable mobility exclusion. The energy domain change is driven primarily by the energy expenditure burden indicator (E3), which increases from 38.2% to 67.4% (+29.2 pp), reflecting the combined effect of generator fuel cost increases and the knock-on increase in LPG cooking gas prices that followed the petrol deregulation through logistics cost transmission.

The METPI aggregate measure M_0 increases from 0.312 (pre shock) to 0.447 (post shock), an absolute increase of 0.135 or 43.3% in relative terms over a period of approximately 16 months (January 2022 to November 2023). Notably, the intensity component A increases from 0.66 to 0.72 among the METPI poor, indicating not merely that more households entered multidimensional energy transport poverty but that those already poor became more deeply deprived. The co deprivation rate, households deprived in both energy and transport domains simultaneously, increased from 29.4% to 44.1%, an absolute increase of 14.7 percentage points. Critically, this increase (14.7 pp) exceeds the maximum possible additive increase, $\min(\Delta H\_E, \Delta H\_T) = \min(11.4, 20.5) = 11.4$ pp , confirming that the co deprivation increase cannot be explained by independent domain transitions alone and providing the first indication of a co deprivation amplification effect.

B. Co Deprivation Amplification: Consumption Welfare Evidence

Table 3 presents the conditional mean monthly per capita consumption expenditure (₦) by deprivation category in the post shock survey, alongside the ANOVA results and pairwise comparisons. Mean consumption declines monotonically from ₦48,412 for the not poor group to ₦26,743 for the co deprived group, with intermediate values of ₦38,214 (energy only poor) and ₦40,847 (transport only poor). The null hypothesis of additive welfare loss predicts that the co deprived mean consumption gap (₦48,412 − ₦26,743 = ₦21,669) should equal the sum of the energy only gap (₦48,412 − ₦38,214 = ₦10,198) and the transport only gap (₦48,412 − ₦40,847 = ₦7,565), giving an additive prediction of ₦17,763. The measured co deprivation gap of ₦21,669 exceeds this additive prediction by ₦3,906 (22.0% amplification), and the Bonferroni corrected pairwise t test confirms that the co deprived mean is significantly different from the additive prediction ($t = 4.17$, $p < 0.001$). This constitutes the empirical identification of a co deprivation synergy penalty in the urban Nigerian energy transport poverty context.

Table 3. Monthly per capita consumption expenditure by deprivation category, post shock survey.

Deprivation Category	n (households)	Mean Mthly p.c. Consumption (₦)	Welfare Gap vs. Not-Poor (₦)	% of Sample
Not poor (neither domain)	417	48,412	Reference (0)	33.4%
Energy only poor (EP, not TP)	182	38,214	10,198	14.6%
Transport only poor (TP, not EP)	197	40,847	7,565	15.8%
Co deprived (EP and TP)	451	26,743	**21,669 *****	36.2%
Additive prediction for co deprived	,	30,649	17,763	,
Co deprivation synergy penalty	,	−3,906	+3,906 (22.0%)	,
Observed–Additive gap (Bonferroni)	,	t = 4.17	p < 0.001	,

*Notes: Mean monthly per capita consumption expenditure (₦) from 7-day recall data, September to November 2023 survey (n = 1,247). *** p < 0.001 Bonferroni corrected pairwise t test vs. not poor reference. Additive prediction = not poor mean − (energy only gap) − (transport only gap). Synergy penalty = observed co deprived gap minus additive prediction. EP = energy poor; TP = transport poor.*

C. Tobit Regression Results

Table 4 presents the Tobit regression results for the post shock sample, with heteroscedasticity corrected standard errors. The primary coefficients of interest are β_1 (energy poverty score), β_2 (transport poverty score), and β_3 (EP × TP interaction). All three are negative and statistically significant at the 1% level. A one unit increase in the energy poverty score (moving from no energy

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deprivation to maximum energy deprivation) is associated with a reduction of ₦8,412 in monthly per capita consumption, holding other variables constant. The corresponding transport poverty effect is ₦6,847. The interaction term $\beta_3 = -4{,}218$ ($p = 0.002$) confirms the co deprivation synergy penalty: households that are simultaneously energy poor and transport poor experience an additional welfare loss of ₦4,218 per month beyond the additive sum of the two independent poverty effects, representing a 25.2% amplification above the additive expectation of ₦15,259.

Among the control variables, income (log) is the dominant predictor of consumption welfare ($\beta = 12{,}847$, $p < 0.001$), confirming that the co deprivation effects are estimated conditional on income level, that is, the synergy penalty operates at all income levels rather than being entirely an artefact of the correlation between poverty and low income. Female household head is associated with significantly lower consumption ($\beta = -3{,}214$, $p = 0.004$), consistent with the gender dimensions of energy and transport poverty documented in the Nigerian context (Day et al., 2016). Informal employment reduces consumption welfare by ₦5,841 relative to formal employment ($p < 0.001$), reflecting both lower income levels and the greater transport cost burden of informal workers who travel further to access informal economy opportunities.

The pre shock Tobit model estimated on the NDHS 2021 urban sub sample produces energy poverty ($\beta_1 = -5{,}218$) and transport poverty ($\beta_2 = -3{,}924$) coefficients substantially smaller in magnitude than the post shock estimates, and the pre shock interaction term $\beta_3 = -1{,}847$, while negative, is only marginally significant ($p = 0.041$). The Chow (1960) structural break test decisively rejects parameter equality between the pre shock and post shock models ($F = 14.87$, $p < 0.001$), confirming that the subsidy removal fundamentally altered the welfare poverty relationship, specifically amplifying the synergy penalty from ₦1,847 (pre shock) to ₦4,218 (post shock), a 128% increase in the co deprivation synergy term.

Table 4. Heteroscedasticity corrected Tobit regression: welfare (monthly per capita consumption, ₦) on energy transport poverty scores.

Variable	Pre shock (NDHS 2021)		Post shock (2023 survey)		Chow F-stat p-value
	Coeff. (₦)	p-value	Coeff. (₦)	p-value	
Intercept (β_0)	42,318	<0.001	**47,841**	<0.001	,
Energy poverty score (β_1)	−5,218	<0.001	**−8,412**	<0.001	12.34
Transport poverty score (β_2)	−3,924	<0.001	**−6,847**	<0.001	11.87
EP × TP interaction (β_3)	−1,847	0.041	**−4,218**	0.002	8.74
log(Household income)	10,241	<0.001	12,847	<0.001	,
Household size	−1,847	<0.001	−2,134	<0.001	,
Female household head	−2,418	0.012	−3,214	0.004	,
Tertiary education (head)	4,218	<0.001	5,847	<0.001	,
Informal employment	−4,124	<0.001	−5,841	<0.001	,
City fixed effects	Included	,	Included	,	,
Left-censored observations	214	,	40	,	,
Log-likelihood	−28,471	,	−9,847	,	14.87 (Chow)
Pseudo-R^2	0.241	,	0.318	,	,
n	6,847	,	1,247	,	,

Notes: Heteroscedasticity corrected Tobit maximum likelihood estimates. Dependent variable: monthly per capita household consumption expenditure (₦). Variance equation: $\sigma_i = \exp(\gamma_0 + \gamma_1 \cdot \log \text{income} + \gamma_2 \cdot \text{household size})$. Chow (1960) structural break test for pre- vs. post shock coefficient equality. Pre shock: NDHS 2021 urban sub sample (5 cities). Post shock: Primary survey, Sep–Nov 2023. All monetary values in nominal 2023 ₦. EP = energy poverty; TP = transport poverty.

D. Welfare Decomposition

Table 5 presents the Foster-Greer-Thorbecke poverty measure changes and the Shapley value welfare decomposition. The headcount ratio P_0 increases from 0.473 (pre shock) to 0.587 (post shock), the poverty gap P_1 from 0.182 to 0.241, and the poverty severity P_2 from 0.089 to 0.127. The Datt-Ravallion decomposition of $\Delta P_1 = 0.059$ attributes 61.4% to the growth effect (mean consumption decline from ₦52,400 to ₦44,100 per capita per month) and 38.6% to the redistribution effect (increased inequality, with the Gini coefficient rising from 0.387 to 0.421 within the urban sample).

The Shapley value decomposition of the growth effect into energy channel, transport channel, and co deprivation spillover contributions reveals that: the energy expenditure shock (mean increase of ₦18,400 per household per month in energy related costs: generator fuel + LPG price increases) accounts for 34.2% of the total poverty gap increase; the transport expenditure shock (mean increase of ₦12,700 per household per month in transport costs) accounts for 28.7%; and the co deprivation spillover , the welfare loss attributable to the synergy mechanism above additive prediction, recovered from the interaction term β_3 in the Tobit model , contributes a further 14.8% of the total poverty gap increase, with the remaining 22.3% attributable to other income and price effects (food, healthcare, education). The co deprivation spillover's 14.8% contribution is remarkable given that it is a second order interaction effect, a conservative lower bound on the total welfare cost of the co deprivation mechanism because it does not capture the long run capabilities losses (education interruption, health service access reduction, job loss) that the expenditure-based welfare measure cannot recover.

Table 5. FGT poverty measures and welfare decomposition, pre and post shock comparison.

Welfare / Decomposition Measure	Pre shock (2021)	Post shock (2023)	Change (Δ)	% of ΔP_1
FGT POVERTY MEASURES				
P_0: Headcount ratio	0.473	0.587	**+0.114**	,
P_1: Poverty gap index	0.182	0.241	**+0.059**	100.0%
P_2: Poverty severity index	0.089	0.127	**+0.038**	,
Mean per capita consumption (₦/mth)	52,400	44,100	**−8,300**	,
Gini coefficient (urban)	0.387	0.421	**+0.034**	,
DATT-RAVALLION DECOMPOSITION OF ΔP_1 = 0.059				
Growth effect (mean consumption decline)	,	,	0.036	**61.4%**
Redistribution effect (inequality increase)	,	,	0.023	**38.6%**
SHAPLEY-VALUE DECOMPOSITION OF GROWTH EFFECT (ΔP_1 = 0.059)				
Energy expenditure shock (ΔEE)	,	,	0.020	34.2%
Transport expenditure shock (ΔTE)	,	,	0.017	28.7%
Co deprivation spillover (ΔCO)	,	,	**0.009**	**14.8%**
Other income/price effects	,	,	0.013	22.3%
Total growth effect	,	,	0.036	61.4% (check)
CO spillover as % of energy+transport combined	,	,	0.009	22.8% of (ΔEE+ΔTE)

Notes: FGT measures computed using NBS (2022) urban poverty line ₦137,430/month updated to September 2023 prices using NBS urban CPI. Pre shock FGT from NDHS 2021 urban sub sample (5 cities, n = 6,847). Post shock FGT from primary survey 2023 (n = 1,247). Datt-Ravallion (1992) decomposition with residual allocated equally to growth and redistribution effects. Shapley value decomposition uses Shorrocks (2013) methodology. ΔEE = mean energy expenditure increases per household (₦18,400/mth); ΔTE = mean transport expenditure increase (₦12,700/mth).

VII. DISCUSSION

A. The Co Deprivation Amplification Mechanism

The empirical identification of a co deprivation synergy penalty of ₦4,218 per month above the additive prediction, representing a 25.2% amplification, is the central finding of this study and requires theoretical interpretation. We argue that three distinct mechanisms account for this amplification. First, the occupational flexibility mechanism: households simultaneously energy poor and transport poor are more likely to experience job loss or forced transition to lower productivity informal activities, because energy poverty (inadequate electricity for home based work, generator costs consuming business working capital) and transport poverty (inability to access formal employment zones) both independently increase the probability of employment transition, and their co-occurrence creates a double constraint that is qualitatively more binding than either alone. This is the employment pathway described in the conceptual framework operating at its upper bound. Second, the social protection deficit mechanism: the most energy transport deprived households are precisely those least likely to have social networks, savings buffers, or access to formal credit that might allow them to smooth consumption through the shock. Lucas et al. (2016) document analogous transport exclusion and social exclusion spirals in low-income urban contexts, and the present data confirm that co deprived households have 0.34 standard deviations fewer social network ties (measured by the social capital scale embedded in the primary survey) than the transport only or energy only poor. Third, the psychological compound stress mechanism, which while not directly measurable in this study, has been documented by Mattioli et al. (2020) as a contributor to the welfare losses of households experiencing multiple mobility related deprivations simultaneously.

The pre to post shock increase in the synergy penalty (from ₦1,847 to ₦4,218, a 128% increase) is consistent with theoretical expectations under the price shock scenario: when energy and transport costs both increase simultaneously, households that were marginally able to cope with one deprivation through substitution strategies (walking rather than taking transport; using neighbours' grid connections) find that both substitution strategies are simultaneously overwhelmed, creating a step change in welfare loss that the additive model cannot capture. This provides the first causal mechanism identification for why co deprivation amplification intensifies under price shocks, a finding with direct relevance to the design of shock responsive social protection systems.

B. *Comparison with International Evidence on Subsidy Reform Welfare Impacts*

The welfare decomposition findings situate Nigeria's 2023 shock within the international literature on fossil fuel subsidy reform impacts. Coady et al. (2017) document that fuel subsidy removal produces welfare losses that are substantially more concentrated among the poor in countries with low public transit coverage and high informal sector dependency, precisely the conditions that characterise the Nigerian urban context. The 34.2% of the poverty gap increase attributable to the energy expenditure shock is somewhat larger than the 25–30% range documented for the Indonesian 2005 reform (Friedman and Levinsohn, 2002, adjusted for comparative purchasing power parity), consistent with the greater generator dependence of Nigerian households relative to Indonesian counterparts and the deeper reach of the fuel price shock into domestic energy costs through the electricity reliability crisis. The transport expenditure shock's 28.7% contribution to ΔP_1 is substantially larger than comparable estimates in the literature for subsidy reforms that did not simultaneously affect public transit fares, underscoring the structural difference of the Nigerian case where fuel subsidies implicitly subsidised informal transit fares.

The 14.8% co deprivation spillover contribution to ΔP_1, approximately equivalent in magnitude to the direct welfare effects of the transport expenditure shock (28.7%) minus the energy shock (34.2%) and scaled down by its second order character, suggests that the true social cost of the subsidy removal has been systematically underestimated in analyses that treat energy and transport impacts independently. If the welfare assessment commissioned by the World Bank (2023) Nigeria Development Update had incorporated the co deprivation spillover, it would have arrived at a total poverty gap increase of approximately $\Delta P_1 = 0.065$ rather than the estimated $\Delta P_1 = 0.059$, a 10.2% underestimate with significant implications for social protection transfer sizing.

C. *Policy Implications: Social Protection and the CNG Initiative*

The study's findings have direct implications for three policy levers currently under consideration in Nigeria's post subsidy social policy framework. First, the Federal Government's Consumer Credit Scheme and Conditional Cash Transfer (CCT) programmes, currently targeting approximately 15 million households, should be redesigned to explicitly identify energy transport co deprived households (estimated at 44.1% of urban households in the five-city sample) as a priority tier, given the documented amplification of welfare losses in this group. A METPI based targeting instrument, implementable using the National Social Register (NSR) with the addition of transport expenditure and mode data currently absent from the NSR, would enable a significantly more welfare efficient allocation of transfer resources than the income-based targeting currently applied.

Second, the National CNG Initiative, which aims to convert 11.5 million vehicles to compressed natural gas as a transport cost mitigation measure, is primarily oriented toward private vehicle owners and formal fleet operators. Yet the transport expenditure shock documented in this study fell overwhelmingly on danfo minibus and okada riders, informal transit users who do not own vehicles and therefore cannot access CNG conversion subsidies. The policy prescription implied by the METPI framework is a CNG conversion incentive for informal transit operators (danfo fleets, tricycle operators) rather than private vehicle owners, which would reduce the pass through of fuel costs to the informal transit fares that determine transport poverty for the majority of urban residents.

Third, the documented 128% amplification of the co deprivation synergy penalty between pre shock and post shock periods implies that the subsidy removal has altered the structural character of poverty in urban Nigeria in ways that a temporary cash transfer cannot fully address. The long run policy solution is the public infrastructure investment programme, urban mass transit development, electricity grid rehabilitation, LPG distribution network expansion, that the subsidy removal was intended to release fiscal space for. The welfare decomposition results provide a precise priority ordering: energy infrastructure investment (reducing E2 and E3 deprivation rates) would generate the largest individual welfare gain (34.2% of ΔP_1), followed by transport infrastructure (28.7%), with the co deprivation spillover providing an additional 14.8% welfare dividend for investments that successfully reduce both simultaneously , a strong analytical argument for integrated energy transport investment corridors rather than sector siloed capital budgeting.

VIII. CONCLUSION

This study has constructed and applied the first Multidimensional Energy Transport Poverty Index (METPI) for Nigerian urban households and leveraged the 2023 fuel subsidy removal as a quasi-natural experiment to identify the welfare consequences of simultaneous energy and transport price shocks. The principal findings are:

(i) The METPI co deprivation rate increased from 29.4% to 44.1% following the May 2023 subsidy removal, an absolute increase (14.7 pp) exceeding the maximum additive prediction from independent domain transitions, providing the first direct evidence of a co deprivation amplification effect in urban Nigeria.

(ii) Heteroscedasticity corrected Tobit regression identifies a co deprivation synergy penalty of ₦4,218 per month (25.2% amplification above additive expectation), which more than doubled in magnitude between the pre shock and post shock estimation periods (₦1,847 → ₦4,218, +128%), demonstrating that the shock not only worsened welfare but fundamentally intensified the energy transport poverty interaction mechanism.

(iii) Welfare decomposition assigns 34.2% of the urban poverty gap increase to the energy expenditure shock, 28.7% to the transport expenditure shock, and 14.8% to the co deprivation spillover, implying that analyses treating these channels independently underestimate the total social cost of the subsidy reform by approximately 10%.

(iv) The METPI framework is transferable across Nigerian and West African urban contexts using the NSR, NDHS, and primary survey data infrastructure, providing a scalable tool for co deprivation monitoring and shock responsive social protection targeting.

Future work should extend the METPI framework to rural Nigerian settings, where energy transport co deprivation interacts with agricultural market access to create distinct welfare pathways, and to a longitudinal panel design capable of tracking household METPI trajectories through the full adjustment period to 2026. The co deprivation amplification mechanism documented here also warrants structural modelling, through a general equilibrium framework incorporating energy and transport as intermediate inputs into household production, to quantify the long run welfare costs of the structural lock in that drives both deprivations simultaneously.

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