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RESEARCH ARTICLE

# The poverty and distributional impacts of carbon pricing on households: evidence from Ghana, Nigeria and Uganda

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**Abstract**
We examine the distributional impact of domestic carbon pricing in three Sub-Saharan African countries. We combine household expenditure surveys and sectoral carbon intensity data derived from a multi-regional input-output model for Ghana, Nigeria and Uganda. Our findings indicate that domestic carbon pricing is progressive in all three countries. This primarily results from higher budget allocations for direct energy consumption in wealthier households, especially concerning motor vehicles and electrical appliances. Disparities in welfare losses within income groups are primarily due to varying energy consumption patterns. Importantly, we identify low-income households as being disproportionately affected by carbon taxes. Lump-sum transfers could fully compensate most households in the bottom two income quintiles, significantly reducing poverty. Our comparative analysis emphasizes the importance of country-specific differences in energy expenditures and carbon intensities in shaping the distributional outcomes of carbon taxes.

**Keywords:** Carbon pricing; distributional effects; poverty; Sub-Saharan Africa; transfers

**JEL classification** D12; Q40; Q56; R15

## 1. Introduction

Carbon pricing is considered an important instrument to reduce the use of carbon-intensive fossil fuels and hence help countries to meet their greenhouse gas reduction targets set in the Paris Agreement (Nordhaus, 2019; Gugler *et al*, 2021). Despite their low carbon emissions today, countries in Sub-Saharan Africa (SSA) have shown high emissions growth rates over the last decade. If growth rates of the economy, population, and energy demand keep their pace, the region might carbonize significantly, unless climate mitigation actions are taken that alter the region's emission path (Steckel *et al*, 2020).

Only a few countries in SSA (such as Côte d'Ivoire or Senegal) are currently considering introducing a carbon price. In most countries, it is politically unlikely to be introduced anytime soon.[1] Yet, there are some arguments to consider a more rapid implementation of carbon prices also in low-emitting, poor countries. First, carbon pricing can be effective in avoiding lock-ins in carbon-intensive infrastructure (Mattauch *et al*, 2015). Second, taxes on emissions can be a feasible way to increase the tax base in developing countries and hence contribute to broader development targets (Besley and Persson, 2014). Third, carbon pricing may be progressive since richer households tend to consume more of the taxable and carbon-intensive goods and services (Dorband *et al*, 2019). Further, climate clubs with carbon pricing and the introduction of carbon border adjustment mechanisms may implicitly push for taxing carbon elsewhere, including in SSA.

Despite the potential progressivity of carbon pricing, one prominent concern against it is the potentially adverse impacts on poverty and specifically vulnerable groups (Dorband *et al*, 2019). Examples include people who are employed in the fossil-fuelled transport sector, satisfy basic needs powered by fossil fuels (such as cooking or transport), or are hit by indirect effects of higher transport and energy prices on food prices. Such potential adverse effects have to be weighed against very limited short- to medium-term emission reductions in return (Jewell *et al*, 2018). The potential trade-off between carbon pricing and poverty reduction is particularly relevant in SSA, where 40 per cent of the population lives below the US$1.90-a-day poverty line (data for 2018), accounting for two-thirds of the global population living in extreme poverty (Schoch and Lakner, 2020). The risk of pushing more people into poverty must be taken very seriously in a region that contributes only little to global emissions.

Prior knowledge about the poverty and distributional effects of carbon pricing is essential to designing policies that mitigate (at least some of) the social downsides. This study therefore provides an ex-ante empirical evaluation of the poverty and distributional impacts of domestic carbon pricing in three African countries.[2] To detect heterogeneous effects and understand which parts of the population are particularly affected, we distinguish between vertical and horizontal inequality effects of carbon pricing, i.e., between and within income groups. To understand which groups are

[1]In the region, only South Africa has a carbon tax. However, because of the differences in income levels and economic structure compared to most other economies in SSA, the country's (still recent) experience is of limited relevance to our analysis.

[2]In this study, we conduct an incidence analysis by calculating the percentage change in total consumption as a proxy for welfare loss and examining how these welfare losses are distributed across and within households' income groups. The term "distributional analysis", as used throughout the paper, refers specifically to this examination of the carbon tax incidence across and within income groups. On the other hand, the term "domestic" carbon pricing indicates that we are solely considering emissions that are released from within the assessed country.

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vulnerable to carbon pricing, we provide an inequality decomposition of the horizontal effects of carbon pricing. We compare Ghana, Nigeria and Uganda to, first, assess the heterogeneity across different African economies, and second, learn about the determinants of poverty and distributional effects of carbon pricing. We look at those three countries as they represent some of the heterogeneity of African economies regarding poverty and inequality, as well as distinct energy consumption patterns and carbon intensities. Ghana is a lower middle-income country (since 2010), with moderate poverty levels, relatively high energy access and a moderately fossil-fuel-dependent power sector. Nigeria is a lower middle-income country as well, but exhibits much higher levels of poverty and energy poverty reflecting the considerable socio-economic inequality in this oil-dependent economy. Uganda is much poorer than the other two countries.[3] Its poverty rate is close to Nigeria's, but access to modern energy remains very low.

Previous analyses on the distributional effects of carbon pricing mainly focus on vertical effects. Welfare effects tend to be mostly regressive in industrialized countries owing to the more carbon-intensive consumption patterns among poorer households (Feng *et al*, 2010; Grainger and Kolstad, 2010; Flues and Thomas, 2015). In low- and middle-income countries (LMICs), most studies find progressive distributional outcomes (see Ohlendorf *et al* (2021) for a recent review), as poor households generally spend a lower share of their expenditures on emissions-intensive energy (Dorband *et al*, 2019). While fuel price increases in LMICs are generally found to be progressive (Sterner, 2012), price increases in electricity, liquefied petroleum gas (LPG), or public transport can be regressive, for instance in Mexico (Renner *et al*, 2018) or Indonesia (Renner *et al*, 2019). There is, however, only limited evidence from SSA on the (potential) distributional consequences of carbon pricing. Dorband *et al* (2022) find progressive results for Nigeria, particularly when revenues are recycled to close infrastructure gaps.

Recently, scholars have put more emphasis on the distributional consequences of energy policies on households within income groups, i.e., horizontal inequality effects (Cronin *et al*, 2019; Fischer and Pizer, 2019; Fremstad and Paul, 2019; Renner *et al*, 2019; Fullerton, 2021; Hänsel *et al*, 2022; Missbach *et al*, 2024). Steckel *et al* (2021) for Asian countries and Missbach *et al* (2024) for countries in Latin America and the Caribbean show that horizontal effects of carbon pricing are usually larger than vertical distributional effects. Hence, a policy reform that appears to be progressive in the aggregate may still imply that particular groups including poor households are heavily affected by the reform. Ownership of "energy process durables," such as motorbikes, are one important source of heterogeneity among households with similar income levels (Renner *et al*, 2019). In the African context, the use of modern fuels for cooking or electricity access may be an additional source (Aggarwal *et al*, 2025). Our study aims to contribute to this evolving literature by providing evidence on both vertical and horizontal distributional effects of domestic carbon pricing in Ghana, Nigeria and Uganda.

[3]The country is in the process of graduating to lower middle-income country status in 2024.

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In this study, we first illustrate the cross-country differences and similarities in (energy) consumption patterns as well as the associated domestic emissions and carbon intensity along the income distribution. Next, we analyse the welfare effects of a relatively ambitious carbon tax of US$40/ton $CO_2$ in each of the aforementioned African countries. For each household, we quantify the welfare losses due to carbon pricing[4] by computing the additional cost required to maintain its initial consumption level considering scenarios with and without revenue recycling (lump sum transfers). We examine both vertical and horizontal variations in the welfare impacts and trace back the sources of the variation in the carbon tax burden to (energy) consumption patterns. Our empirical approach is suited to capture the heterogeneity in household-level emissions from "carbon-taxable" consumption and hence allows for granular distributional analyses.

Our results indicate overall progressive effects of carbon pricing in all three countries, accompanied by sizeable average welfare losses of up to 2.9 per cent in Ghana in a scenario without compensation. These findings suggest that carbon taxation would increase the number of people living in poverty unless appropriate revenue recycling schemes are implemented. The welfare effects vary across households, and we find pronounced within-income group variation. The drivers of this heterogeneity vary not only between countries but also at different income levels. Within-group heterogeneity is greater in the upper tail of the income distribution than in the lower tail. However, variation is more readily captured by our approach in the upper tail, where it is closely linked to observable differences in taxable fuel use associated with ownership of energy-intensive durables such as motor vehicles and refrigerators. In contrast, heterogeneity in the lower tail may be driven more by differences in substitution behaviour or in food consumption patterns, which our approach and data do not fully capture.

Our results should be interpreted in light of several caveats, including the assumption of constant consumption quantities. The analysis does not account for behavioural responses to price changes, such as substitution from taxed modern fuels to untaxed traditional fuels like firewood or charcoal. For some — mainly rural — households, firewood may be freely accessible. If these households switch to firewood, the monetary welfare costs of carbon pricing would be lower than our estimates suggest. However, the literature has shown that this shift or a shift from LPG to charcoal can also generate negative externalities, most notably health and environmental costs (Greve and Lay, 2022; Lenz *et al*, 2023). Thus, our estimates can be interpreted as upper bounds on short-term welfare effects unless such negative externalities are accounted for (see Ohlendorf *et al*, 2021). Both substitution behaviour and the extent of negative externalities are likely to differ systematically between certain groups of households, especially between urban and rural households but also between richer and poorer households.[5]

The remainder of the paper is organized as follows. The following section introduces the expenditure and carbon emissions data. It also presents descriptive statistics.

[4]The terms carbon pricing and carbon tax are used interchangeably throughout the text.

[5]Two recent studies indicate that such behavioural responses are likely to matter. A recent ex-post evaluation of a fossil fuel subsidy removal in Ghana finds that large price increases of LPG led to a rise in average charcoal consumption in urban areas (Greve and Lay, 2022). For Uganda, Aggarwal *et al* (2025) find that higher fossil fuel prices may lead to households using more biomass and firewood.

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Section 3 outlines the applied methods. Section 4 discusses the results on vertical and horizontal variation, respectively. Section 5 looks at revenue recycling schemes before section 6 concludes, along with some policy implications.

## 2. Data and descriptive statistics

### *2.1. Data*

Table 1 indicates considerable differences among these three countries in terms of economic development, energy use and inequality. The average PPP-adjusted GDP per capita in 2023 for Ghana and Nigeria is roughly similar and more than double that of Uganda. However, in current US$, Nigeria's GDP per capita (US$1,597) is closer to the regional average (US$1,623), which is not the case for the PPP-adjusted average. This discrepancy likely reflects Nigeria's overvalued currency (World Bank, 2025a). Further, average consumption estimates from household surveys (deflated to 2014 US$) are much higher for Ghana than for Nigeria. The discrepancy between survey-based consumption measures and GDP per capita may be attributed to the fact that surveys often capture top income (or top consumption) less accurately, which is particularly relevant in Nigeria's highly unequal society. Uganda is much poorer than the two West African countries on average: GDP per capita and per capita consumption from the survey are lowest in Uganda at US$1,002 and US$400, respectively. Accordingly, Uganda has the highest extreme poverty rate with more than 40 per cent. Yet, despite much higher average income, Nigeria's poverty level is very close to Uganda's. In contrast, both extreme and moderate poverty are much lower in Ghana, where access to modern energy is also highest. With its high share of the population still living in poverty and using dirty cooking fuels, Nigeria resembles a low-income country, reflecting the highly unequal distribution of income in this country. Further details about these country-specific contexts are presented in section A.1 of the online appendix.

To assess the welfare impacts of domestic carbon pricing, we rely on annual household consumption expenditures, because it is less sensitive to shocks and exhibits less severe life-cycle patterns compared to income (Cronin *et al*, 2019). We compute our welfare measure from expenditure data from the Ghana Living Standards Survey (GLSS) 2016/17, the Nigeria Living Standards Survey (NLSS) 2018/19 and the Uganda National Household Survey (UNHS) 2016/17.

The surveys comprise detailed consumption modules on yearly, monthly and weekly expenditures on a whole range of consumption items, including food, energy and other consumption. Energy items include fossil fuels (i.e., kerosene/paraffin, petroleum, diesel, LPG, other liquefied cooking fuels and natural gas), electricity, and biomass (i.e., charcoal, marketed firewood and other traditional fuels). We scale up the expenditures on food, energy and other items to one year.

To link consumption to emissions and to estimate the indirect welfare effects, we complement the household expenditure data with carbon emissions data from an environmentally-extended multiregional input-output (MRIO) table, extracted from the Global Trade Analysis Project (GTAP 10) database for the year 2014 (Aguiar *et al*,

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**Table 1.** Country-level statistics

| | Ghana | Nigeria | Uganda | SSA |
|---|---|---|---|---|
| GDP per capita (current US$) | 2260.3 | 1596.6 | 1002.3 | 1622.8 |
| GDP per capita (PPP, current Int.$) | 7543.0 | 6207.4 | 3097.6 | 4766.2 |
| Exp. per capita, from GTAP (current US$) | 900 | 2348 | 471 | – |
| Exp. per capita, from survey (current US$) | 720 | 482 | 400 | – |
| Population (millions) | 33.8 | 227.9 | 48.7 | 1259.9 |
| Poverty headcount at $1.90 a day (% of pop.)[a] | 12.7 | 39.1 | 41.3 | 42.3 |
| Poverty headcount at $3.20 a day (% of pop.)[a] | 29.3 | 71 | 69.6 | 68.5 |
| Access to clean cooking fuels and technologies (% of pop.) | 31.0 | 25.6 | 0.6 | 22.2 |
| Access to electricity (% of pop.) | 85.1 | 60.5 | 20.4 | 51.5 |

Notes: Data on GDP per capita and population are from the year 2023 (World Bank, 2025a). Data on access to electricity and access to clean cooking fuels are from the year 2022 (World Bank, 2025a, 2025b). Expenditure per capita, deflated to 2014 current US$, is obtained from the survey years 2016/17 for Ghana and Uganda and 2018/19 for Nigeria, while the GTAP data corresponds to the year 2014.
[a]Data on poverty headcount for Ghana and Uganda from 2016 and for Nigeria from 2018.

2019).[6] Utilizing the conversion table provided by GTAP, over 200 consumption items from household surveys are matched to corresponding GTAP sectors. Data related details are presented in section B of the online appendix.

We hereby consider solely emissions that have eventually been emitted within the country of investigation. We use the methodology described by Peters *et al* (2011) to construct the MRIO. GTAP covers 141 regions including Ghana, Nigeria and Uganda, and 65 homogenized sectors (see table A1a in the appendix). The coverage of the GTAP data is limited to fossil-fuel-related $CO_2$ emissions, thus the carbon pricing policy considered in this study excludes other greenhouse gas emissions such as methane, nitrogenous oxide, or $CO_2$ emissions from land use change (Dorband *et al*, 2019). Similarly, GTAP disregards emissions from charcoal or firewood; hence, our analysis assumes no resulting price changes for biomass and omits these items, thus excluding indirect effects on biomass consumption.

### 2.2. Descriptive statistics

Figure 1 shows the domestic carbon intensity (in $tCO_2$/US$) of broad consumption categories: fossil fuels (including petroleum, diesel, kerosene and natural gas), electricity, public transportation, food, and other goods (including durable items), taking

[6]Tables A1a and A1b in the appendix give an overview of considered domestic embodied carbon intensities per GTAP sector and how they perform in comparison with the sample of countries.

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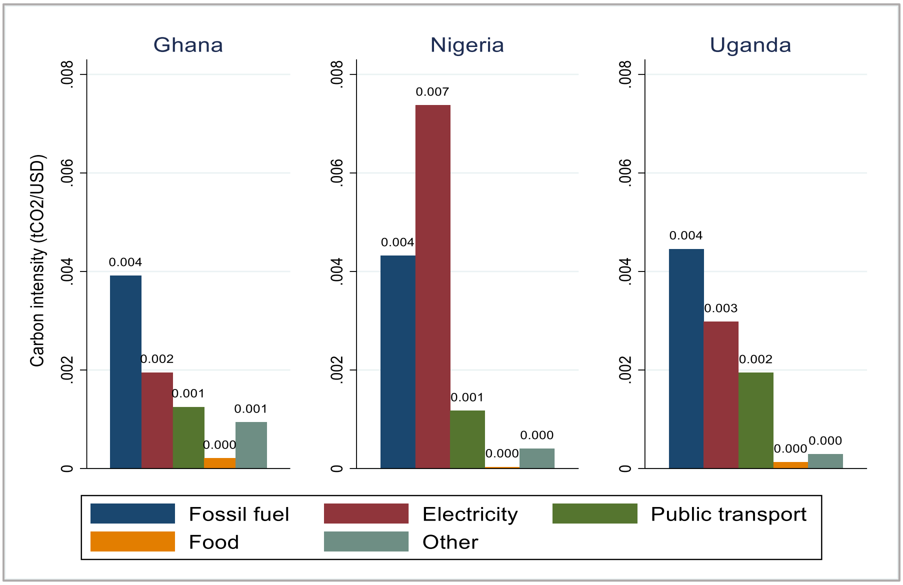


**Figure 1.** Embodied domestic carbon intensity (in tCO2/US$) of selected consumption categories for Ghana, Nigeria and Uganda.

into account local emissions. Of the selected countries, Nigeria has the highest domestic carbon intensity for the electricity sector due to the higher dependence on fossil fuels in electricity generation, especially gas, which accounts for 86 per cent of the on-grid power generation capacity (Oyewo *et al*, 2018). Note that the absolute figures (measured per output in US$ terms) must be interpreted with caution because of the large adjustment factor, which — again — may reflect the overvalued Naira (Nigeria's currency). This may also mean that Nigeria's "true" carbon intensities may even be much higher. In contrast, in Uganda, the main source of electricity generation comes from hydropower (80 per cent), whereas in Ghana it is hydro (38 per cent) together with thermal electricity fuelled by crude oil (61 per cent) (Ministry of Energy, 2021; USAID, 2021). Please note that the intensity alone does not serve as a predictor for the expected incidence.

Table 2 presents each quintile's expenditure share for all consumption items including food, other, and more disaggregated energy items. Further, the bottom panel of the table shows the main cooking fuel used by the household. Figure A1 in the online appendix shifts the focus to energy goods, visually presenting each per capita quintile's expenditures on these items as a share of total expenditures. There is a great heterogeneity in expenditure shares of energy items across income groups and between countries. Average households spend about 11, 7 and 2 per cent of their budgets on energy items (including fossil fuel, electricity and biomass) in Ghana, Nigeria and Uganda, respectively. Nigerian households exhibit the highest shares of fossil fuel expenditure across all income groups. The relatively low average budget share of energy items in Uganda is attributable to the very low incidence of modern fuel use. In all countries, expenditures on fossil fuels, electricity and public transportation typically have a larger budget share in the upper tails of the income distribution. For example, LPG expenditure shares rise with higher incomes and account for about 1 per cent of expenditure of the richest 20 per cent in both Ghana (0.86 per cent) and Nigeria (1.2 per cent).

The increasing consumption shares of energy-intensive goods across income quintiles are consistent with the ownership pattern of electrical appliances and motor vehicles. We illustrate this with some insights from the Nigerian data. For example, only about 2 per cent of the Nigerian households in the bottom quintile own a fridge, while this rate is nearly 60 per cent among the richest income group. The rate of motor vehicle ownership is similarly high among the richest (top 20 per cent) Nigerian households. This compares to less than one-fifth of the households from the poorest income group owning a personal vehicle. In parallel, petroleum expenditure shares in Nigeria increase from about 2.4 per cent in the first quintile to approximately 4 per cent in the fifth quintile. Similar patterns can be observed in Ghana and Uganda, but while the fossil fuel share rises with income in both countries, it is markedly higher only in the fifth income quintile. With about 7 per cent (for quintiles 2 to 5) the expenditure share on public transportation is relatively high in Nigeria (less than 3 per cent in Uganda even among richer most likely urban households, 3.5 to 5.5 in the second to fourth quintile in Ghana). Even the poorest 20 per cent spend 5 per cent of their budget on public transport.

For biomass consumption, mainly used for cooking, we see the opposite patterns. The corresponding expenditure shares fall with higher incomes in Ghana and Nigeria. This is also reflected in the rapid decline of firewood as the main cooking fuel with higher income. However, while in Ghana only 6 per cent of the households in the highest income quintile use firewood, this figure still stands at 33 per cent for Uganda and 25 per cent for Nigeria (see table 2). Transition fuels, including charcoal and kerosene (only in Nigeria owing to the presence of large production sites in the country; see Adeniji *et al*, 2015), exhibit some interesting patterns. While the budget share of charcoal increases monotonically with higher income in Uganda, we can observe an inverted U-shape in the two richer economies, Ghana and Nigeria. This is plausible, as households tend to use more transition fuels before they eventually turn to modern fuels. Modern fuel use, LPG and electricity are more common among richer households, although electricity's role in cooking is (still) negligible in all countries. Ugandan households mainly use firewood and charcoal and, even in the top income quintile, only four per cent of households mainly use modern fuels (table 2, bottom panel).[7]

As presented in table 2, food consumption comprises the greatest expenditure share in Nigeria and Uganda for all quintiles, as well as for the poorest households in Ghana. As expected, the food share decreases with higher incomes (80–50 per cent in Uganda; 46–30 per cent in Ghana). This well-known pattern does not seem to hold for Nigeria where the food expenditure is around 60 per cent for all income groups except the

[7] There is a clear distinction between urban and rural households, with urban households spending a relatively larger share on charcoal and/or kerosene (see table A3 in the appendix).

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**Table 2.** Mean expenditure shares and main cooking fuels by income quintile

| | GHANA | | | | | NIGERIA | | | | | UGANDA | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q5 | Q1 | Q2 | Q3 | Q4 | Q5 | Q1 | Q2 | Q3 | Q4 | Q5 |
| **Expenditure share (%)** | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) |
| Petroleum | 1.18 | 0.89 | 0.58 | 0.71 | 1.86 | 2.42 | 3.25 | 3.74 | 4.21 | 4.16 | 0.31 | 0.29 | 0.31 | 0.66 | 2.03 |
| LPG/gas | 0.01 | 0.08 | 0.29 | 0.54 | 0.86 | 0.01 | 0.11 | 0.30 | 0.67 | 1.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Electricity | 2.03 | 3.45 | 3.90 | 4.35 | 5.11 | 0.50 | 0.90 | 1.07 | 1.38 | 1.52 | 0.01 | 0.09 | 0.33 | 0.60 | 1.15 |
| Public transp. | 2.41 | 3.47 | 4.26 | 5.46 | 6.64 | 5.55 | 7.23 | 7.35 | 7.72 | 7.47 | 0.87 | 1.37 | 1.71 | 2.28 | 2.89 |
| Charcoal | 0.56 | 1.22 | 1.52 | 1.68 | 0.97 | 0.14 | 0.27 | 0.34 | 0.29 | 0.16 | 0.08 | 0.19 | 0.34 | 0.55 | 0.59 |
| Firewood | 1.79 | 0.81 | 0.32 | 0.18 | 0.06 | 3.02 | 1.97 | 1.25 | 0.77 | 0.32 | 0.17 | 0.17 | 0.18 | 0.12 | 0.07 |
| Food | 46.31 | 40.76 | 36.80 | 34.50 | 29.49 | 52.14 | 56.93 | 59.24 | 59.44 | 59.00 | 79.99 | 74.82 | 69.12 | 62.42 | 50.21 |
| Other | 45.70 | 49.33 | 52.32 | 52.59 | 55.00 | 36.22 | 29.34 | 26.70 | 25.51 | 26.16 | 18.56 | 23.09 | 28.00 | 33.37 | 43.05 |
| **Main cooking fuel (shares)** | | | | | | | | | | | | | | | |
| Kerosene | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.10 | 0.23 | 0.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| Charcoal | 0.09 | 0.33 | 0.45 | 0.50 | 0.33 | 0.02 | 0.05 | 0.08 | 0.08 | 0.06 | 0.03 | 0.09 | 0.17 | 0.36 | 0.62 |
| Firewood | 0.91 | 0.63 | 0.39 | 0.19 | 0.06 | 0.97 | 0.90 | 0.75 | 0.51 | 0.25 | 0.96 | 0.90 | 0.83 | 0.63 | 0.33 |
| LPG/gas | 0.00 | 0.03 | 0.14 | 0.29 | 0.55 | 0.00 | 0.01 | 0.06 | 0.16 | 0.44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| Electricity[a] | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | - | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |

*Note:* [a]The Nigerian survey does not directly ask about the main source of cooking fuel but instead reports the fuel used in the primary cook stove and electricity is not among the listed items. For each country, the entries display rounded numbers.

poorest, for whom it is even somewhat lower. The second greatest consumption share in Nigeria and Uganda corresponds to the category for other goods and services with no uniform patterns across countries. Note that differences in survey design, for example, the number and kinds of items included in the questionnaire (see table A2), are likely to explain part of the differences in expenditure patterns across countries (table 2).

## 3. Methodology

We examine a domestic carbon tax of US\$40/t$CO_2$, following the recommendation by the "High-Level Commission on Carbon Prices" about the minimum carbon price level of US\$40-80/t$CO_2$ to be consistent with achieving the Paris Agreement temperature target (World Bank, 2017). Arguably, this is a very high tax rate, especially considering that carbon pricing has not yet been implemented in any low-income countries, and only in a few middle-income countries. For instance, Mexico implemented a tax of US\$3.5 per ton of $CO_2$ equivalent for specific fuels and end-users in 2014 (Prat, 2020); South Africa introduced a carbon tax in 2019 and recently raised the rate to US\$10.09 per ton of $CO_2$ (Steenkamp, 2022; World Bank, 2025c); Indonesia launched a carbon tax (i.e., emissions trading system for the power sector) in 2023 of about US\$0.61 (Yulisman, 2021; World Bank, 2025c). The simulated tax rates are thus likely to be well above what could be achievable or politically feasible in the chosen country cases. We nevertheless want to highlight the potential welfare effects of a carbon tax rate that is consistent with reaching climate goals.

The methodological details of our study are presented in section A.2 in the online appendix. We deliberately focus on the welfare effects of carbon pricing under the conditions prevailing in the three country case studies. One important condition is that traditional fuels like firewood are not taxed, in contrast to modern fuels and electricity. This implies that substitution effects may come into play. There is substantial evidence, including from recent experimental and quasi-experimental studies (e.g., Greve and Lay, 2022; Jeuland *et al*, 2023; Aggarwal *et al*, 2025), that fuel use behaviour among lower-income households is highly price sensitive, and that substitution into untaxed traditional biomass is a likely response to rising modern fuel prices — especially among rural households with easier access to biomass. Importantly, our analysis does not explicitly model such substitution behaviour. Finally, and related to this, our analysis is not concerned with the effectiveness of carbon taxes in reducing emissions. Substitution effects towards traditional fuels might well render carbon taxes less effective in bringing down emissions.[8]

The methodological approach adopted in this study has its merits in terms of granularity that it can provide for distributional analysis. Further, it is simple and tractable and therefore allows us to trace the observed welfare effects of carbon pricing to its key determinants: the importance of specific goods in household consumption, the carbon intensity of these goods, and the size of the tax. Yet, it also has important limitations. While the assumption of constant consumption quantities is standard in evaluations of

[8]An important effect could be emissions that result from deforestation. Note that the literature on the (causal) effect of increased charcoal or firewood use on deforestation is scarce, with some highlighting potentially large effects (Rose *et al*, 2024). We do not consider those effects in our study.

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the short-run effects of carbon pricing (e.g., Renner *et al*, 2019; Steckel *et al*, 2021), there are reasons to doubt whether it holds true even in the short run. Poorer households, constrained by tight budgets, may respond to rising fuel prices by quickly shifting from LPG to cheaper alternatives such as charcoal or firewood, as shown for Ghanaian households by Greve and Lay (2022).

The high price sensitivity of fuel use among low-income households (see also Jeuland *et al* (2023) for LPG subsidies in India) implies a high propensity to switch to untaxed traditional biomass in response to a carbon tax — particularly given the availability of firewood in some rural areas. Such substitution suggests that the incidence estimates presented in this study may overstate the actual welfare losses for some households.

At the same time, substitution opportunities are not uniform across households even within the same income group. For instance, rural households typically have easier access to traditional fuels than urban households. As a result, rural households are more likely to substitute into untaxed biomass. These spatial differences in substitution behaviour are not considered in our analysis, which may hence underestimate the variance of the tax burden, particularly within the lower income quintiles.

While substitution behaviour may dampen the adverse monetary effects of higher taxes, substitution into traditional fuels has been shown to entail important costs. It has been shown that the increased use of traditional biomass can generate significant negative externalities, including elevated indoor air pollution — particularly from particulate matter (PM2.5) (Lenz *et al*, 2023). These externalities are especially pronounced in contexts where access to biomass is unpriced, as is often the case in rural areas. This may be particularly harmful when energy choices are inefficient because of male-dominated intra-household decision-making (Das *et al*, 2022; Chandrasekaran *et al*, 2023; Krishnapriya *et al*, 2024). In light of these considerations, we acknowledge that the estimates provided here serve as a useful upper-bound approximation of short-term welfare impact only when the potential negative externalities associated with substitution toward traditional biomass in response to carbon taxation are ignored. In our view, the short-term time horizon on the household side is in line with our input-output-based partial equilibrium approach that does not capture (long-run) general equilibrium economy-wide effects that would be better analysed using general equilibrium models.

## 4. Results

### *4.1. Vertical progressivity*

For each of the three countries under consideration, the welfare loss of a domestic carbon price of US\$40/t$CO_2$ is computed as a percentage change in total consumption by per capita expenditure percentiles, following the methodology described in section A.2.2. in the appendix. The welfare effects are plotted in figure 2. The downward-sloping incidence curves indicate progressive effects in all three countries, i.e., average losses for poorer households are smaller than those for richer households. Overall, average welfare losses are the lowest in Uganda (1.1 per cent), higher for Nigeria (2.5 per cent) and the highest in Ghana at 2.9 per cent of total expenditures. Note that the relatively low average burden for Nigeria may be caused partially by the overvalued

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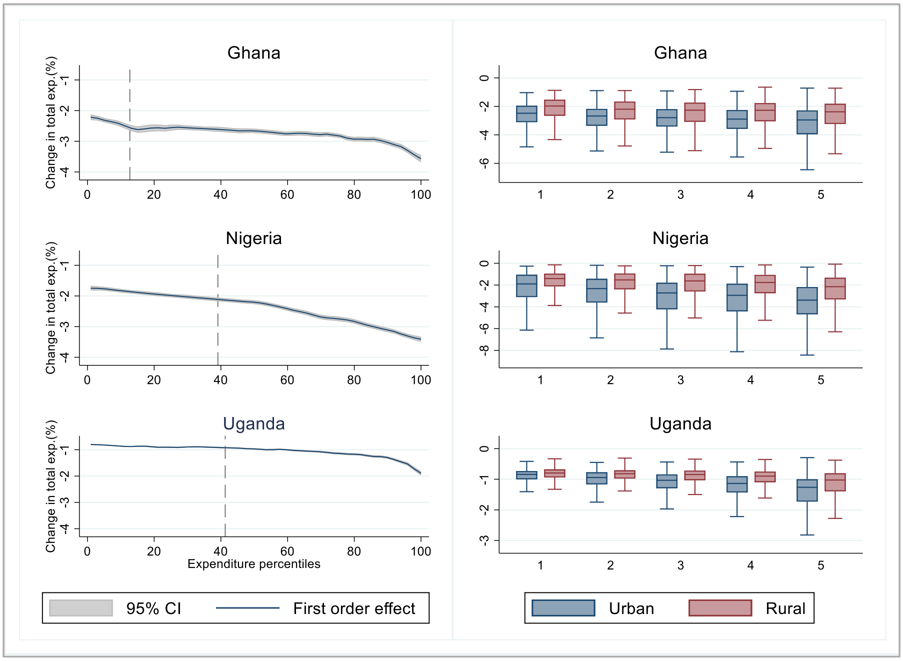


**Figure 2.** Welfare effects of a domestic carbon tax of US$40/tCO2 over the entire income distribution and by urban-rural divide.

*Notes:* The Y-axis represents the percentage change in households' total expenditures. The X-axis in the left and right panel represents expenditure percentiles and quintiles, respectively, which are calculated based on households' total real expenditures. The dashed lines in the left panel indicate the extreme poverty line (at US$1.9 per day). The boxes in the right panel indicate the interquartile range (25th percentile to 75th percentile) and the horizontal line in each box represents the median value. The upper (lower) whiskers capture the upper (lower) percentage changes corresponding to the value at the third (first) quartile plus (minus) 1.5 times the interquartile range.

national currency, so this estimate might be too low. For households living in extreme poverty, the welfare loss amounts to about 2.3 per cent in Ghana, 2 per cent in Nigeria and 0.9 per cent in Uganda (poverty lines are indicated in the left panel of figure 3). The number of people pushed into poverty is about 140 thousand, 1.9 million and 247 thousand in Ghana, Nigeria and Uganda, amounting to an increase in the poverty headcount by 0.51, 0.93 and 0.62 percentage points, respectively. The poverty impacts in Nigeria would also be greater if consumption in US$ were higher. The cross-country differences in the average tax burden are attributable to both household spending patterns and energy systems (now abstracting from exchange rate conversion problems). In Uganda, households rarely use modern (and therefore taxable) fuels, while Nigerian households commonly consume kerosene and richer Ghanaian households use LPG as a main cooking fuel. Further, electricity is generated with a relatively high emission intensity in these two countries compared to Uganda. These factors explain the lower average impact of carbon pricing in Uganda compared to Nigeria and Ghana, which face comparable welfare losses on average.

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**Table 3.** Relative and absolute burden across income quintiles due to domestic carbon taxation

| | Ghana | | | | | |
|---|---|---|---|---|---|---|
| | Avg. | Q1 | Q2 | Q3 | Q4 | Q5 |
| Expenditure per capita ($) | 900 | 185 | 401 | 641 | 995 | 2281 |
| Tax burden per capita ($) | 29.4 | 4.7 | 10.8 | 18.1 | 29.8 | 83.8 |
| Standard deviation | 107 | 3.5 | 4.9 | 7.2 | 11.9 | 231 |
| Incidence (mean, %) | 2.88 | 2.51 | 2.68 | 2.82 | 2.99 | 3.39 |
| | Nigeria | | | | | |
| | Avg. | Q1 | Q2 | Q3 | Q4 | Q5 |
| Expenditure per capita ($) | 2348 | 449.2 | 954.0 | 1597.0 | 2624.3 | 6115.7 |
| Tax burden per capita ($) | 67.9 | 8.6 | 20.5 | 37.7 | 73.4 | 199.1 |
| Standard deviation | 157.8 | 7.5 | 15.5 | 28.1 | 51.5 | 311.2 |
| Incidence (mean, %) | 2.47 | 1.90 | 2.14 | 2.35 | 2.78 | 3.19 |
| | Uganda | | | | | |
| | Avg. | Q1 | Q2 | Q3 | Q4 | Q5 |
| Expenditure per capita ($) | 471 | 136.2 | 222.2 | 314.3 | 463.8 | 1065.7 |
| Tax burden per capita ($) | 6.6 | 1.2 | 2.0 | 3.2 | 5.5 | 19.2 |
| Standard deviation | 15.3 | 0.5 | 0.8 | 1.3 | 3.1 | 28.0 |
| Incidence (mean, %) | 1.11 | 0.86 | 0.92 | 1.00 | 1.16 | 1.60 |

Notes: p.c. = per capita. Standard deviation corresponds to the absolute carbon tax burden per capita in US$. Mean carbon tax incidence is in percentage of total expenditure per capita. The prefix Q stands for quintile, for example. All statistics are calculated using survey weights.

In addition to the average tax incidence, table 3 presents the absolute burden due to the domestic carbon tax in US dollars. An average Nigerian person in the bottom income quintile must increase their expenditures by 2.5 per cent to maintain their current consumption level, which corresponds to a tax burden of US$9. Both absolute and relative burden rise with income: The richest families in Nigeria have, on average, US$200 of tax burden, accounting for 3.2 per cent of these households' total expenditures. In Uganda, where average expenditure is much lower than in Nigeria, the tax burden is much lower also in relative terms at about 1.1 per cent on average, which corresponds to approximately US$7. In both Uganda and Ghana, the domestic carbon tax is fairly progressive: in Uganda people in the bottom quintile exhibit welfare losses of about 0.9 per cent compared to 1.6 per cent for the top quintile. In Ghana, the poorest people would experience a welfare loss of about 2.5 per cent (US$5) on average, compared to 3.4 per cent (US$84) for the richest.

Given the different consumption patterns in rural and urban areas (see table A3 in the appendix), we break down the results in the right panel of figure 2. Among the selected countries, the urbanization rate is the highest in Ghana; here, 51 per cent of households reside in urban areas, which is about 15 and 25 percentage points larger than the rate in Nigeria and Uganda, respectively. In all countries, the effects are still progressive within both rural and urban areas. Yet, progressivity is more pronounced in urban areas, in line with the relatively larger share of the most energy-intensive

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items in urban households' budgets. In Nigeria's rural areas, the progressive effects are somewhat more muted.

The right panel of figure 2 further suggests that there is substantial horizontal variation (within income groups) that tends to be larger in the upper tail of the income distribution. For example, as can be detected upon closer examination of figure 2, the difference in median welfare loss between the second and fifth quintiles in Nigeria, measuring vertical (across income) variation, falls within the interquartile range of the first quintile, indicating horizontal (within-group) variation. We observe a similar pattern in Ghana and Uganda. In the subsequent section, we will delve into this horizontal variation and its underlying sources in greater detail.

Next, we dissect the welfare effects by consumption categories to pinpoint which category primarily contributes to the (vertical) progressivity of the overall carbon tax burden. The results illustrated in figure A1 in the appendix highlight the role of other (non-fossil-fuel) expenditures in all three countries for the effects and progressivity of the carbon tax. In Nigeria, fossil-fuel expenditure matters a great deal and the effects due to these expenditure items are steeply progressive. In Ghana, while there is still a progressive impact stemming from fossil fuels, it is relatively modest compared to the effects of other goods. In Uganda, the fossil fuel incidence curve is flat, indicating that the overall progressivity of the carbon tax only comes from other expenditure items.[9]

### *4.2. Horizontal variation and its sources*

For comparison, we quantify the vertical variation based on the difference in the mean incidence between the most (top) and least (bottom) affected income quintiles, which is 0.9 percentage points for Ghana, 1.3 percentage points for Nigeria and 0.7 percentage points for Uganda (see table 3). Now, we compute a metric of horizontal variation: the incidence differences between the 90$^{th}$ and 10$^{th}$ percentiles of each quintile population when observations within each income group are ordered by percentage welfare loss (see table 4). To illustrate, the difference in percentiles (p90-p10) within the first income quintile is 2.4 percentage points in Ghana, 2.9 percentage points in Nigeria and 0.5 percentage points in Uganda. Conversely, for the wealthiest group, this difference reaches 3.2, 4.4 and 2.1 percentage points respectively.

In Ghana and Nigeria, horizontal variation thus holds greater significance than vertical variation. It is worth noting that, firstly, within each quintile, the horizontal variation is primarily driven by a larger dispersion of losses above the group median (i.e., p90-50, not reported). Secondly, the within-group variation tends to be higher in higher-income groups, with the richest quintile exhibiting particularly high levels of within-group variation.

Next, we apply the Shorrocks (1982) decomposition technique detailed in section A.2.3. in the appendix in order to quantify the relative contribution to the variation of

[9]Although biomass is outside the scope of the incidence analysis, the extensive use of charcoal and firewood especially in Uganda can also explain the progressivity. The lower-income Ugandan households who spend less than 0.5 per cent of their budget on fossil fuels and electricity are likely to meet their energy needs by non-marketed fuels and hence are less affected by carbon pricing (Steckel *et al*, 2021), although higher prices for modern fuels likely prevent adoption of modern, healthier and cleaner fuels such as LPG.

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**Table 4.** Horizontal variation of carbon tax ($40/tCO2) incidence

| | Ghana | | | | |
|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q5 |
| Incidence (P10, %) | 1.41 | 1.60 | 1.75 | 1.83 | 1.90 |
| Incidence (P90, %) | 3.76 | 3.82 | 4.00 | 4.14 | 5.08 |
| Incidence (P90-P10, pp.) | 2.35 | 2.23 | 2.24 | 2.31 | 3.18 |
| | Nigeria | | | | |
| | Q1 | Q2 | Q3 | Q4 | Q5 |
| Incidence (P10, %) | 0.80 | 0.66 | 0.65 | 0.60 | 0.79 |
| Incidence (P90, %) | 3.87 | 3.23 | 3.83 | 4.44 | 5.27 |
| Incidence (P90-P10, pp.) | 3.06 | 2.57 | 3.17 | 3.84 | 4.48 |
| | Uganda | | | | |
| | Q1 | Q2 | Q3 | Q4 | Q5 |
| Incidence (P10, %) | 0.61 | 0.64 | 0.66 | 0.72 | 0.79 |
| Incidence (P90, %) | 1.13 | 1.25 | 1.42 | 1.67 | 2.87 |
| Incidence (P90-P10, pp.) | 0.51 | 0.60 | 0.76 | 0.96 | 2.08 |

Notes: Carbon tax incidence is in the percentage of total expenditure per capita at the respective quintiles Q. The difference is in percentage points. All statistics are calculated using survey weights.

welfare impacts that can be attributed to the respective consumption categories (i.e., factors). We first examine the sources of the overall variation in the carbon tax burden. Then, we decompose the variation within income quintiles to identify the sources of horizontal variation. Note again that these exercises only quantify the variation of welfare changes — without considering the position of the household in the welfare distribution (within the respective quintile).

Figure 3 shows the proportional contribution of consumption categories to the overall variation in the carbon tax burden ($s_k$ from equation (A6), section A.2.3 in the appendix). The findings suggest that fossil fuels contribute the most to the variance of welfare loss due to carbon pricing in Nigeria and Uganda. Among fossil fuels, gas accounts for the largest share (37 per cent) in Nigeria, a finding that is consistent with the high carbon intensity of the gas sector in the country. In Uganda, most variation in welfare impacts comes from petroleum products (67 per cent). Electricity also has a sizable share for Nigeria (22 per cent), less so for Uganda (6 per cent). This is reversed for public transport: it contributes only 5 per cent in Nigeria and 16 per cent in Uganda. In contrast, the tax burden variation in Ghana is mainly due to differences in other expenditures (71 per cent), while fossil fuels contribute only about 17 per cent. This finding can be rationalized by the comparably high embodied domestic carbon intensity of other expenditures in Ghana.[10]

[10] Given the size limit, further detailed results on the decomposition analysis — including breakdowns by rural-urban divide and income quintiles — are discussed in section A.3 of the appendix.

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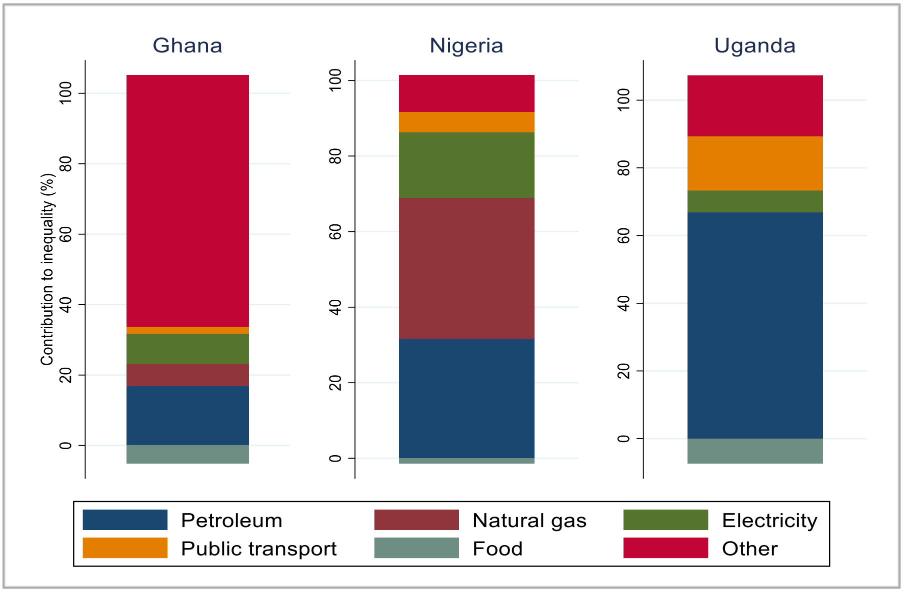


**Figure 3.** Relative contribution of factors to the overall variation in the domestic carbon tax burden.
*Notes:* The proportionate contribution of a factor (i.e., consumption category) to variation of the total carbon tax burden is computed as the ratio of the covariance between the tax burden from that factor and the total carbon tax burden (as described in equation (9)). The percentage relative contributions add up to 100.

Furthermore, the expenditure patterns of relatively affluent Ghanaians differ significantly. It is important to remember that Uganda is generally much poorer, and a substantial number of Nigerian households live below the poverty line. Ghanaian households allocate approximately 52 per cent of their income to 'other' expenses, whereas this figure stands at approximately 29 per cent for Nigerian and Ugandan households. Notably, in none of these countries does food play a significant role in explaining the variation in welfare loss.[11]

## 5. Compensation schemes

Revenues from carbon pricing could be used to alleviate some of its adverse effects. To date, most countries in SSA do not have the capacity to organize effective transfers that can ensure compensation for the majority of the most disadvantaged households (Hanna and Olken, 2018; Bah *et al*, 2019). Yet, the literature frequently discusses the use of transfers as a means to compensate the poorest parts of the population and bolster the acceptability of reforms (Baranzini *et al*, 2017). Improvements in state capacity could well change the feasibility of implementing compensation schemes in the mid-term — which we consider a prerequisite before considering carbon taxes for countries in SSA. In the following, we examine the impacts of lump-sum transfers to examine

[11]Given space constraints, methodological limitations in capturing horizontal variation are discussed in section A.4 of the appendix.

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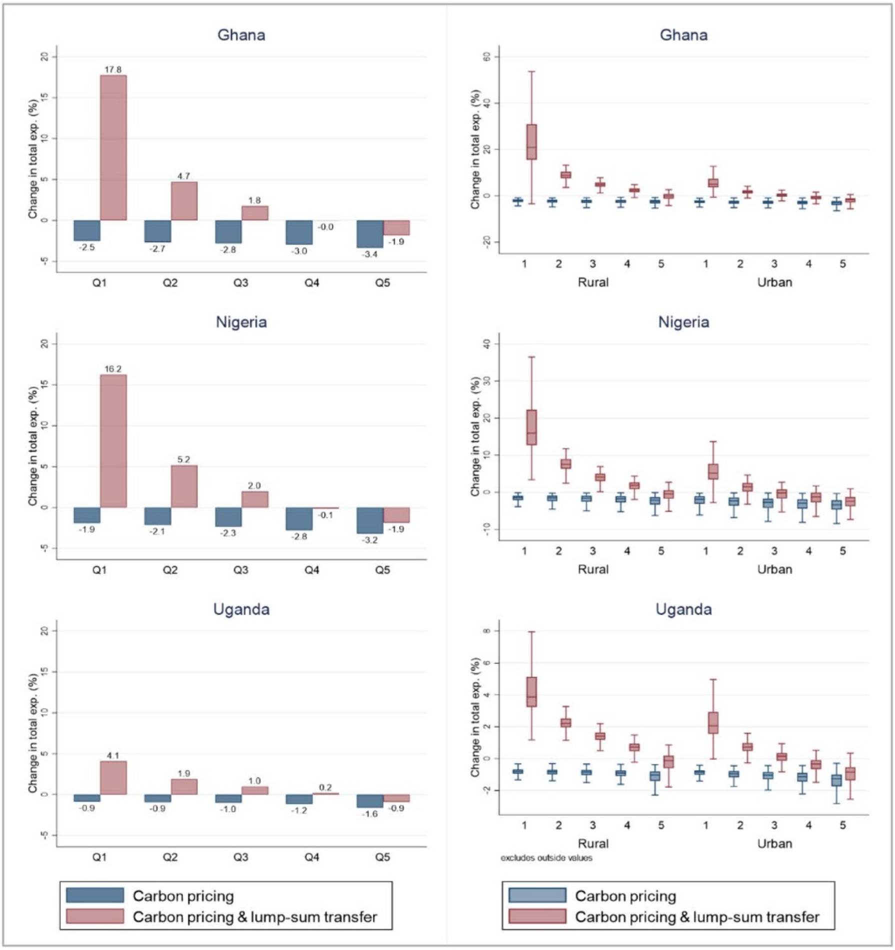


**Figure 4.** Welfare effects of a domestic carbon tax of \$40/tco2 with lump-sum transfers per capita over income quintiles, for the entire distribution and by rural and urban areas.

*Notes:* the y-axis represents the percentage change in households' total expenditures, and the x-axis represents income quintiles that are calculated based on households' total real expenditures. While the left panel depicts average welfare effects due to carbon pricing for the entire sample, the right panel shows the welfare effects by rural and urban areas separately. Both panels show the welfare effects with and without a revenue-recycling scheme. Revenues are distributed to households equally via lump-sum transfers.

whether a simple compensation mechanism can effectively work to mitigate welfare losses in the presence of important horizontal variation.

Figure 4 illustrates the extent to which lump-sum transfers can offset welfare losses resulting from carbon pricing. Due to significant income disparities between the rich and the poor, the latter would benefit greatly from the lump-sum transfer of carbon tax revenue. On average, households in the bottom income quintile would experience substantial net welfare gains, with percentages ranging from 4.1 per cent in Uganda to 16 per cent in Nigeria and 18 per cent in Ghana (as shown in the left panel). While welfare losses due to carbon pricing are on average more than fully compensated for the

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first three quintiles by lump-sum transfers, the richest two quintiles experience minor welfare losses on average in Ghana and Nigeria. The richest households pay the bill, on average.

Hence, carbon taxes with lump-sum transfer schemes are redistributive, on average. Almost all low-income households are more than fully compensated. Despite a large horizontal variation within the bottom quintile, less than 1 per cent of households in this quintile experience a welfare loss after receiving transfers (i.e., 0.4 per cent in Ghana, 0.05 per cent in Nigeria and 0.04 per cent in Uganda). Even in the second quintile, the share of households with welfare losses is very low at 0.9 per cent in Ghana and 1.6 per cent in Nigeria, and at an ignorable level (of 0.3 per cent) in Uganda. Among middle-income households (quintile 3), these shares rise to 6 per cent in Ghana, 10 per cent in Nigeria and 3 per cent in Uganda. Only by the fourth quintile, does a significant share of Ugandan households — around 21 per cent — face welfare losses despite lump-sum transfers.

From a "horizontal perspective," an interesting pattern emerges. The lump-sum transfers create huge gains for some poor households, which were not hurt much by the carbon tax. The transfer scheme, however, produces huge variation in welfare changes (see figure 4, right panel), as an important number of poor households would have experienced substantial welfare losses in the absence of the transfers. This pattern is most visible in the bottom quintile of both the urban and rural income distribution. For higher income groups, the horizontal variation (as can be seen from the boxplots) does not differ much between the schemes with and without revenue-recycling.

Lump-sum transfers would be particularly beneficial for rural households in the bottom quintile when compared to other income quintiles and their urban counterparts (figure 4, right panel). While the rural households are, on average, fully compensated up to the fourth income quintile, an average middle-income urban household (third quintile) experiences welfare losses despite the transfers. Urban households that experience welfare losses in the third (and fourth) quintile exhibit higher expenditure shares of direct energy consumption and lower food expenditure share, while also earning slightly more income (see tables A4–A6 in the appendix[12]). The same is also observed for rural households. Hence, even among middle-income households, those with slightly higher total expenditures experience larger welfare losses due to higher energy expenditure shares even after receiving lump-sum transfers.

Consequently, lump-sum transfers reduce the poverty incidence significantly: in Ghana, the percentage of poor people living in extreme poverty decreases from about 12.7 per cent to about 10.4 per cent — a 2.3 percentage point reduction. The lump sum transfers are less effective in alleviating poverty in Nigeria and Uganda where we observe a 1.3 and 0.6-percentage point decrease in the poverty incidence, respectively (down from 39.1 per cent in Nigeria and 41.3 per cent in Uganda as of 2016; see table 1).

[12]Tables A4, A5 and A6 show the mean differences in the expenditure shares between households experiencing welfare loss and those experiencing gains for urban and rural areas, separately. The tables are limited to income quintiles 3 and 4 because the poorer households are almost fully compensated, while the richest quintile is less interesting from a policy perspective.

A promising complementary approach to lump-sum redistribution could involve adjusting other tax policies, such as reducing VAT on food. This could potentially enhance the progressivity of the overall policy package, particularly for middle-income households who may experience welfare losses despite receiving transfers. An important unknown, however, in VAT reforms in developing countries with large informal sectors is the share of (food) consumption that is effectively covered by VAT. The feasibility and effectiveness of such a combined policy would depend on the baseline VAT rates, the pass-through of VAT reductions to consumers, and the relative importance of food expenditures — covered by VAT — across income groups. Further research could explore such complementary fiscal measures in greater detail.

## 6. Discussion and conclusion

We investigate the distributional effects of domestic carbon pricing in three SSA countries — Ghana, Nigeria and Uganda — considering both vertical and horizontal effects. Our findings indicate that domestic carbon pricing has moderately progressive effects in all these countries, aligning with and extending previous evidence on the distributional impacts of carbon taxation. This pattern is driven by the relatively lower energy expenditure shares of poorer households, as observed in other low- and middle-income countries (Dorband *et al*, 2019; Ohlendorf *et al*, 2021). The progressive effects are in contrast to those observed in industrialized countries, which often report regressive welfare effects due to higher energy expenditure shares among poorer households (Grainger and Kolstad, 2010; Flues and Thomas, 2015).

Our comparative approach reveals a considerable cross-country heterogeneity in the magnitude of the effects highlighting the need to "look beyond averages" when discussing climate policy in SSA. For a domestic carbon tax of US$40/ton $CO_2$ without revenue recycling, we find average income losses ranging from about 1.1 per cent in Uganda to 2.5 per cent in Nigeria and 2.9 per cent in Ghana. These differences in average carbon tax burden originate from a combination of country-specific factors. In Uganda, the main reason for a relatively low burden is the low average access to and use of modern fuels combined with a low-carbon energy sector. In Ghana and Nigeria, the same carbon tax level leads to higher average welfare losses because energy systems are more fossil-fuel dependent, especially in Nigeria. Yet, adverse welfare is higher in Ghana since the use of "taxable" energy sources is far more widespread than in Nigeria. There are also commonalities: in all three countries, urban households are relatively more affected by the carbon pricing scheme, though the difference in welfare losses between urban and rural areas is comparatively small. This is in line with findings by Connolly *et al* (2022) showing that for regions below the global average carbon footprint, urban settlements have a higher footprint than rural areas.

Our study highlights significant horizontal heterogeneity within income groups, aligning with the findings from other world regions. This within-group variation is particularly pronounced among wealthier households but also present among lower-income households. Even carbon taxes that would be judged progressive overall may impose substantial burdens on specific subgroups, such as households with high energy consumption due to their reliance on modern cooking fuels or transport needs (Renner *et al*, 2019; Aggarwal *et al*, 2025).

Accordingly, decomposing the variation in the carbon tax burden, we show that direct energy expenditures on petroleum products, natural gas/LPG and electricity explain the largest part of this variation in Uganda and Nigeria. Direct energy consumption is closely tied to the ownership of motor vehicles and electrical household appliances. In Ghana, the richest of the three countries studied, expenditures on non-energy goods matter more. The carbon intensity of energy is also critical: for example, Uganda's relatively clean electricity supply reduces the role of electricity in carbon tax burden variation, while Nigeria's high leakage rates make natural gas particularly "dirty," driving heterogeneity in welfare impacts within richer quintiles.

These findings reinforce the importance of revenue recycling mechanisms, such as lump-sum transfers, in mitigating poverty impacts. Our analysis shows that a 40-dollar carbon tax would lead about 140 thousand people in Ghana, 1.9 million in Nigeria and 247 thousand in Uganda to fall below the international poverty line (at US$1.90 a day) — without compensation through revenue recycling. However, in principle, simple lump-sum transfers could fully compensate the poorest households. This aligns with findings from both developed (Fremstad and Paul, 2019) and developing countries (Sterner, 2012), demonstrating that redistribution schemes are critical for addressing equity concerns.

While lump-sum transfers are a useful illustrative experiment, they may not fully address welfare losses for certain middle-income households. This raises the need for complementary policies, such as reducing VAT on essential goods, which could further improve equity outcomes. Our study, however, does not explicitly consider interactions between carbon taxes and the broader tax system. It may be argued that these interactions could have significant implications for aggregate welfare, particularly if carbon taxes yielded "double-dividends," i.e., if carbon tax revenues could be used to reduce previous distortionary taxes and improve overall economic efficiency, an argument often raised in favour of carbon taxes. However, in the countries studied and other low- and middle-income countries that struggle with domestic revenue mobilization, such considerations may not be so relevant, as long as their tax revenues remain at levels considered too low for their level of economic development.

Moreover, the significant heterogeneity of impacts within income groups poses challenges for designing compensation mechanisms. While income-targeting may be feasible, compensating non-poor losers or cushioning negative impacts on specific vulnerable groups, such as those reliant on fossil fuels for cooking, remains complex (Missbach *et al*, 2024). This complexity underscores the need for price reforms to be carefully designed and sequenced, with potential adverse effects assessed ex-ante.

One specific risk of taxing modern fossil fuels is the incentive it creates to substitute for traditional biomass, such as firewood or charcoal, which may not be desirable (Greve and Lay, 2022; Aggarwal *et al*, 2025). Exempting fuels prone to substitution by traditional biomass (such as LPG for cooking) or subsidizing clean alternatives could mitigate this risk (Steckel *et al*, 2021).

By analysing these dynamics in three diverse SSA countries, our study provides insights into how low- and middle-income countries can tailor carbon taxation to address both environmental and social objectives. The significant heterogeneity across countries highlights the importance of context-specific approaches that account for local energy use patterns, income distributions and administrative capacities. These

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approaches would benefit from further context-specific research into complementary policies, such as fuel subsidies or differentiated tax designs, which could enhance the overall fairness and effectiveness of carbon pricing.

**Supplementary material.** The supplementary material for this article can be found at https://doi.org/10.1017/S1355770X25100120

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