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Research article

Household carbon and energy inequality in Latin American and Caribbean countries

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ABSTRACT

Reducing inequality, eradicating poverty and achieving a carbon-neutral society are recognized as important components of the United Nations' Sustainable Development Goals. In this study, we focus on carbon and energy inequality between and within ten Latin American and Caribbean (LAC) countries. Detailed carbon and energy footprint were estimated by combining the consumption profiles (2014) in ten LAC countries with environmental extended multi-regional input-output (MRIO) analysis. Our results show significant inequality of regional total and per capita carbon and energy footprint across the studied LAC countries in 2014. The top 10% income category was responsible for 29.1% and 26.3% of the regional total carbon and energy footprint, and their per capita carbon and energy footprint were 12.2 and 7.5 times of the bottom 10% earners in that region. The average carbon footprint of studied LAC countries varied between 0.53 and 2.21 t CO_2e/cap (ton of CO_2 equivalent, per capita), and the energy footprint ranged from 0.38 to 1.76 t SOE/cap (ton of Standard Oil Equivalent, per capita). The huge difference in total and per capita carbon emissions and energy consumption of different income groups suggests notable differences in climate change responsibility, and supports policies for achieving sustainable consumption in terms of carbon tax, renewable energy subsidy, and decarbonizing the consumption structure in different LAC countries.

1. Introduction

UN's Sustainable Development Goals on reducing inequality and eradicating poverty (United Nations, 2015) and the Paris Agreement on holding the global average temperature increase below 2 °C compared with the pre-industrial level (UNFCCC, 2015) are key goals for the global community. Achieving the Paris Agreement requires a systematic reduction of Greenhouse Gas (GHG) emissions on both production and consumption sides at the global scale (von Stechow et al., 2016; Creutzig et al., 2016, 2018). Current consumption levels and structure are critical drivers for unsustainable energy use and huge GHG emissions, which contribute to global climate warming (Hubacek et al., 2009; Jones and Kammen, 2011; Day et al., 2016; Wood et al., 2018). Consumption must become sustainable to significantly reduce GHG emissions and mitigate climate warming, thus avoid irreversible ecosystem distruction and socio-economic crisis (Welch and Southerton, 2019), especially in Latin American and Caribbean (LAC) countries where biodiversity is vulnerable to climate change, and potential economic cost may reach up to 5% of the region's Gross Domestic Product in 2050 (United Nations, 2015).

Sustainable consumption is fundamentally an issue of inequality (Chakravarty et al., 2009; Welch and Southerton, 2019). Carbon footprint vary widely globally. For example, in China, the top 5% of income earners accounted for 17% of the national household carbon footprint, while the bottom 50% only accounted for 25% (Wiedenhofer et al., 2017). Similarly, in European regions, embodied per capita GHG emissions varied significantly from 0.6 to 6.5 t CO_2e/cap (ton of CO_2 equivalent, per capita) (Ivanova et al., 2017). Globally, the wealthiest 10% of income earners were responsible for 36% of total GHG emissions, while the bottom 50% caused only 15% of total emissions (Hubacek et al., 2017). Such severe GHG emissions inequality between different

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income groups should be considered to ensure the fairness of GHG reduction policies.

However, little efforts have been made to quantify the differences of carbon and energy footprint associated with household consumption in low and middle income countries, such as LAC countries where most countries' carbon footprint are relatively moderate and declining since the beginning of this century (Vergara et al., 2013, 2015). Many LAC countries' decarbonization pathways focus on direct carbon emissions reduction (Vergara et al., 2015), and mostly identified inequality using production-based direct carbon emissions without considering indirect or embodied carbon emissions via supply chains driven by household consumption (Mittmann and Mattos, 2020). In comparison, by employing a detailed household consumption survey of different income groups in combination with multi-regional input-output (MRIO) analysis, each group's responsibility for carbon emissions reduction can be identified (Vogt-Schilb et al., 2019; Mi et al., 2020). Our study highlights the inter-regional disparities of embodied carbon and energy footprints within and between different income groups in ten LAC countries, by integrating household consumption data of different income groups with MRIO analysis. In addition, we quantify environmental inequality using the Gini index of carbon and energy footprints. The huge differences in total and per capita carbon and energy footprints in LAC countries suggest different climate change responsibilities for different income groups.

2. Method and data

In this study, the calculation of carbon and energy footprints for different income groups was based on environmental extended MRIO analysis, using the data of consumer consumption profiles of 200 income groups and international trade flows from the GTAP database (Aguiar et al., 2019). We also employed the income and environmental Gini index (Mi et al., 2020) to further analyze the inequality in each studied LAC country.

2.1. Environmental extended MRIO analysis

The environmental extended MRIO (Wiedmann, 2009) has been widely applied to identify the embodied environmental impacts/pollution associated with the international/inter-regional trade flow matrix through the whole supply chain (Dalin et al., 2012; Yu et al., 2013; Hubacek et al., 2017; Zhang et al., 2018; Zhao et al., 2019). The MRIO table describes the interactions in terms of monetary flow between sectors in the domestic and inter-regional economic linkage. The basic equation of input-output analysis is as follows (Eq. (1) and Eq. (2)):

$$X = (I - A)^{-1} \times Y \tag{1}$$

$$X = \begin{bmatrix} x^1 \\ x^2 \\ \vdots \\ x^m \end{bmatrix}, A = \begin{bmatrix} a^{11} & a^{12} & \cdots & a^{1m} \\ a^{21} & a^{22} & \cdots & a^{2m} \\ \vdots & & \ddots & \vdots \\ a^{m1} & a^{m2} & \cdots & a^{mm} \end{bmatrix}, Y = \begin{bmatrix} y^{11} & y^{12} & \cdots & y^{1m} \\ y^{21} & y^{22} & \cdots & y^{2m} \\ \vdots & & \ddots & \vdots \\ y^{m1} & y^{m2} & \cdots & y^{mm} \end{bmatrix} \tag{2}$$

where X, Y and I refer to the total output, final demand and identity matrix. $(I - A)^{-1}$ refers to the Leontief inverse matrix and A is the technical coefficients matrix. m refers to the total number of sectors in a region.

In the MRIO analysis, the total output vector $X = (x_i^r)$ stands for the total output of sector i in region r. The final demand vector $Y = (y^{rs})$ stands for the final demand of region s derived from region r. The technical coefficients $A = (a_{ij}^{rs})$ stands for the technology transforms the inputs from sector i in region r to sector j in region s. The technical coefficients matrix is calculated by $\left(z_{ij}^{rs} / x_j^s\right)$ where z_{ij}^{rs} stands for the monetary flow from sector i in region r to sector j in region s, and x_j^s stands for the total inputs of sector j in region s.

The LAC countries' carbon and energy footprint were calculated using the total outputs of sector i in region r and the corresponding coefficients, which were the carbon emissions (in terms of CO_2 equivalent, CO_2e) and energy consumption (in terms of Standard Oil Equivalent, SOE) intensity to produce per unit of economic output in each sector. The equation (Eq. (3)) is as follows:

$$E = Coe \times (I - A)^{-1} \times Y \tag{3}$$

where E refers to environment impact footprint, Coe refers to the environmental coefficient.

In this study, we focused on household consumption causing direct and indirect carbon emissions (carbon footprint) and energy consumption (energy footprint). In order to estimate the environmental impacts of different income groups in each LAC country, the GTAP household final consumption vector in each country was sub-divided into 10 income groups according to the share of each group's consumption to the total consumption of each household product category. Therefore, the new equation (Eq. (4)) will be:

$$E_{group} = Coe \times (I - A)^{-1} \times HY_{group} \tag{4}$$

where E_{group} is the total carbon/energy footprint of each income group in a country, HY_{group} is the household final demand for each income group in a country.

2.2. GTAP and household consumption profiles

The Global Trade Analysis Project (GTAP) version 10 database (year 2014) (Aguiar et al., 2019) was selected for the MRIO analysis. This database includes input-output tables, employment compensation fixed capital consumption, value added and household consumption for 141 countries/regions and 65 economic sectors.

The household consumption profiles from the World Bank were employed to obtain the final demand of each income group in LAC countries. It contains the share of 33 standard sectors of products and services in the total household consumption of each income group. The household consumption was converted from local currency to Purchasing Power Parity ($ PPP) for all the countries. These profiles were applied to sub-divide the GTAP household final demand for each income group in different LAC countries. The household consumption profiles were generated from the household survey microdata from the World Bank for the reference year 2011. We matched each GTAP sector (65 sectors) with the same/similar sector in the World Bank Global Consumption Database (33 sectors) according to their definition, and assumed that the share of each sector's final demand in each income group was the same as the share of the correspondent household consumption's sector and income group. The consumer price indices from the World Bank and the household consumption growth rates from the International Monetary Fund were employed to obtain consumption values estimates for the reference year 2011. We aggregated the original 200 groups' profiles into 10 groups according to the share of each income group's population and per capita household consumption, so that each group accounted for 10% of the total population.

There are few uncertainties from the variety of sources when we matched the 33 household consumption sectors and the 65 GTAP economic sectors to sub-divided the final demand into different income groups. First, the definition and classification of sectors in the two databases are different and there are fewer economic sectors in the profile database compared with GTAP, such matching procedure may lead to some overlapping and few GTAP sectors may have identical values from the same household consumption sector. Further uncertainties are due to the assumption of consumption represented direct energy quantity consumed, and the energy sources structure was the same for all the income groups within a country. In addition, carbon and energy footprint might be overestimated for higher income groups. For example, because of the higher price of renewable energy, higher income people can afford the new low-carbon technologies and lifestyle while poorer people will still stay in the relatively cheaper and traditional carbon-intensive energy sources and consumption patterns. Combining the physical consumption data with monetary consumption data will help to reduce such uncertainties (Min and Rao, 2018).

2.3. Income and environment Gini index

The Gini index was applied to describe the income inequality in the LAC countries, which ranged from complete equal (0) to absolute unequal (1) (Ceriani and Verme, 2012). The income Gini index was calculated as follows (Eq. (5)):

$$G = \sum_{i=1}^{n} P_i Y_i + 2 \times \sum_{i=1}^{n} P_i (1 - C_i) - 1 \tag{5}$$

where G refers to the Gini index. P_i and Y_i are the population and income share of income group i in each LAC country. C_i is the cumulative share of the income group i. We used the household consumption data from the World Bank (200 groups) to calculate the household consumption Gini index. We also calculated the carbon footprint Gini and energy footprint Gini using the same method, where the income in equation (5) was replaced by carbon footprint or energy footprint of different income groups between and within LAC countries.

3. Results

3.1. Consumption inequality in LAC countries

First, we identified the consumption inequality within and across the studied LAC countries (Fig. 1). The regional average per capita consumption was 4245.1 $ PPP (i.e. Purchasing Power Parity). The highest consumption group's consumption (group 10, 16541.1 $ PPP) was 25.5 times of the lowest one (group 1, 655.4 $ PPP), which reflects a huge inequality across the region. Nicaragua's per capita consumption (2025 $PPP) was the lowest, which was only 39.4% of Paraguay's per capita consumption (5133 $ PPP).

3.2. Carbon and energy footprint inequality among income groups

Fig. 2 shows both total and per capita carbon and energy footprint of each income group in all studied LAC countries.

In general, carbon emissions and energy consumption tend to be highly correlated with income. The wealthiest 10% contributed 29.1% of the total carbon footprint, which is about 10.6 times higher than the bottom 10%.

Our results also show that the per capita carbon and energy footprint among all the income groups was also highly unequal. The per capita carbon footprint of the richest income group (4.65 t CO_2e/cap) was 12.2 times compared with the lowest income group (0.38 t CO_2e/cap), while the per capita energy footprint of the two groups were 3.54 t SOE/cap and 0.48 t SOE/cap (7.45 times) respectively. The average per capita carbon and energy footprint of all the studied LAC countries were 1.5 t CO_2e/cap and 1.3 t SOE/cap, respectively.

3.3. Carbon and energy footprint inequality among countries

The carbon and energy footprint inequality was also quite pronounced among LAC countries (Fig. 3). Most countries' per capita carbon footprint was below the regional average of 1.54 t CO_2e/cap, except for Jamaica (1.75 t CO_2e/cap) and Mexico (2.21 t CO_2e/cap). Honduras's per capita carbon footprint was the smallest (0.53 t CO_2e/cap), which was 23.8% of Mexico's per capita carbon footprint (2.21 t CO_2e/cap). In terms of energy footprint, only Brazil (1.35 t SOE/cap) and Mexico (1.76 t SOE/cap) had a higher per capita energy footprint than the regional average (1.3 t SOE/cap). The smallest per capita energy use of Honduras was 21.8% of the biggest one of Mexico.

Compared with Brazil, Jamaica had less per capita energy consumption but higher per capita carbon emissions. This indicates that Brazil's energy structure was less carbon-intensive than Jamaica's, which can be partly attributed to Brazil's policy of adopting "greener" bio-ethanol fuel, sufficient land and water resources for sugarcane cultivation and new generation technologies in producing bio-ethanol from sugarcane bagasse (La Rovere et al., 2011). The per capita carbon and energy footprint of Honduras and Nicaragua were the lowest among all countries, which were also the poorest LAC countries. But there are some interesting regional differences. For example, although the consumption of Paraguay was the highest, Paraguay's per capita carbon and energy footprint were much lower than Mexico, Brazil and Jamaica.

3.4. Consumption, carbon and energy footprint inequality within countries

A closer observation of the per capita consumption of each income group (Fig. 4) showed that there was a severe inequality within each LAC country and across all the LAC countries. Of all the income groups in LAC countries, the richest group in Brazil as an average per capita income of 20588.2 $ PPP/cap, which was 65.4 times compared with the poorest group in Honduras (314.6 $ PPP/cap). Paraguay had the highest national average consumption of 5133.3 $ PPP/cap, which was 3108.3 $ PPP/cap higher than the lowest one of Nicaragua (2025 $ PPP/cap). Within each country, Brazil had the biggest domestic consumption gap of 20018.6 $ PPP/cap between the richest and poorest group, the consumption of the richest were 36.1 times compared with the poorest one. Although Nicaragua's national average consumption (2025 $ PPP/cap) was the lowest of all LAC countries, its consumption inequality was the second smallest, where the top 10% consumption per capita was 15.5 times of the bottom 10%. Even in the "most equal" country, i.e. Jamaica, the consumption per capita ratio between the richest and the poorest

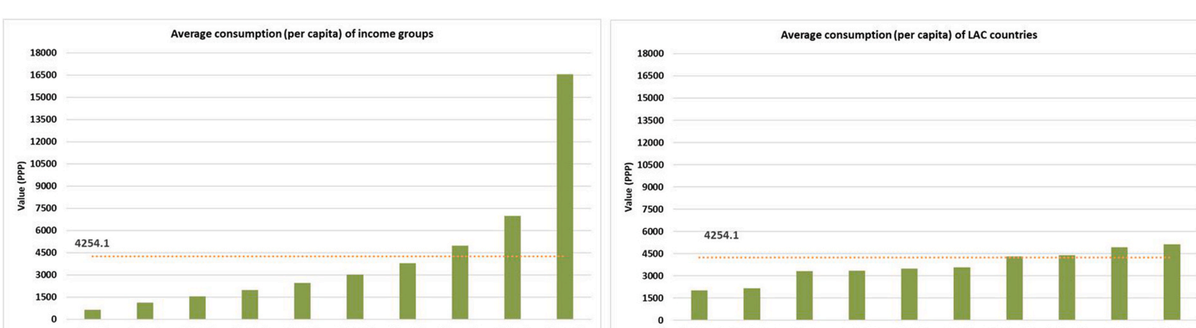

Fig. 1. Average consumption by country and group in LAC countries.

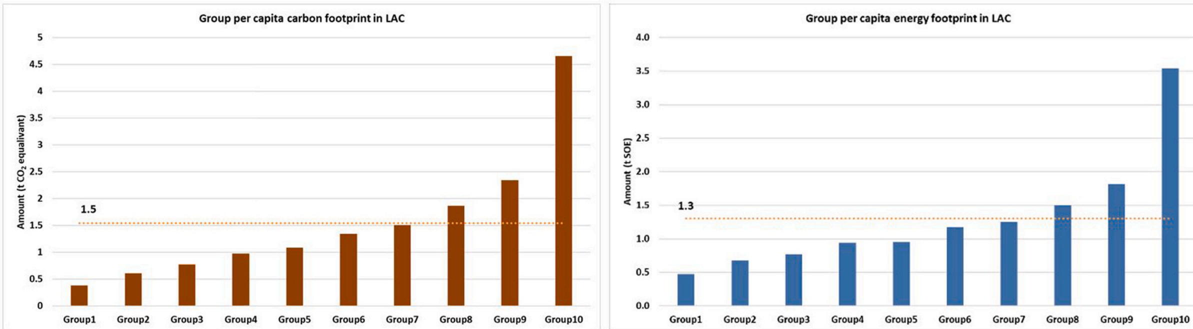

Fig. 2. Carbon and energy footprint of each group in LAC.

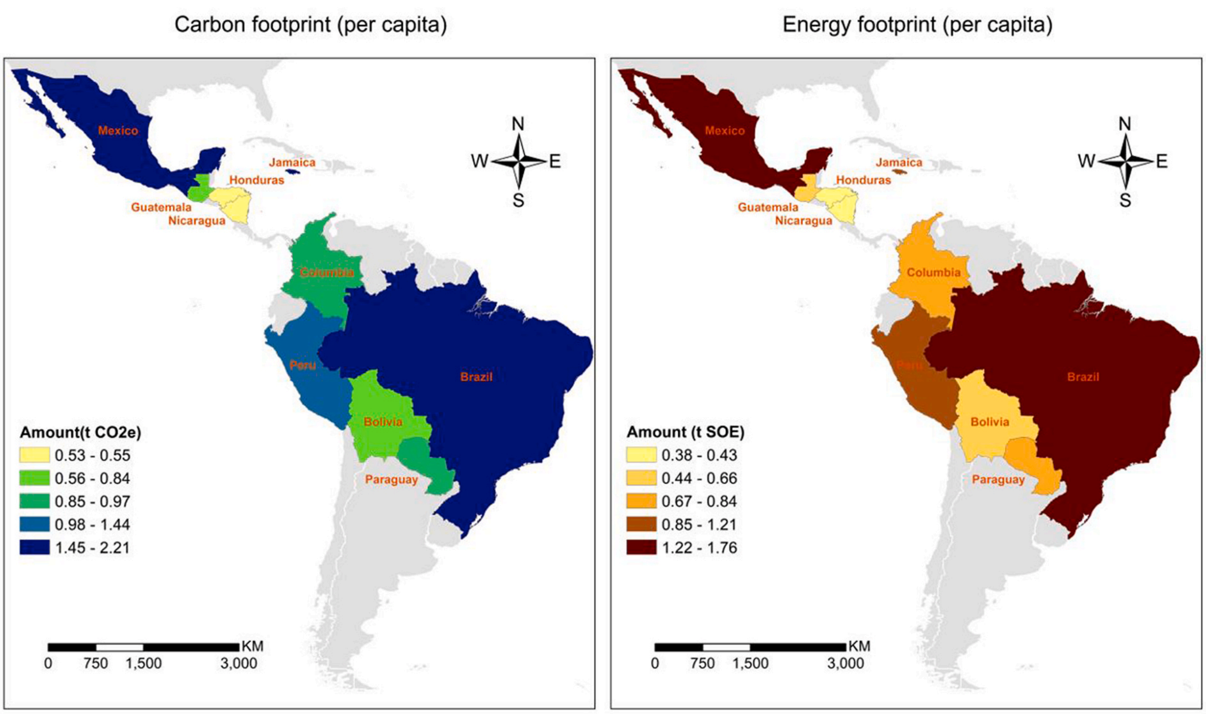

Fig. 3. Carbon and energy footprint (per capita) of each LAC country.

group was 13.7 times.

Fig. 4 also shows the distribution of per capita carbon and energy footprint of all the income groups in each country. The highest income group contributed much greater carbon and energy footprint in all the countries. But for the national per capita carbon and energy footprint, the national average income level did not necessarily lead to higher carbon emissions and energy consumption. Among the top 4 carbon emitters and energy consumers (per capita) of Brazil, Jamaica, Mexico and Peru, only Brazil's income level was relatively high, Peru and Jamaica were two low income countries. The disagreement between the average income and carbon and energy footprint in Peru, Jamaica and Mexico indicates that energy consumption in those countries contributes a much larger portion of the household total consumption, thus led to heavier energy use and higher carbon footprint compared with Brazil.

3.5. Inequality of consumption, carbon and energy footprint measured by Gini index

In order to quantify the inequality of consumption and environmental impacts, the Gini index and environmental Gini indexes based on carbon emissions (carbon Gini index) and energy consumption (energy Gini index) results were calculated in this study (Table 1). The LAC countries were regrouped into two categories: 1) consumption Gini index value bigger than both carbon and energy Gini index values; 2) consumption Gini index value smaller than both carbon and energy Gini index values (Table 1).

According to the United Nation's standard of income inequality, the Gini index <0.2 is considered as "perfect" equality, 0.2-0.3 seen as relative equality, 0.3-0.4 as adequate equality, 0.4-0.5 as big income inequality and a Gini index >0.5 as severe inequality. The same inequality standard was also applied to evaluate the carbon and energy inequality in each country. In terms of consumption inequality, only Jamaica can be labeled as adequate equality (Gini 0.39) whereas Brazil would be considered as severe inequality (Gini 0.52). All the remaining countries would fall under adequate equality.

Most countries' environment inequality is smaller than consumption inequality, except for Jamaica, Nicaragua and Honduras. We can see a stark contrast of both consumption inequality and energy and carbon inequality in Brazil. Brazil had the most severe consumption inequality, but with relatively low carbon and energy footprint inequality. This may be attributed to the lower fuel price and adoption of greener bio-ethanol fuel in the domestic market in Brazil (Munoz Castillo et al., 2017).

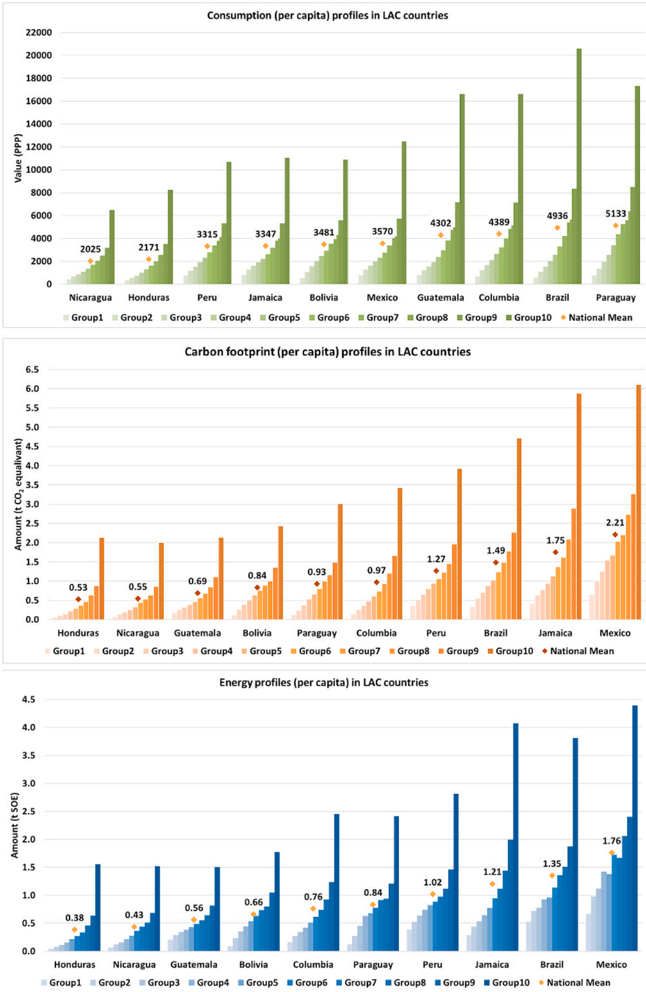

Fig. 4. Profiles of consumption, carbon and energy footprint (per capita) in LAC countries.

Table 1
Gini coefficients of consumption, carbon and energy footprint in LAC countries.

Country	Gini coefficients		
	Consumption	Carbon footprint	Energy footprint
Peru	0.40	0.36	0.30
Bolivia	0.41	0.39	0.36
Mexico	0.42	0.33	0.27
Paraguay	0.45	0.43	0.37
Columbia	0.47	0.46	0.41
Guatemala	0.48	0.39	0.31
Brazil	0.52	0.39	0.31
Jamaica	0.39	0.41	0.41
Nicaragua	0.42	0.47	0.46
Honduras	0.48	0.52	0.52

Mexico had the lowest carbon and energy footprint inequality of 0.33 and 0.27, but at a very high level of both the highest per capita carbon emissions and energy consumption. In comparison, three low-income countries of Jamaica, Nicaragua, Honduras had "big inequality" of both carbon and energy footprint. The consumption inequality of these three low income countries were between 0.39 and 0.48, which were under the range from "adequate equality" to "big inequality".

4. Conclusions and discussions

Our results show that the carbon and energy footprint inequality were quite pronounced between different income groups in the studied LAC countries. By calculating the carbon and energy footprints of different income groups, we found that the wealthiest group's (top 10%) total carbon and energy footprints accounted for respectively 29.1% and 26.3% of the regional totals, which were respectively 11.5 and 7 times of the poorest group (bottom 10%). A similar severe inequality also existed for different income groups in each studied country, where the wealthiest group accounted for a large portion of the national total carbon and energy footprint. Such inequality was even more severe in some low income countries.

Carbon taxes and subsidies, which encourage the consumption of renewable energy (e.g. bio-ethanol fuel), should be carefully designed to benefit lower income groups and low-income countries. Our results show that some of the poor countries, such as Nicaragua, Honduras, Jamaica, had even a higher carbon and energy footprint inequality compared with richer LAC countries. For example, Jamaica ranked the fourth poorest county, but had the second and third highest per capita carbon and energy footprint, respectively. The highly carbon intensive energy structure of Jamaica was an important factor that led to a high carbon footprint. More efforts will be needed to promote renewable energy usage to reduce the overall carbon intensity of the national energy structure in the future. But of course, the this will not change much the unequal distribution which is due to other factors in the respective countries. Future estimation under scenarios of adopting more renewable energy and shifting current fossil fuel-based energy sources to a less carbon-intensive and more sustainable energy structure will provide a solid foundation for policies in different LAC countries. More detailed analysis on the carbon and energy footprint of different household consumption categories, major energy sources and their carbon intensity for different income groups will help to have a better understanding of the carbon and energy footprint distribution in different sectors. These analyses will support environmental tax decisions by considering people's basic needs for goods and services, especially for low-income groups (Vogt-Schilb et al., 2019).

Author statement

Honglin Zhong, Conceptualization, Methodology, Data Curation, Investigation, Formal analysis, Writing - Original Draft, Writing - reviewing and editing. Kuishuang Feng, Conceptualization, Methodology, Formal analysis, Writing - Original Draft, Writing- Reviewing and Editing. Laixiang Sun, Supervision, Formal analysis, Writing- Original draft preparation, Writing- Reviewing and Editing. Li Cheng, Writing- Reviewing and Editing. Klaus Hubacek, Writing - reviewing and editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Abbreviations table.

Abbreviations	Explanation
MRIO	Multi-Regional Input Output
GTAP	Global Trade Analysis Project
LAC	Latin American and Caribbean
GHG	Greenhouse Gases
SOE	Standard Oil Equivalent
CO_2e	Carbon dioxide equivalent
PPP	Purchasing Power Parity

General data and parameters information.

Study year	2014				
Study country	Bolivia	Brazil	Columbia	Guatemala	Honduras
	Jamaica	Mexico	Nicaragua	Paraguay	Peru
Income group	10 income groups and each income group accounts for 10% of the total population, which are sorted by ascending order of household consumption from group 1 to group 10.				
Parameters	**Footprint**	Carbon footprint	Energy footprint		
	Gini index	Carbon footprint Gini index	Energy footprint Gini index	Consumption Gini index	
	MRIO calculation	Input-output table of GTAP	Final demand of LAC countries	Household consumption profiles	Carbon and energy coefficients
	Economic sectors	65 GTAP sectors	33 World Bank household consumption database sectors		

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