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Urban and rural carbon footprints in developing countries

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Abstract

A good understanding of household carbon emissions is an important part of forming climate mitigation strategies to achieve the goals set out in the Paris Agreement. Numerous studies have been carried out on emissions from household consumption and the inequality between urban and rural areas in high-income developed countries, but there is a lack of in-depth analysis of such differences in developing countries. Our research details household carbon footprints (CFs) of four urban and four rural income categories for 90 developing countries, by linking global expenditure data to the environmentally extended multi-regional input–output approach. We show that there are large inequalities between urban and rural areas in developing countries. The average per capita CF in urban areas tends to be larger than that of rural inhabitants ranging from twice as large to nine times larger. We find that electricity consumption and transport are the largest contributors to the total CF in all expenditure groups. High-income rural households have an average per capita CF of 12.38 t CO_2 which is 25% higher than the equivalent urban high-income group, which deviates from the literature looking at a subset of cases. Our study contributes to the existing research on CFs by providing knowledge on the consumption patterns and related carbon emissions of urban and rural populations in these understudied parts of the world.

1. Introduction

The impacts of climate change are far-reaching and threaten to expose the vulnerabilities of individual countries to environmental damage, such as flooding and loss of habitats as well as leading to socioeconomic impacts, such as migration (Klingelhöfer *et al* 2020). The Intergovernmental Panel on Climate Change (IPCC) has proposed that a transition is needed also in household consumption, to increase our chances of limiting warming to 1.5 °C above pre-industrial levels, one of the goals set out in the Paris Agreement (Masson-Delmotte *et al* 2018). Worldwide, households contribute directly and indirectly 72% to greenhouse gas emissions (Dubois *et al* 2019). This fuels the need for research, to form a better understanding of not only the origins of carbon emissions in high-income countries, but to have a comprehensive understanding of how to mitigate the impacts of climate change, in all regions of the world.

There are considerable differences between the lifestyles of urban and rural populations, such as diversity in the amount of consumption in specific sectors such as transport, electricity and fuel which influences the consumption-based carbon emissions associated with living in these areas. To change consumption patterns or lower the absolute volume of high levels of consumption, it is necessary to understand differences within countries such as between urban and rural areas in order to implement targeted actions to reduce consumption-based carbon emissions. Consumption-based emissions refer to emissions along the entire supply chain of products consumed by final consumption, in this case households. It is important to consider emissions embodied in trade rather than allocating all carbon emissions to the country of production, which can have a negative result on allocated emissions for net exporting countries, and a more favourable outcome for net importers, mainly high-income countries.

Identifying differences in consumption-based emissions between types of households can inform more fine-grained and targeted mitigation policies, rather than one-size-fits-all approaches, such as policy action on access and affordability of clean, efficient energy options to manage the unequal distribution of energy footprints in developing countries (Oswald *et al* 2020, Baltruszewicz *et al* 2021).

The literature on consumption-based carbon emissions of urban and rural residents mainly focuses on high-income countries such as Germany (Gill and Moeller 2018) and Finland (Heinonen and Junnila 2011), and upper–middle-income countries, such as China (Ravallion and Chen 2007, Liu *et al* 2011, Wiedenhofer *et al* 2016). There are only a limited number of studies on lower income countries, e.g. on India (Hubacek *et al* 2007, Wang and Wang 2020) or for specific regions such as the Brazilian and Peruvian Amazon (Padoch *et al* 2008) and no global comparative studies on consumption patterns and related carbon emissions of urban and rural residents of developing countries. To the best of our knowledge, the most geographically comprehensive study on urban and rural energy-related carbon emissions focuses specifically on the Asian continent (Krey *et al* 2012), depicting a clear gap in the literature for a global comparative lens across developing countries.

Considering this research gap, our study investigates and compares differences in consumption patterns for four income groups in urban and rural areas and the associated carbon emissions in 90 developing countries. We use expenditure data of 25 economic sectors from the World Bank's Global Consumption Database (WBGCD) of 2011. These 90 developing countries, represent 75% of the global population, 35% of global GDP, and 63% of global annual carbon emissions for the year 2011 (Centre for Global Development 2011). We use multi-regional input–output (MRIO) analysis to calculate the per capita carbon footprint (CF) of four expenditure groups in urban and rural areas, respectively, for each country, and identify the most important consumption items and their direct and indirect emissions. We argue that these findings will be of particular importance in forming climate mitigation strategies in the future, by providing new information on the consumption patterns and related CO_2 emissions of different economic groups in urban and rural areas.

2. Methodology

2.1. Environmentally extended MRIO (EEMRIO) analysis

In this research, we use the EEMRIO approach (see e.g. Hertwich and Peters (2009) and Ivanova *et al* (2017)). In the EEMRIO framework, Z_{ij}^{rs} represents the interregional trade between sector i in region r and sector j in region s while the total output of sector j in region s is computed and represented by x_j^s. We can then calculate the matrix of technical coefficients by using equation (1):

$$a_{ij}^{rs} = \frac{Z_{ij}^{rs}}{x_j^s}. \qquad (1)$$

The A-matrix represents the technical coefficients a_{ij}^{rs}. Final demand, Y, consists of y_i^{rst}, the final demand for sector i in region r from region s and in the final demand category t. The Leontief inverse matrix is then used to calculate the effects on total output, Δx, by multiplying the Leontief inverse with the changes in final demand, ΔY, as seen in equation (2):

$$\Delta x = (I - A)^{-1} \Delta Y. \qquad (2)$$

To compute the consumption-based carbon emissions, CO_2 coefficients must first be determined by dividing the CO_2 emissions provided by the Global Trade Analysis Project (GTAP) database, by the previously determined total output, x. The combined CO_2 emissions are then used to form a matrix C, which when multiplied by the total output matrix X, results in a matrix of consumption-based CO_2 emissions ε, associated with final demand Y, as shown in equation (3):

$$\varepsilon = C \cdot X = C(I - A)^{-1} Y. \qquad (3)$$

2.2. Household expenditure data

We use the WBGCD, to capture the consumption patterns of urban and rural populations in developing countries. This database has been used in previous studies on carbon emissions and inequality (Hubacek *et al* 2017a, 2017b, Dorband *et al* 2019, Zhong *et al* 2020). The WBGCD provides household consumption data for 90 developing countries, for the year 2011, with expenditure converted into US dollar (USD) purchasing power parities (PPP). Each country in the database is separated into urban and rural population, as well as into four income categories. The per capita consumption categories consist of (a) the lowest level with expenditure below $2.97 per day, (b) the low level with expenditure between $2.97 and $8.44 per day, (c) middle level between $8.44 and $23.03 per day, and (d) high with expenditure above $23.03 per day. Global income distribution data is also used to rank these consumption groups. The lowest level is made up of the population living below the 50th percentile of the global distribution, low is between the 51st and 75th percentiles, middle is between the 76th and 90th percentiles and the highest consumption segment is situated above the 90th percentile.

2.3. Bridging the datasets

We use two data sets in this study. The WBGCD contains final demand of consumption of 25 products and services for urban and rural households for 90 developing countries, covering 87% of the world population. GTAP 10 MRIO consists of 65 economic sectors and their respective CO_2 emissions of 121 countries and 20 aggregate regions of the world.

The first problem to solve with regards to matching these two data sets, involves the aggregate regions reported in GTAP. The 90 developing countries under analysis do not always have a perfect match with the relevant region in GTAP. This means that countries, for example Afghanistan, do not have a matching country in the GTAP database, rather being subsumed under the aggregate region 'Rest of South Asia'. To match the datasets through individual countries, UN population data from 2014 is used to divide the aggregate region into the relevant country size. This approach was required for 27 countries. Furthermore, using consumer price indices from the WBGCD of 2011 is inflated to the year 2014, in order to match the MRIO of GTAP 10.

The WBGCD contains 25 different products and services while GTAP has 65 sectors and 141 countries and regions, which accounts for 92% of the world population. Therefore, to match the two data sets, we must match the 25 sectors of the WBGCD with the 65 sectors of the final demand vector in the GTAP dataset. This is done by a bridging process, as in Hardadi *et al* (2021) whereby a matrix which is made up of 0's and 1's is used to allocate comparable sectors.

The idea behind matching and bridging the data, is to end up with a vector of total country expenditure, which matches the final demand vector of GTAP 10. There are eight consumption groups in the original expenditure data set of the WBGCD, representing urban and rural areas and within these areas, four income groups. The final bridged expenditure data will be identical to the final demand vector of GTAP, which will ensure accurate results for the EEMRIO analysis.

2.4. Limitations

Household surveys of individual countries potentially taken at different time points, may affect the accuracy of the data and lead to a reduction in quality of the results (The World Bank 2021). Another problem of using consumer expenditure surveys is insufficient sector resolution, which requires aggregation of sectors that may potentially have large differences in emissions intensity, and a mismatch between consumption categories and sector resolution (see e.g. Wiedmann (2009) and Hubacek *et al* (2017a)).

Another problem is the exclusion of certain energy sources, which can be considered as 'unmarketed', such as burning biomass (Martinot *et al* 2002, Bruckner *et al* 2022). The high percentage of non-commercialised energy sources can be seen in rural China, where large shares of the populations burn waste, wood, and crop residues as a source of energy. This is a typical practice in many low-income, developing countries as the connections to the energy grid is not as well-maintained as in wealthier regions (Zhang 2013, Vishwanathan and Garg 2020). The lowest income households are particularly reliant on non-commercial energy sources such as burning biomass like wood and crop residue for cooking, as they often do not have access to clean fuels (IEA 2020). This has an impact on the findings as it means that the CF of the low income consumption groups may not accurately reflect the actual carbon emissions associated with their energy consumption.

While the World Bank database covers 90 developing countries, there are still several low-income countries such as Iran, Somalia, Myanmar, and Cuba missing. The UN classification of 2014 lists 134 countries as developing, of these countries 67% are included in this study. In addition, there is missing data within specific countries. An example is Montenegro, where the lowest income group in urban areas is missing, or Mali with an underreporting in both the middle and high-income groups in rural areas. There are also many zero values in countries where there is no data on expenditure in certain sectors. The highest number of missing values is in the high-income expenditure groups of rural households, where 34% of the 90 countries have zero values.

Another source of potential error is the separation of aggregate regions in the GTAP database into individual countries to match with the WBGCD, based on the assumption that the economies of the countries within the region are structurally very similar. Finally, the WBGCD contains the expenditure data from the year 2011, while the GTAP 10 data is based on the year 2014, which are both now fairly old but still the best available dataset that provides the required consumption information for global income categories for all countries in this widely used standard format. This may introduce considerable uncertainties if the expenditure data has had a substantial increase or decrease in value during these years. In the case that the consumption data may have changed between the years 2011 and 2014. We correct this by using consumer price indices from the WBGCD of 2011 is inflated to the year 2014, in order to match the MRIO of GTAP 10. An even stronger assumption and potential problem is for countries that have experienced fast economic growth during and since this time period as lifestyles in transition economies have most likely undergone profound changes but there is no recent database that is able to capture those.

3. Results

3.1. Per capita CFs in urban and rural areas

We find that the average per capita CF of urban inhabitants in developing countries is 1.49 t CO_2, 45% higher than the average value of 0.82 t CO_2 in rural

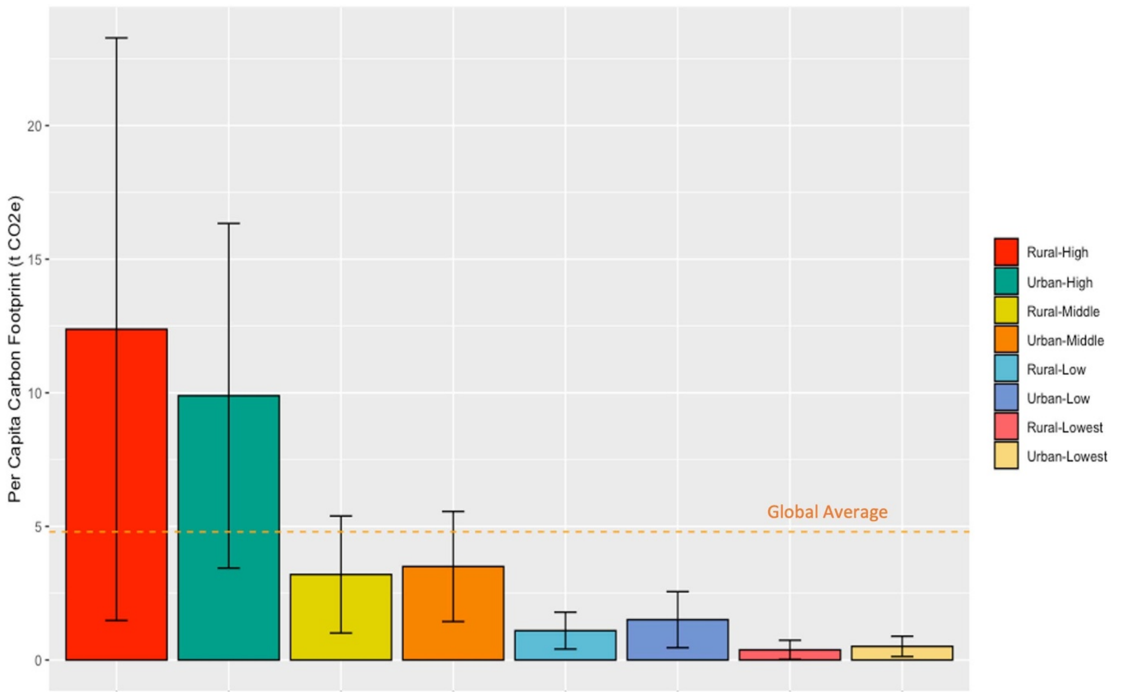

Figure 1. The average per capita CFs of the different income levels within urban and rural consumption groups, in all the 90 developing countries. The whisker plot displays one standard deviation from each of the average values. The dotted line shows the global average per capita CF (CAIT data, 2020).

areas. When considering the overall consumption-based emissions , the rural high-income group are responsible for just 1% of total household emissions of the 90 countries, in comparison to the urban middle-income group, accountable for the largest share of consumption-based emissions at 28%, followed by the urban low-income group with a 24% share and the rural lowest income group contributing just 6%.

Our results for the CF analysis demonstrate distinct differences between income groups within urban and rural areas. In figure 1, this contrast is apparent and although in the lowest-, low- and middle-income groups, the urban areas have a larger per capita CF, whereas CFs in the high rural group with an average of 12.38 t CO_2 is larger than in the high-urban income group with 9.89 t CO_2 per capita. We find an unequal distribution between the lowest income groups of urban and rural areas, with a footprint of just 0.38 t CO_2 per capita in rural areas and 0.51 t CO_2 in urban areas. The low-income group also have a higher footprint in urban areas, at 1.51 t CO_2, compared to the rural population's 1.1 t CO_2 footprint. Our study found the smallest division between urban and rural footprints in the middle-income group, with just an 8.6% difference between these populations. The distribution of emissions within income groups has a large overlap, as indicated by the large standard deviation. This ranges from a deviation of 10.9 t CO_2 from the average value of 12.38 t CO_2 for the rural high-income group, to 0.38 t CO_2 from the average value of 0.51 t CO_2 for the urban lowest income group. This is due to these values being an average of all of the 90 countries in our study and the CFs of particular income groups varying widely between countries, and thus causing a large standard deviation.

Figure 2 shows that the lowest income groups have similar values to one another compared to those of the high-income groups. The high-income groups show extreme per capita CF values in comparison, more noticeably in countries such as Egypt but still visible in Eastern Europe and Central Asia. We find that both Latin American and Caribbean nations, with an average per capita CF of 2.1 t CO_2 in rural areas and 2.3 t CO_2 in urban areas, have one of the smallest differences between urban and rural. In comparison, China has greater inequality between urban and rural areas, where the high-income group have an average per capita CF of 10.7 t CO_2 in urban areas compared to 8.1 t CO_2 in rural areas. We find a similar result for Eastern Asia and Pacific nations, as the high-income groups show the most significant differences, of 18.8 t CO_2 and 12.4 t CO_2 in urban and rural areas, respectively.

India shows a large difference between the high- and middle-income groups living in urban areas, with a difference of 10 t CO_2 per capita between the two groups. In the rural high-income groups of both India and Nigeria, there is no available data, an example of underreporting in high-income groups. We find the largest difference between middle-income groups in urban and rural areas in Sub-Saharan Africa, whereby urban inhabitants have a CF of 7.1 t CO_2 compared

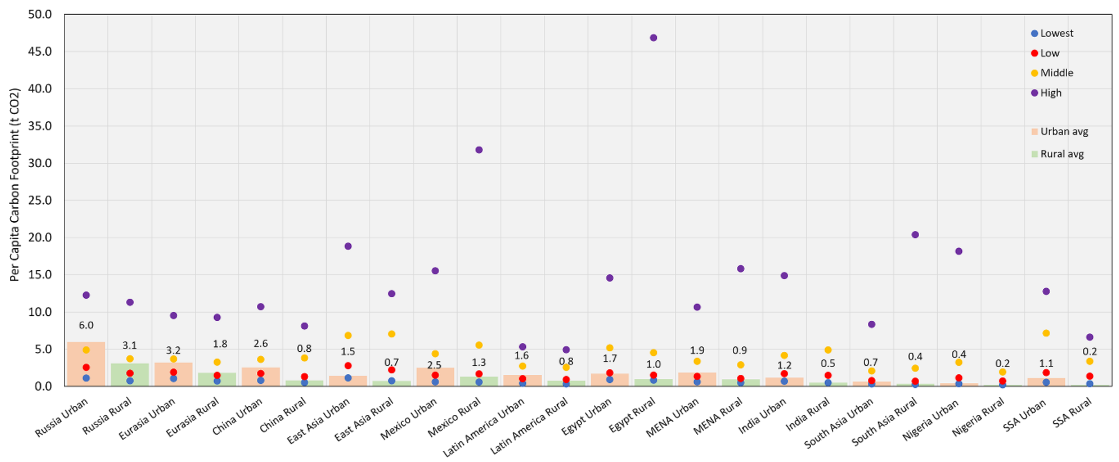

Figure 2. Comparison of per capita CFs of different income groups living in urban and rural areas in specific countries and their region. A representative country from each region is shown, chosen with regards to the largest economies in each region, and the remaining countries are grouped together in their respective region. The region Eurasia includes Eastern Europe and Central Asia, Latin America also includes the Caribbean, MENA represents the Middle East and North Africa, SSA is Sub-Saharan Africa and Eastern Asia also includes the Pacific nations. The colour-coded points represent the four income categories as shown in the legend. Please note that we include all the houshold categories to calculate the average per capita carbon footprint in this figure, some of the values are outliers with high uncertainties.

to just 3.3 t CO_2 for rural inhabitants. The highest average per capita CF in urban areas is found in Kazakhstan, at 6.42 t CO_2 compared to the highest in rural areas, found in Belarus, at 4.9 t CO_2. Belarus is the only country in our analysis, where the average rural CF is larger than its urban counterpart, by almost 2 t CO_2.

The average values for per capita CFs in urban and rural areas is shown by the bar graphs in figure 2. We find that the largest average per capita CF belongs to the Russian Federation, which was expected based on per capita values reported by the World Bank (The World Bank 2021). In all of the consumption groups, the average urban per capita CF is larger than the rural, ranging from a factor of 5 and a half in Sub-Saharan Africa to a factor of 3 in China. Russia's urban per capita CF of 5.97 t CO_2 is almost 14 times that of Nigeria's urban inhabitants 0.43 t CO_2. Russia, Eastern Europe and Central Asia, China and Mexico all have an average urban per capita CF which is greater than the average value of 1.93 t CO_2 for all countries in our analysis.

Only India, South Asia, Nigeria, and Sub-Saharan Africa have average rural CFs which lie below the 0.63 t CO_2 average for rural inhabitants, in these 90 countries. The highest percentage of national population living in rural areas is observed in Burundi, where 87% of the national population live in rural areas. In connection with this, Burundi also has one of the largest divides between urban and rural CFs, considering that the urban per capita CF is eight and a half times larger than its rural counterparts, at 1.19 t CO_2 and 0.14 t CO_2, respectively. We find a similar situation in Rwanda, where the average urban CF is 8.7 times higher than rural inhabitants. Burundi and Rwanda are both classified as low-income countries by the UN, and thusly show the greatest inequality between urban and rural areas.

3.2. Expenditure categories contributing to the urban–rural divide

To further analyse the divide between urban and rural areas in developing countries, and to understand why this difference in CFs occurs, we present a more comprehensive review of contributing expenditure categories. Each of the consumption groups in this analysis had the largest share of consumption-based emissions related to direct and indirect emissions of electricity and transport, as can be seen in figure 3.

The diagram presents each household category, with the size of the square representing the contribution to overall household consumption-based emissions in the developing world. The colour scale shows the carbon intensity of expenditure for each of the sectors within these consumption groups. The carbon intensity of each sector corresponds to the amount of CO_2 that is emitted directly and indirectly along the entire supply chain per USD PPP. The most carbon intensive expenditure category is electricity of the urban middle-income group, at 0.3 kg CO_2/USD compared to the lowest value in the rural high-income group at 0.17 kg CO_2/USD. In contrast, the rural high-income group has the greatest carbon intensity of expenditure in the transport sector at 0.2 kgs CO_2/USD while the lowest carbon intensity of expenditure is seen in the lowest income groups in both areas at 0.09 kgs CO_2/USD. The urban middle income group has the highest carbon intensity of expenditure in the fuels sector, with 0.08 kgs CO_2/USD.

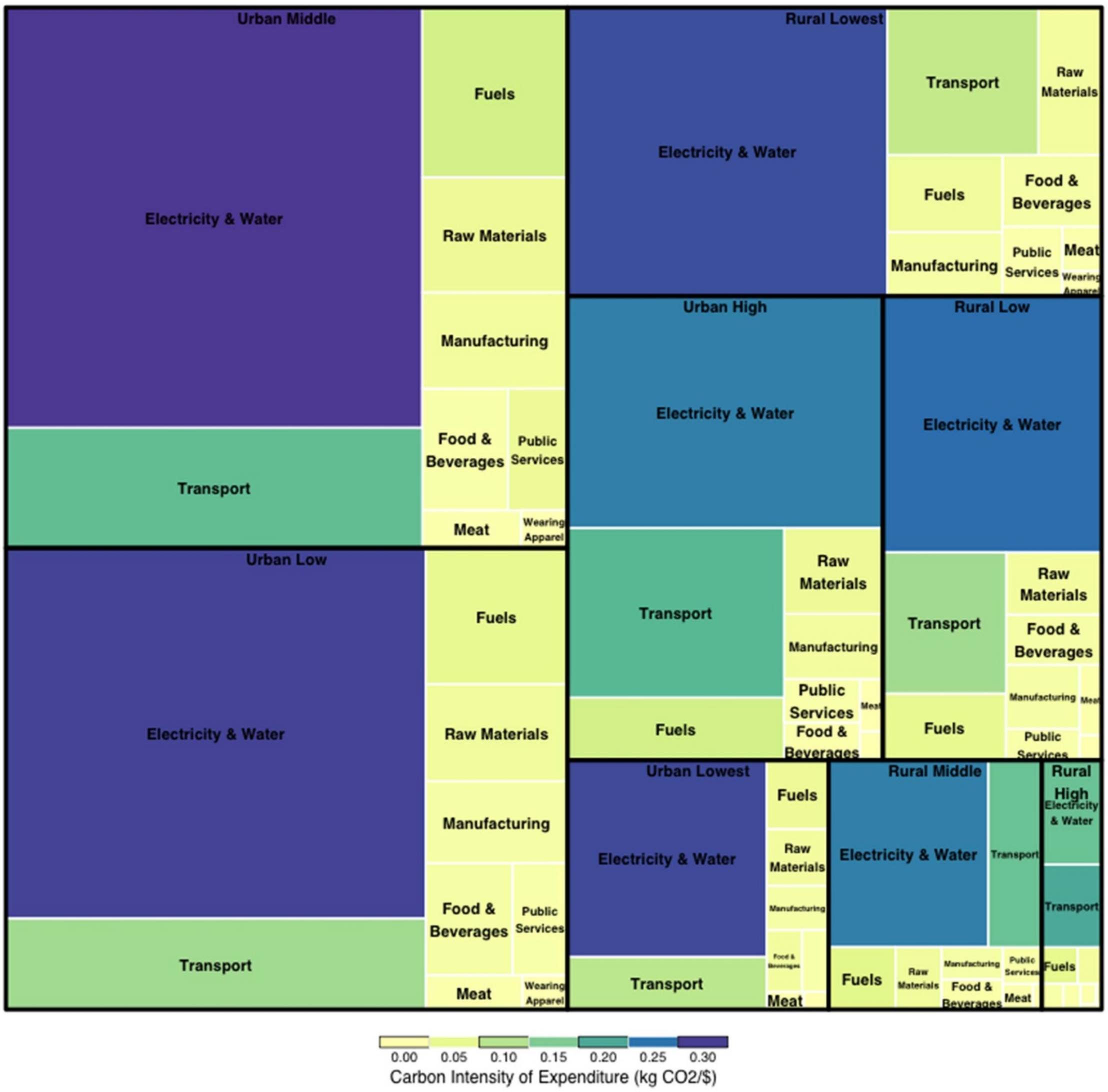

Figure 3. Contribution of nine different categories of products and services to the eight different household groups of the 90 developing countries. The highest contributor to the overall emissions is for electricity consumption, followed by transport. The carbon intensity of expenditure is shown by the colour scale, where the most intensive sector is electricity and water.

Our study shows that the two most contributing expenditure categories for consumption-based emissions are electricity and transport, with shares of the per capita CFs in these sectors shown in figure 4. As income increases, the share of CF in the transport sector also increases. This is noticeable in both the urban and rural sectors, but slightly more pronounced in rural areas, especially in South Asia. In South Asia, among the inhabitants of the highest income group in rural areas, over 70% of the average per capita CF is due to transport. The urban high-income group in South Asia's urban areas also has the highest share in transport but significantly lower than their rural counterparts, at a 46% share.

The opposite effect can be observed to the right panel of figure 4, in the share of per capita CF in the electricity sector, where as income increases the share of the CF in this sector decreases. In rural areas, the highest share of CF in the electricity sector is seen in Eastern Europe and Central Asia, where the lowest income group have an almost 70% share of their CF due to electricity consumption. This could be caused by the more polluting fuel types in use in these regions. In conclusion, we show in figure 4 that transport has a greater effect on the CF of higher income groups, especially in rural areas, while lower income groups contribute a higher share of their CF due to electricity consumption, which is more pronounced in urban areas.

We have shown that Mexico and Egypt had a huge variation in the per capita CF of the high-income rural population in comparison to the high-income urban consumption group. When looking into the specific sectors which contribute to this variation the transport sectors in both countries had much higher values per capita especially for motor vehicles, which were 3.5 times higher in rural areas of Mexico and 6 times higher in rural areas of Egypt, compared to their

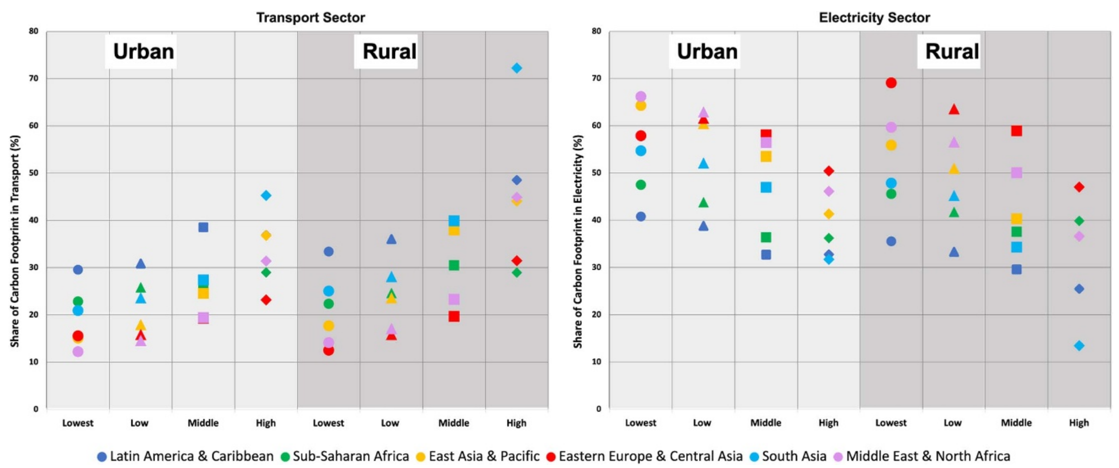

Figure 4. The percentage contribution to the total per capita CF of the transport and electricity expenditure categories. As income increases, the percentage share of CF transport also increases, in both urban and rural areas, but slightly more pronounced in rural areas. The opposite trend can be seen in the electricity sector, where as income increases, the share of CF in the electricity sector decreases.

urban counterparts. Other sectors which contributed to the divide were the petroleum sector as well as oil and gas, which were all more than double the values in rural high-income groups compared to the urban high-income group in both countries.

4. Discussion and conclusions

Our study reveals average per capita CFs of 90 developing countries listed by the World Bank, which agree with previous literature values (Hertwich and Peters 2009, Wiedmann 2009, Aichele and Felbermayr 2012, Chancel and Piketty 2015, Hubacek *et al* 2017a). This research places a particular emphasis on the inequality of CFs within countries of the developing world, between different economic groups living in urban and rural areas. One of the most surprising results is that for the high-income group within countries (especially in Mexico, Egypt, and the regions of the Middle East, North Africa and South Asia), the per capita CF of high-income rural residents is higher than that of the high-income urban residents. This could be the result of several factors. For example, dwelling sizes in rural areas tend to be larger than in urban areas. Smaller dwelling size in urban areas allows lower per capita energy consumption and more efficient living. The electricity sector was identified in this study as one of the most carbon-intensive sectors. Therefore, rural lifestyles can be considered as more carbon intensive as people often choose to live in rural areas to have more space and larger households which leads to an increase in per capita electricity use. In addition to the electricity sector, the transport sector was also identified as being extremely carbon intensive. Rural households have to travel larger distances, and this is mostly in personal vehicles running on fossil fuels rather than using public transportation. An increase in public transport alternatives for rural residents could reduce the emissions related to transport in rural areas.

Our study shows that the transport sector had a greater share of the consumption-based emissions in rural areas within the high-income consumption group. As found by Druckman and Jackson (2016), when studying the emissions intensity of different income groups, more 'necessary' items, often with higher carbon intensity tend to take a larger share in lower income groups, while 'discretionary' items that tend to be less carbon intensive prevailed in higher income groups. This is also shown in this research, whereby the lower income groups living in rural areas have the highest share of their CF driven by the demand for electricity, which can be looked at as a necessity for households. Therefore, a greater investment into cleaner energy sources as well as improved access for these communities should be prioritized, with reference to possible energy poverty dimensions in these areas of concern to national policy. It has been found that more polluting fuel types are used in lower income households which are often non-marketed fuels such as crop waste and wood, whereas higher income households can afford and access more efficient and modern fuel types which are accounted for in the data (Baltruscewicz *et al* 2021). This can lead to a potential underreporting of consumption-based carbon emissions in lower income groups and could be a potential root cause of the higher values in high-income groups.

Our results show that a higher carbon share is taking up by the consumption of high-income groups in both urban and rural areas. With regard to the global emission reductions needed to stay within planetary boundaries, estimated at 2 tonnes of carbon dioxide, only the lowest and low income groups lie within this boundary needed to tackle global warming (Bruckner *et al* 2022). This finding has been explored in other research where it has been emphasised that the most affluent groups of society should be targeted in consumption-based carbon reduction policies (Wiedmann *et al* 2020, Oswald *et al* 2021). According to Oxfam, the richest 10% of the world population 'squandered' one third of the residual global carbon budget of 1.5C between 1990 and 2015, compared to just 4% for the most impoverished half of the world (Gore 2020). Therefore, a greater proportion of the global carbon budget should be allocated to developing economies, to allow these nations to progress and grow without the restraint of adhering as strictly to carbon mitigation strategies. Another option which has been researched is to increase carbon taxes in the richest countries, where research by Chancel and Piketty (2015) suggested that Europe should increase its contribution to adaptation funds by a factor of 3 and North America by greater than 15. It is especially important now, with countries such as the United Kingdom, who have suggested large cutbacks in foreign-aid budgets due to the coronavirus pandemic's effect on the national economy, that the richest nations do not slack in their responsibilities to contribute to the just transition for developing nations (Else 2021). If anything, these countries owe more to the development of climate mitigation technologies in the poorest nations.

The climate crisis will have the most severe consequences for vulnerable communities in developing countries, from flooding to famine, even though they have some of the lowest per capita CFs (and thus lowest carbon responsibility) in the world, as highlighted in the recently published IPCC Sixth Assessment Report (The International Panel on Climate Change (IPCC) 2022). This will be particularly evident in rural areas, which are very dependent upon agriculture, and coastal communities in small island developing states (Acheampong *et al* 2019). The cost of carbon inequality between western and developing countries, between the richest and the poorest populations, will be most visible and will disproportionately touch on the poorest, rural communities (Hughes *et al* 2016). It is therefore, of utmost importance to protect the most vulnerable communities. A further understanding of the lifestyles of urban and rural populations in impoverished areas is necessary for future advancements in policy making. A fair and just approach to implementing policies is necessary for reducing inequality between and within countries as shown by Wang and Zhou (2018), while studying global carbon inequality. In the future, international climate agreements should share the responsibility of emissions abatement between differing countries on the basis of varying economic stability, to encourage and allow growth for the poorest nations (Hertwich and Peters 2009).

The duty of the richest nations to support emerging economies in their development is an extremely important point to discuss in the topic of carbon inequality, also considered by the United Nations in the sustainable development goal (SDG) on climate mitigation. The SDG on climate change also includes the role that should be employed by richer nations to reconcile with the developing world in the fight against climate change (Bolea *et al* 2020). It will become increasingly important for richer nations to support emerging economies in their economic growth. This is discussed by Deloitte (2015), in relation to Australia and countries responsibility to assist in reducing emissions, through technology deployment in poorer countries aimed at decreasing carbon intensity. This can be achieved through investments into more renewable energy technologies, since it has been shown in this study that the electricity sector contributes the most to the household consumption-based CFs in developing countries. The richest countries could offset some of the increased emissions associated with economic growth in emerging economies of the developing world, through deployment of wind and solar farms and providing technological solutions to reduce carbon emissions. It will be especially important in the case of rural areas for the purposes of rural revitalization, to invest in renewable energy technologies and increase access to low carbon electricity.

The key point to take away from this study is that although there is carbon inequality between countries, and especially between different countries of economic development status, there are also divisions within countries. These divisions, such as between urban and rural areas, should be included when policymakers are considering targeted actions to reduce global warming activities in national policies. As these nations develop economically, the negative impact of living in urban areas on the per capita CF should be further examined, especially when more people move to cities for more opportunities (Lall 2006). We look into several economic sectors and their individual impact on the average CF of each income group, considering the urban–rural divide, but a more in-depth analysis of these sectors, keeping these findings in mind, would help to contribute to considerably more knowledge on how the consumption patterns and habits of the most carbon-intensive income groups can be mitigated through targeted national policy actions. Internationally, we should not neglect less affluent countries in furthering scientific knowledge on the topic of climate change and consumption-based emissions, especially with a still growing global population and the right of these countries to develop economically while also mitigating the destructive effects of the climate crisis.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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