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Do the rich pollute more? Mexican household consumption by income level and CO_2 emissions

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Abstract

Purpose – The purpose of this paper is to quantitatively examine if varying household consumption activities at different income levels drove CO_2 emissions to different degrees in Mexico from 1990 to 2014.

Design/methodology/approach – The paper applied a simple expenditure-CO_2 emissions elasticity model – a top-down approach – using data from consumption-based CO_2 emission inventories and the "Household Income and Expenditure Survey" and assuming a range of 0.7-1.0 elasticity values.

Findings – The paper results show a large carbon inequality among income groups in Mexico throughout the period. The household consumption patterns at the highest income levels are related to significantly more total CO_2 emissions (direct + indirect) than the household consumption patterns at the lowest income levels, in absolute terms, per household and per capita. In 2014, for example, the poorest household decile emitted 1.6 tCO_2 per capita on average, while the wealthiest decile reached 8.6 tCO_2 per capita.

Practical/implications – The results suggest that it is necessary to rethink the effect of consumption patterns on climate change and the allocation of mitigation responsibilities, thus opening up complementary options for designing mitigation strategies and policies.

Originality/value – The paper represents an alternative approach for studying CO_2 emissions responsibility in Mexico from the demand side, which has been practically absent in previous studies. The paper thereby opens a way for studying and discussing climate change in terms of consumption and equity in the country.

Keywords CO_2 mitigation, Consumption patterns, Demand analysis, Carbon inequality, Elasticity model

Paper type Research paper

1. Introduction

Climate change is currently one of the most complex problems facing our society. Despite a number of important national and global initiatives aimed at mitigating greenhouse gas emissions – primarily carbon dioxide (CO_2), the most abundant greenhouse gas and one with a long atmospheric life – these emissions have continued to increase in many countries and at the global level.

Economics tends to approach climate change mitigation on the basis of neoclassical theory but recognizing the existence of market failures and relevant government

JEL classification – D12, D30, Q43, Q56, R21

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intervention, that is, a kind of "extended mainstream" (de la Vega Navarro, 2015). Most climate change mitigation strategies and policies are based on this economic approach, while also drawing on findings from other fields such as natural sciences and engineering. This conventional approach is characterized by the underlying idea that technological development, adequate funding and public policy (if it is necessary) together ensure compatibility between economic growth and climate change mitigation. According to this approach, decoupling economic growth from CO_2 emissions can be mainly achieved by energy efficiency and the replacement of fossil fuels by forms of clean energy to reduce both energy intensity and carbon intensity in accordance with the following formula:

$$\frac{CO_2}{GDP} = \frac{Energy}{GDP} * \frac{CO_2}{Energy}$$

However, this conventional approach to climate change mitigation has mostly focused on supply and little on demand, as if the latter did not interfere with climate change and as if sustainable production were a guarantee of sustainable consumption. Indeed, this approach only takes into account the influence of the energy demand (electricity, gas, gasoline, diesel, etc.) on CO_2 emissions, while overlooking the influence of most consumption activities on CO_2 emissions, some of which could hinder or reverse the progress of current mitigation strategies. Two examples of such consumption activities would be:

(1) a possible energy demand so high (induced by a high demand for final goods and services) that it cannot be satisfied by forms of clean energy, which face several difficulties to meet a massive increase in their use (Bird *et al.*, 2011; Fargione *et al.*, 2008; Guijarro *et al.*, 2009; IPCC, 2012; IPCC, 2014; Ledec *et al.*, 2011; Patzek *et al.*, 2005; Simms *et al.*, 2010; Trainer, 2007; WEC, 2015); or

(2) a direct or indirect rebound effect on energy demand as an adverse effect of energy efficiency (also known as the "Jevons paradox") (Font Vivanco *et al.*, 2016; García Ochoa, 2010; Hertwich, 2005; IPCC, 2014; Simms, Johnson, and Chowla, 2010; Trainer, 2007).

While production sectors ostensibly try to mitigate CO_2 emissions, other activities tend to increase them because the varying and rising demand for final goods and services of households promoted by economic growth (even when such growth is small) and prevailing consumption patterns, together with demographic growth. So far, the boost to CO_2 emissions has surpassed the quantity of avoided CO_2 emissions. Consequently, the path of these emissions has not shown an inflection point driving to a low carbon economy in most countries.

In the case of Mexico, CO_2 emissions have continuously risen despite mitigation strategies guided by the conventional approach. For this reason, the time has now come to explore the climate problem from alternative perspectives that take into account not only the supply but also the demand to obtain more effective mitigation results. While various studies have examined the relationship between climate change and the varying household direct energy demands at different income levels, the relationship between climate change and the varying total household demands at different income levels has not been sufficiently examined. Thus, the objective of this study is to quantitatively analyze if the varying Mexican household consumption patterns at different income levels were related to different levels of CO_2 emissions during the period 1990-2014.

2. Literature review

Climate change has typically been approached from a neoclassical perspective of economics. While such an approach has mostly focused on supply, we identified two alternative analytical perspectives to study climate change from the demand side:

(1) CO_2 emissions responsibility can be allocated to the consumer country using consumption-based CO_2 emission inventories;

(2) consumption-based CO_2 emissions within a country are heterogeneous among households (or individuals), and such differences could be linked with income levels and prevailing consumption patterns. Neither of these has been deeply analyzed for the case of Mexico.

2.1 Consumption-based CO_2 emission inventories

CO_2 emission inventories are an important tool for analyzing the progress of climate change mitigation strategies at the macro level. The most common inventories, in fact used in the UNFCCC, are territorial CO_2 emission inventories that allocate most of the carbon responsibility to the producer. They take into account CO_2 emissions generated by domestic and foreign production sectors in a country, as well as part of the emissions related to final consumption, which are directly derived from energy consumption by fuel combustion (gas, gasoline, diesel, etc.) in the country.

In contrast, consumption-based CO_2 emission inventories constitute a way to allocate carbon responsibility to the consumer (Munksgaard *et al.*, 2009). This methodology is a combination of Input-Output (I-O) techniques and Ecological Footprint analysis (Turner *et al.*, 2007). Consumption-based CO_2 emission inventories take into account CO_2 emissions directly derived from energy consumption (henceforth referred to as "direct CO_2 emissions") as well as CO_2 emissions embodied in the domestic demand for final goods and services of a country (henceforth, "indirect CO_2 emissions"), whether locally produced or imported. Thereby these inventories exclude emissions from the exported domestic production and include emissions from the imported final demand (Aall and Hille, 2010).

To better understand the categories included in a consumption-based CO_2 emission inventory, it is necessary to analyze the composition of the demand. The final demand of an economy is made up of goods and services bought by the household, business, government and foreign sectors ($GDP = C + I + G + NX$)[1]. The internal final demand of an economy is made up of final goods and services bought by the household, business and government sectors ($ID = C + I + G$)[2]. The net exports are the difference between the exports and the imports ($NX = X - M$)[3]. This difference is calculated because the imports are also included in other GDP components. In this way, the internal demand includes the imports for the final goods and services of each consumption sector.

As the goal of consumption-based CO_2 emission inventories is assessing the effect of final consumption activities of a given country on CO_2 emissions, these inventories take into account CO_2 emissions directly derived from energy consumption within the country and CO_2 emissions embodied in the domestic demand for final goods and services (household consumption, investment and government expenditure). CO_2 emissions embodied in imports of final goods and services are included within the CO_2 emissions embodied in any of the domestic final demand expenses.

Although there are certain difficulties involved in estimating consumption-based CO_2 emission inventories, this line of research has progressed considerably[4]. Nowadays consumption-based CO_2 emission inventories for the period of 1990-2014 are available for practically all countries (Le Quéré *et al.*, 2016; Stadler *et al.*, 2015; Wiebe and Yamano, 2016).

In these databases, every consumption-based inventory is parallel to a territorial inventory, which allows comparing and contrasting them.

In general, the comparison between territorial and consumption-based CO_2 emission inventories suggests that developed countries import many CO_2 emissions from developing countries by importing products. That is to say, an important part of the production of developing countries meets the consumption necessities of developed countries, whose emissions are nonetheless attributed to the producing country. Thus, developed countries are generally net importers of CO_2 emissions, while developing ones are net exporters of carbon[5] (Davis and Caldeira, 2010; Fernández-Amador *et al.*, 2016; Kanemoto, *et al.*, 2014; Wiebe and Yamano, 2016).

Although consumption-based inventories provide a good indicator of CO_2 emissions related to consumption activities of countries, they remain vastly at the international level of analysis. To study these emissions within countries, some research has incorporated the heterogeneous demand of households (or individuals) in its analysis. The following section delves into this literature.

2.2 CO_2 emissions and consumption patterns by income level within countries

The diversity of household (or individual) consumption at different income levels can be studied through two macroeconomic approaches: top-down and bottom-up[6]. Broadly speaking, top-down methodology consists of applying a simple expenditure (or income)-CO_2 emissions elasticity model. This model uses data on household expenditure by income level (or income distribution) and CO_2 emission inventories, and it assumes an elasticity value of 1 or close to 1 based on previous findings of bottom-up studies, which have analyzed the relationship between household expenditure (or income) and total CO_2 emissions[7], and which have found a direct relationship between these variables. In fact, the design of the elasticity model derives from the observation of this direct relationship, where the elasticity value plays an important role. The expenditure (or income)-total CO_2 emissions elasticities estimated by bottom-up studies can range from 0.4 to 1.4, but a range of 0.7-1.0 is much more typical[8] (Chakravarty *et al.*, 2009; Chancel and Piketty, 2015; Cohen *et al.*, 2005; Lenzen, 1998; Pachauri, 2004; Park and Heo, 2007; Vringer and Blok, 1995; Weber and Matthews, 2008).

Top-down studies have been conducted in recent years at the international level to allocate global CO_2 emissions among households (or individuals) of different income levels with different consumption patterns. To our knowledge, Chakravarty *et al.* (2009) was the first study of this kind, and although it has received some criticism[9], it represents an innovative way of studying the importance of income distribution and consumption patterns within countries. A number of subsequent analyses have used similar methodological strategies. These include the Climate Equity Reference Project (EcoEquity and Stockholm Environment Institute, 2015), Chancel and Piketty (2015) and OXFAM (2015). These studies have improved upon the study of Chakravarty *et al.* by, for example, using consumption-based CO_2 emission inventories instead of territorial CO_2 emission inventories.

When top-down studies use consumption-based CO_2 emission inventories, they relate expenditure (or income) to both direct and indirect CO_2 emissions (i.e. to total CO_2 emissions). In this way, all expenses are related to CO_2 emissions. The results of the top-down studies above-mentioned show a big carbon inequality between the rich and the poor, which is derived from different consumption patterns. Wealthy people significantly emit more CO_2 than poor people do. As wealth is distributed unevenly worldwide, there are high emitters in both developed and developing countries; thus, it does not make sense to treat all individuals in any given country as a homogenous block in terms of mitigation responsibilities (Chakravarty *et al.*, 2009; Chancel and Piketty, 2015; EcoEquity and Stockholm Environment Institute, 2015; OXFAM, 2015).

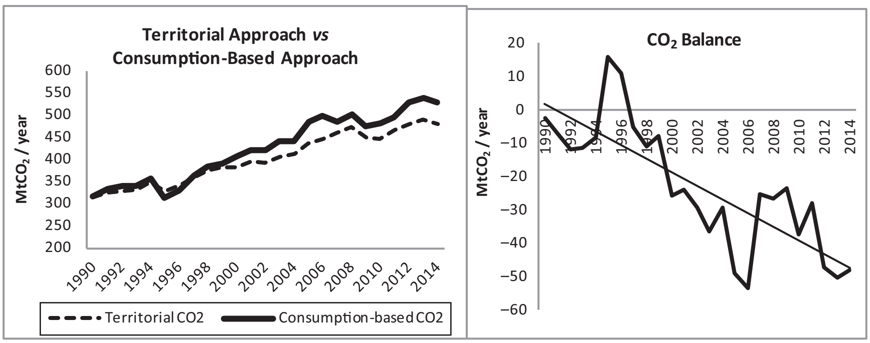
2.3 Knowledge of the relationship between climate change and final demand in Mexico

The role of Mexican final consumption activities as a possible driver of CO_2 emissions is evident when checking consumption-based CO_2 emission inventories. Consumption-based CO_2 emission inventories are usually global projects that calculate CO_2 emissions at national levels, but they do not include a detailed analysis of each country. However, important information regarding Mexico's CO_2 emissions can be drawn from these inventories.

According to several estimates of territorial and consumption-based CO_2 emission inventories, Mexico is currently a net importer of CO_2 emissions (Chancel and Piketty, 2015; Davis and Caldeira, 2010; Fernández-Amador *et al.*, 2016; Le Quéré, *et al.*, 2016; Stadler, *et al.*, 2015; Wiebe and Yamano, 2016). This situation contradicts the idea of developing countries as net CO_2 emission exporters, which is even more surprising because Mexico has an economic model based on exports.

Mexico's situation could be explained by various factors. Trade liberalization in Mexico has meant not only a large increase in exports but also a significant increase in imports of both final and intermediate goods. Many imported final goods come from the manufacturing industry. For this reason, the CO_2 emissions embodied in them are significant and push up the consumption-based CO_2 emission inventory. In addition, many imported intermediate goods are only assembled and then re-exported as either final or intermediate goods to be part of the global production chain again; thus, they do not have an effect on the consumption-based CO_2 emission inventory. Seen in this light, Mexico's exporting activity is not very carbon-intensive, resulting in lower territorial CO_2 emissions. Based on the data of Le Quéré, *et al.* (2016)[10], Mexico has been a net importer of CO_2 emissions since 1996, and this trend has generally been on the rise, except in times of crisis (Figure 1).

Regarding the effect of income inequality and consumption patterns within the country on climate change, some studies have examined household energy expenditure in Mexico on the basis of the "Household Income and Expenditure Survey" to determine the following: how much money each income group spends on energy (Chapa and Ortega, 2016; Cruz Islas, 2012; Jiménez and Yépez-García, 2017; Navarro, 2014); how much energy each income group consumes (Cruz Islas, 2012; Cruz Islas, 2016; Rosas, 2011; Rosas *et al.*, 2010; Sánchez Peña,



Source: created by authors based on Le Quéré, *et al.* (2016)

Figure 1.
Comparison of CO_2 emissions in Mexico, 1990-2014

2012a; Sánchez Peña, 2012b); and how much CO_2 derived from the energy consumption each income group emits (Chapa and Ortega, 2016; Cruz Islas, 2016; Rosas *et al.*, 2010).

All these studies have found a direct relationship between income level and drivers of climate change (i.e. energy spending, energy consumption or direct CO_2 emissions): the higher the household income, the more the household tends to adversely affect climate change. Nevertheless, some of these analyses have indicated that the relationships are not perfectly linear: the increase of drivers of climate change when income grows at the highest income levels is smaller than when income grows at the lowest income levels (Chapa and Ortega, 2016; Jiménez and Yépez-García, 2017; Navarro, 2014).

3. Methodology and data

We applied a top-down quantitative analysis, a simple expenditure-CO_2 emissions elasticity model, to allocate carbon emissions among household income groups according to their consumption patterns from 1990 to 2014[11]. Even though top-down studies have only been used to allocate CO_2 emissions among households (or individuals) at the international level, we also consider this approach useful at the national level, especially when it is difficult to obtain enough information to perform a bottom-up study, as in the case of Mexico and other developing countries.

We followed the methodology developed by Chancel and Piketty (2015) with a few adaptations to our case study[12], using the following formula:

$$CO2_i = f_i \left(\frac{CO_2}{\sum_{i=1}^{N} f_i * y_i^e} \right) y_i^e \tag{1}$$

where:

f_i = the share of the income group i within the total population;
y_i = mean expenditure in income group i;
CO_2 = consumption-based CO_2 emissions in Mexico (household consumption);
N = number of income groups; and
e = the expenditure-CO_2 elasticity.

The data sets used were mainly two:

(1) the consumption-based CO_2 emission inventory from Le Quéré, *et al.* (2016), which estimates CO_2 emissions in Mexico annually from 1990 to 2014; and

(2) the "Household Income and Expenditure Survey" (*Encuesta Nacional de Ingresos y Gastos de los Hogares, ENIGH*) carried out by the National Institute of Statistics and Geography (Instituto Nacional de Estadística y Geografía – INEGI), which reports the income and expenditure data of Mexican households for 1989 and biennially from 1992 to 2014.

Synthetically, in Le Quéré *et al.* (2016), the consumption-based CO_2 emission inventory of a country has the following features:

- it includes CO_2 emissions from fossil fuel combustion and oxidation as well as from cement production and excludes CO_2 emissions from bunker fuels;
- it takes into account the direct CO_2 emissions generated within the country and the CO_2 emissions embodied in final goods and services demanded by households, investment and government; and

- it considers indirect CO_2 emissions that could be generated either in the national production sector or in foreign production sectors, even among several countries.

As the aim of this research is to analyze the relationship between Mexican household consumption and total CO_2 emissions, using the total consumption-based CO_2 emission inventory could be considered controversial because it includes CO_2 emissions embodied in the demand for final goods and services made by households, business and government in Mexico. For this reason, unlike Chancel and Piketty (2015), we only used the share of the consumption-based CO_2 emission inventory that is attributed to household consumption. Given that the consumption-based CO_2 emission inventory from Le Quéré *et al.* (2016) so far does not separately report every component of the internal final demand, it was necessary to use other estimates. According to data provided by Glen Peters of the Center for International Climate and Environmental Research – Oslo, 75 per cent of the total consumption-based CO_2 emissions in Mexico in 2011 were related to household consumption[13]. Based on this estimate, we assumed that 75 per cent of the total CO_2 emissions reported in the Mexican consumption-based CO_2 emission inventory by Le Quéré *et al.* (2016) were related to household consumption between 1990 and 2014.

The second data set, the ENIGH, is a survey based on a sample in which the observation unit is the household and the sampling unit is the housing unit (INEGI, 2018). We used microdata from the ENIGH to analyze income and expenditure household through the Stata software. Given that there is one survey for 1989 and then biennial surveys 1992-2014, we used the 1989-ENIGH as a proxy for 1990 to cover our period of study in a biennial form. To obtain the annual data on both household income and household expenditure, it was assumed that the quarterly data reported in the ENIGH were the same in all the quarters of every year.

We classified the households by income level in ten groups (deciles)[14]. For that purpose, we used the total income[15] data because it represents the best way to analyze how much income households can spend. For analyzing the expenditure, we did not use total expenditure[16] because it includes financial and capital expenditures that are hardly related to CO_2 emissions. Instead, we assessed the current expenditure per income decile, which includes monetary and non-monetary expenditures. We did not exclusively use monetary expenditure because there are items that, while they are not part of monetary movements, could be drivers of CO_2 (e.g. self-consumption, transfers, remunerations in-kind, etc.).

For this study, we worked with elasticity values ranging from 0.7 to 1.0, given that there is no consensus about expenditure-CO_2 emissions elasticity (i.e. it can vary from country to country and over time) and given that there is no expenditure-CO_2 emissions elasticity estimate for Mexico. This elasticity range has been generally found by bottom-up estimates for other countries and often used by top-down international studies. In fact, some top-down studies have argued that the main results of the elasticity models are quite insensitive to the elasticity value and stay robust if the elasticity values are near 1.0 (Chakravarty, *et al.*, 2009; Chancel and Piketty, 2015).

4. Results and discussion

In this section, we present the results of the expenditure-CO_2 emissions elasticity model using the average values obtained from applying the model with elasticities of 0.7, 0.8, 0.9 and 1.0. The separate results of the model with each elasticity value can be consulted in the Appendix (Tables AI, AII and AIII) of this paper.

In general, we found that the household consumption patterns at the highest income levels are related to significantly more total CO_2 emissions (direct + indirect) than the household consumption patterns at the lowest income levels in Mexico from 1990 to 2014, both in absolute terms and in relative terms – per household and per capita[17] (Table I). These results show a big carbon inequality for the case of Mexico, which is in line with the previously mentioned top-down studies at the global level and bottom-up studies for other countries.

In absolute terms, Figure 2 illustrates two important trends. First, during the period 1990-2014, there was a rise in CO_2 emissions related to Mexican household demand (from 237.4 $MtCO_2$ to 396.3 $MtCO_2$): the CO_2 emissions increased in every income group. This is relevant because the residential sector is almost always analyzed as if it only produced direct CO_2 emissions within the dwelling (the CO_2 emissions derived from natural gas, LP gas and other heating fuels). According to the National Greenhouse Gas Emissions Inventory of the country (INECC-SEMARNAT, 2018), for example, the CO_2 emissions coming from the residential sector grew around 2 per cent between 1990 and 2014: they increased between 1990 and 1998, then they fell and remained relatively stable during the 2000's, and later, they diminished in the first half of this decade. However, if consumption responsibilities are taken into account, then the household sector is also related to CO_2 emissions from electricity and transport, as well as indirect CO_2 emissions that are embodied to a different degree in almost all consumption goods and services (e.g. food, cars, tourism, clothes, electronic devices, home appliances, education, health services, jewelry, etc.). When we considered all of these, the household CO_2 emissions path was radically different: the total CO_2 emissions coming from the Mexican household sector increased by about 67 per cent from 1990 to 2014.

The second trend that can be observed in Figure 2 is that there was a contrasting carbon responsibility among the households by income level. Between 1990 and 2014, the 10 per cent of households with the highest income in Mexico emitted on average 88 $MtCO_2$ a year. In contrast, the 10 per cent of the households with the lowest income in Mexico emitted on average 10.4 $MtCO_2$ a year. In proportional terms, the CO_2 emissions produced by the richest and the poorest deciles averaged 27.7 and 3.2 per cent, respectively (Table I).

Although during the period examined here the growth rates of CO_2 emissions of the households with low income were higher than the ones of the households with high income, the CO_2 emission differences in absolute terms among the income groups still continued to be significant at the end of the period (Table I). The difference between CO_2 emissions from the richest decile and the ones from the poorest decile (black line in Figure 2) did not diminish; in fact, it slightly increased (the difference rose from 60.3 $MtCO_2$ to 89.4 $MtCO_2$). This trend suggests that CO_2 emission growth might be mainly attributed to the high consumption levels of the richest and not to a greater energy access or better living conditions for the poorest.

Notwithstanding the growing CO_2 emissions gap between the poorest and the richest deciles, there were some changes in the other income groups that drove the carbon inequality slightly downward, at least when it is assessed through the Gini Index or the Lorenz Curve. There has been a more equitable distribution of the CO_2 emissions among households in recent years than in the 1990s or in the first half of the 2000s. This trend in CO_2 emissions inequality roughly followed the trend in the current expenditure inequality and (to a lesser extent) total income inequality (Table II). The Gini Index of the CO_2 emissions decreased by 12 per cent between 1990 and 2014, while the Gini Indexes of current expenditure and total income decreased by 11 and 6 per cent, respectively.

The different inequality levels of the three distributions can also be illustrated by the average Lorenz Curves for 1990-2014 (Figure 3). As we expected, the CO_2 emissions inequality was less than the current expenditure inequality, and this, in turn, was less

Table I. Indicators of CO_2 household emissions by income decile in Mexico, 1990-2014 (Annual Data)

Deciles	Average total income per household (thousands of Mexican pesos) 1990	2014	CO_2 emissions ($MtCO_2$) 1990	2014	Average	CO_2 emission shares (%) 1990	2014	Average	Growth rates of CO_2 emissions (%) Average biennially	Total	CO_2 emissions per household (tCO_2) 1990	2014	Difference	CO_2 emissions per capita (tCO_2) 1990	2014	Difference
First	2.3	32.0	7.2	15.1	10.4	3.0	3.8	3.2	6.6	109.8	4.5	4.8	0.3	1.1	1.6	0.5
Second	4.0	52.3	10.5	20.3	14.6	4.4	5.1	4.5	5.8	92.9	6.6	6.4	−0.2	1.5	1.9	0.4
Third	5.4	68.3	12.6	23.8	17.7	5.3	6.0	5.5	5.6	88.9	7.9	7.5	−0.4	1.6	2.2	0.5
Fourth	6.8	84.7	14.7	27.2	20.6	6.2	6.9	6.4	5.4	84.5	9.2	8.6	−0.7	1.9	2.3	0.4
Fifth	8.4	101.8	17.3	30.5	23.8	7.3	7.7	7.4	5.0	76.8	10.8	9.6	−1.2	2.2	2.5	0.3
Sixth	10.4	122.3	20.1	34.2	27.2	8.5	8.6	8.5	4.7	70.1	12.6	10.8	−1.8	2.4	2.7	0.3
Seventh	12.8	148.5	24.1	38.4	31.6	10.1	9.7	9.9	4.2	59.7	15.1	12.1	−3.0	2.8	2.9	0.1
Eighth	16.3	187.6	28.3	45.4	37.5	11.9	11.4	11.8	4.2	60.3	17.7	14.3	−3.4	3.4	3.4	0.0
Ninth	22.5	257.2	35.2	57.0	47.8	14.8	14.4	15.0	4.3	62.2	22.0	18.0	−4.1	4.2	4.2	0.0
Tenth	55.4	595.8	67.4	104.4	88.0	28.4	26.4	27.7	4.2	54.8	42.2	33.0	−9.3	8.6	8.6	0.0
*Total†/Average**	*14.4**	*165.1**	*237.4†*	*396.3†*	*319.2†*	*100.0†*	*100.0†*	*100.0†*	*5.0**	*76.0**	*14.9**	*12.5**	*−2.4**	*3.0**	*3.2**	*0.3**

than the total income inequality. The former difference is because we applied the model with expenditure-CO_2 emissions elasticity values between 0.7 and 1.0. The latter difference is because the current expenditure could overcome the total income when income is low, and because income might not be completely intended for current expenditure when income is high. In other words, the marginal propensity to spend decreases when the income is higher.

Finally, CO_2 emissions in relative terms – per household and per capita – of each income group from 1990 to 2014 are presented in Figures 4 and 5, both of which show an extreme carbon inequality but also a little fall in this inequality during the period. The per household CO_2 emissions gap between the highest and the lowest deciles decreased by 25 per cent from 1990 to 2014 (the gap fell from 37.7 tCO_2 to 28.2 tCO_2). This reduction could be mainly explained by a declining trend in per household CO_2 emissions in the tenth decile. Despite the decreasing gap, the average CO_2 emissions per household of the richest decile were almost seven times the average CO_2 emissions per household of the poorest decile at the end of the period (Table I and Figure 4).

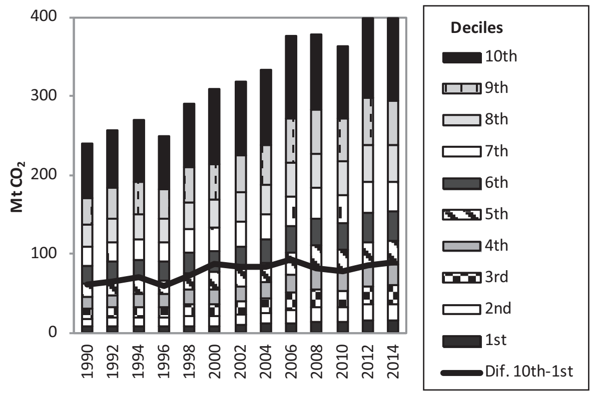


Figure 2. CO_2 emissions of households by income group in Mexico, 1990-2014

Table II. Gini indexes of CO_2 emissions, current expenditure and total income in Mexico, 1990-2014

Year	Gini index CO_2 emissions	Gini index Current expenditure	Gini index Total income
1990	0.35	0.41	0.47
1992	0.36	0.41	0.49
1994	0.36	0.42	0.48
1996	0.34	0.40	0.47
1998	0.35	0.41	0.48
2000	0.38	0.44	0.50
2002	0.36	0.42	0.47
2004	0.35	0.41	0.46
2006	0.34	0.40	0.46
2008	0.31	0.36	0.47
2010	0.31	0.36	0.44
2012	0.31	0.36	0.45
2014	0.31	0.36	0.45

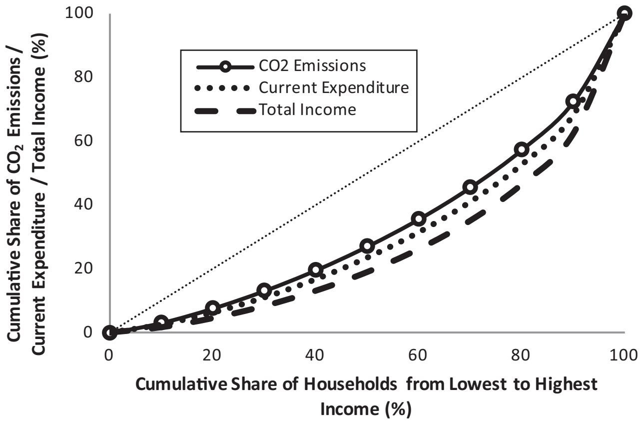


Figure 3.
Lorenz curves for Mexican households by income level, 1990-2014

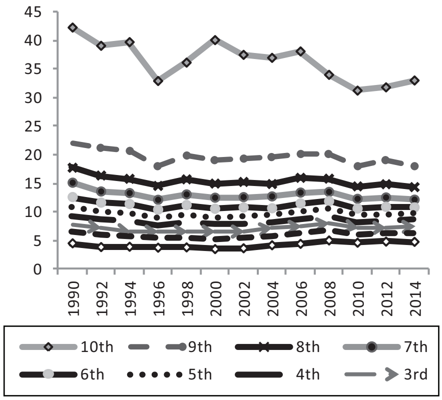


Figure 4.
Per household CO_2 emissions by decile in Mexico, 1990-2014 (tCO_2)

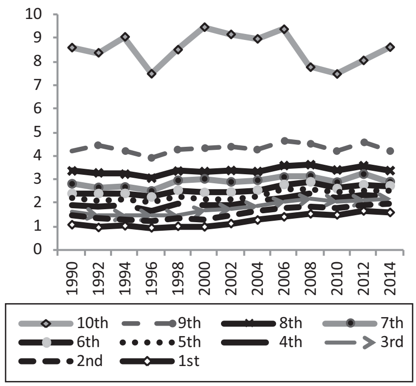


Figure 5.
Per capita CO2 emissions by decile in Mexico, 1990-2014 (tCO2)

The per capita CO_2 emissions gap between the tenth and the first deciles showed a smaller reduction than the per household CO_2 emissions gap. This divergence is because of the size of the households. On the per capita basis, the gap between the highest and the lowest deciles declined by 7 per cent from 1990 to 2014 (it fell from 7.5 tCO_2 to 7.0 tCO_2). On the one hand, this slightly narrowing gap could be explained by the increasing per capita CO_2 emissions from the poorest deciles. On the other hand, this could be because of the relatively stable per capita CO_2 emissions from the richest deciles. Even though this trend, in 2014, the CO_2 emissions per capita of the affluent top 10 per cent were 5.4 times the CO_2 emissions per capita of the poorest 10 per cent. The poorest household decile emitted 1.6 tons of CO_2 per capita on average in 2014, while the wealthiest decile reached 8.6 tons of CO_2 per capita (Table I and Figure 5).

Notwithstanding the diverse trends among CO_2 emissions in absolute terms, per household and per capita, we observe a big carbon inequality and worrying high CO_2 emission levels at the richest deciles in the three cases. The absolute, per household and per capita total CO_2 emissions at the tenth decile are not comparable to those any other decile. Moreover, it is possible that CO_2 emissions of the wealthy are underestimated because of the high rate of non-response to surveys and the under-reporting of consumption activities of persons in the high income strata.

5. Conclusion

In this paper, we have presented an alternative approach for studying CO_2 emissions responsibility in Mexico from the demand side. Such an approach has been absent in previous studies and is necessary to complement the current climate change mitigation strategies and policies, which have mainly focused on the supply side.

We found a very high carbon inequality among households at different income levels through the application of a simple expenditure-CO_2 emissions elasticity model for Mexico from 1990 to 2014 using data from consumption-based CO_2 emission inventories and the "Household Income and Expenditure Survey" (*Encuesta Nacional de Ingresos y Gastos de los Hogares, ENIGH*) and assuming a range of 0.7-1.0 elasticity values. The consumption activities of the richest households account for a large proportion of the total consumption-based CO_2 emissions of the country, which are made up of both direct CO_2 emissions (directly derived from energy consumption) and indirect CO_2 emissions (embodied in goods and services).

Given that consumption patterns as a whole are drivers of climate change, it is necessary to reconsider and broaden the focus of mitigation to take them into account. Even though some efforts have been made in this regard, most research still focuses on supply and policies addressing the demand side are only beginning to be discussed. This research opens a way for studying and discussing climate change in terms of consumption and equity, not only in Mexico but perhaps also in other developing countries without enough information to elaborate a bottom-up study. Our findings may have implications for climate change mitigation strategies and policies because our analysis makes connections among income level, consumption and CO_2 emissions that have been disregarded by researchers and policy-makers in this kind of countries.

The results of this paper suggest that the high-income groups should be primary targets for future climate policies; nevertheless, further research is needed to more accurately allocate carbon emission responsibilities among income levels, both in Mexico and worldwide. Future work is planned to identify the varying structure of household demand by income level and its total carbon intensity, which should prove useful for identifying carbon intensive sectorial consumptions by income level, estimating the expenditure-CO_2

emissions elasticity along the income curve and avoiding the assumption a homogeneous elasticity for all households. Likewise, future work could include using econometric techniques to determine if there is causality and not just a relationship between income level and CO_2 emissions and to reveal the effect of a change of income on the amount of CO_2 emissions.

Following such a line of research could help to identify the groups and activities with a large potential for reducing CO_2 emissions from the demand side, which has thus far been almost completely ignored. Research on consumption patterns related to climate change will be crucial in this regard, and therefore, the social sciences should have a critically important role in any such future investigations.

Notes

1. GDP: Gross Domestic Product; C: Consumption; I: Investment; G: Government Spending; NX: Net Exports.
2. ID: Internal Demand; C: Consumption; I: Investment; G: Government Spending.
3. NX: Net Exports; X: Exports; M: Imports.
4. Hoekstra (2010) quoted in Tukker and Dietzenbacher, (2013), Wiedmann *et al.* (2007), and Wiedmann (2009), for example, conducted an extensive review of several studies and the evolution of consumption-based emission inventories.
5. A positive difference between a consumption-based inventory and a territorial inventory of a country indicates that the country is a net importer of emissions; a negative difference indicates that the country is a net exporter of emissions.
6. For the purpose of this paper, we discuss the top-down approach more extensively than the bottom-up approach. However, the latter is also referred to because it complements the former.
7. Total CO_2 emissions = Direct CO_2 emissions + Indirect CO_2 emissions.
8. Instead of assessing total CO_2 emissions by income level, some bottom-up studies have assessed total energy consumption (direct + indirect) by income level as a way to relate consumption patterns (or income distribution) to climate change. Such a distinction is beyond the scope of this paper.
9. See, for example, Grubler and Pachauri (2009).
10. We used CO_2 emission inventories from Le Quéré, *et al.* (2016) to study the case of Mexico because this source meets requirements of reliability, data availability, and coverage over an extended period of time.
11. We defined this period of time because of data availability. As we will detail later, our principal datasets only cover this period.
12. Chancel and Piketty (2015) applied a simple elasticity model at the global level, where CO_2 was taken from total consumption-based CO_2 emission inventories, y_i was estimated based on income or expenditure data, and global population was divided into eleven income groups. In contrast, we applied a simple elasticity model at the national level for the case of Mexico, where CO_2 was taken from the share of the consumption-based CO_2 emission inventory that has been attributed to household consumption, y_i was estimated based on expenditure data, and the national population was divided into ten income groups.
13. At the global level, Ivanova *et al.* (2016) attributed 65 per cent (± 7 per cent) of the total CO_2 emissions of the final domestic demand to household consumption in 2007, and OXFAM (2015) calculated approximately 64 per cent in 2014. Although these proportions are very similar, they could vary over time and among countries, about which there is no data available so far.

14. Although we used microdata, we only divided the national population into ten groups to keep the distribution statistically significant at 1 per cent.
15. Total income includes both current income (monetary and non-monetary) and financial and capital gains (monetary and non-monetary).
16. Total expenditure includes current expenditure (monetary and non-monetary) and financial and capital expenditures (monetary and non-monetary).
17. Per household and per capita CO_2 emissions were estimated based on the data on the number of households and members per household from the ENIGH.

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Appendix

e	Decile/Year	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014
0.7	*I*	9	9	10	10	11	11	11	13	15	17	16	18	18
	II	12	13	13	13	14	15	16	17	20	22	21	23	23
	III	14	16	16	15	17	18	19	21	24	25	24	26	27
	IV	17	18	18	18	20	21	22	23	27	28	27	29	30
	V	19	20	21	20	23	24	25	26	30	31	30	32	33
	VI	21	23	24	23	26	27	28	29	34	35	33	36	36
	VII	25	26	27	26	30	31	32	34	38	39	37	41	40
	VIII	28	30	32	30	35	36	38	38	44	44	43	47	45
	IX	34	38	39	36	42	44	46	48	53	53	52	57	55
	X	58	62	67	58	69	80	78	81	90	82	80	87	90
	Total	237	255	267	248	288	306	315	330	374	376	361	396	396
0.8	*I*	8	8	8	8	9	9	10	11	13	15	14	16	16
	II	11	12	12	12	13	13	14	15	18	20	19	21	21
	III	13	14	14	14	16	16	17	19	22	23	22	24	25
	IV	15	17	17	16	19	19	20	22	25	27	25	28	28
	V	18	19	20	19	22	22	24	25	29	30	29	31	31
	VI	21	22	23	22	25	26	27	28	32	34	32	35	35
	VII	24	26	26	25	29	30	31	33	37	38	37	40	39
	VIII	28	30	31	30	35	36	38	38	44	44	43	47	46
	IX	35	39	41	37	43	45	47	50	55	55	53	59	56
	X	64	69	74	64	76	90	87	90	99	90	88	96	99
	Total	237	255	267	248	288	306	315	330	374	376	361	396	396
0.9	*I*	7	6	7	7	8	7	8	10	11	13	13	14	14
	II	10	10	10	10	11	11	13	13	16	18	17	19	19
	III	12	13	13	13	14	15	16	17	20	22	20	22	23
	IV	14	15	16	15	18	18	19	20	23	25	24	26	26
	V	17	18	19	18	21	21	22	24	27	29	27	30	30
	VI	20	21	22	21	24	24	26	27	31	33	31	34	34
	VII	24	25	26	25	29	29	31	32	36	37	36	39	38
	VIII	28	30	31	30	35	35	37	38	44	44	43	47	45
	IX	36	40	42	38	45	46	48	51	56	57	55	61	58
	X	71	76	82	71	84	100	96	99	109	99	96	105	109
	Total	237	255	267	248	288	306	315	330	374	376	361	396	396
1.0	*I*	5	5	6	6	6	6	7	8	9	11	11	12	12
	II	9	9	9	9	10	10	11	12	14	16	15	17	17
	III	11	12	12	12	13	13	14	16	18	20	18	20	21
	IV	13	14	14	14	16	16	17	18	21	23	22	24	25
	V	16	17	17	17	19	19	21	22	25	27	26	28	28
	VI	19	20	21	20	23	23	25	25	30	31	30	32	32
	VII	23	24	25	24	28	28	29	31	35	37	35	38	37
	VIII	28	30	31	30	35	35	37	37	43	44	43	47	45
	IX	36	41	42	39	45	46	49	52	57	58	56	62	59
	X	77	83	90	77	92	110	106	109	120	108	105	114	119
	Total	237	255	267	248	288	306	315	330	374	376	361	396	396

Table AI.
CO_2 emissions by income group in Mexico, 1990-2014 ($MtCO_2$)

Table AII.
Per household CO_2 emissions by income group in Mexico, 1990-2014 (tCO_2)

e	Decile/Year	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014
0.7	*I*	5.7	4.9	5.0	4.7	4.8	4.5	4.6	5.2	5.5	6.0	5.6	5.8	5.7
	II	7.8	7.0	6.7	6.4	6.5	6.3	6.6	6.7	7.3	7.7	7.0	7.2	7.4
	III	9.1	8.4	8.1	7.5	7.9	7.7	7.8	8.1	8.6	9.0	8.0	8.2	8.4
	IV	10.4	9.6	9.4	8.6	9.2	8.8	8.9	9.1	9.8	10.1	9.1	9.3	9.4
	V	11.8	11.0	10.7	9.8	10.4	10.0	10.2	10.3	11.0	11.3	10.2	10.3	10.3
	VI	13.4	12.4	12.2	11.0	11.9	11.3	11.5	11.4	12.2	12.4	11.1	11.4	11.4
	VII	15.6	14.1	13.8	12.5	13.5	13.0	13.1	13.2	13.8	13.8	12.6	12.8	12.5
	VIII	17.8	16.4	15.9	14.5	15.7	15.1	15.3	15.0	16.0	15.7	14.4	14.8	14.4
	IX	21.2	20.4	20.0	17.6	19.0	18.5	18.7	18.8	19.4	19.1	17.4	18.0	17.3
	X	36.1	33.4	33.8	28.3	31.0	33.9	31.9	31.5	32.6	29.4	27.0	27.5	28.4
	Total	14.9	13.8	13.6	12.1	13.0	12.9	12.9	12.9	13.6	13.5	12.2	12.5	12.5
0.8	*I*	4.8	4.1	4.2	4.0	4.1	3.8	3.9	4.5	4.7	5.3	4.9	5.1	5.0
	II	7.0	6.2	5.9	5.7	5.8	5.5	5.8	5.9	6.5	7.0	6.3	6.6	6.7
	III	8.2	7.6	7.3	6.9	7.2	6.9	7.1	7.4	7.9	8.3	7.4	7.6	7.8
	IV	9.6	8.9	8.7	8.0	8.6	8.1	8.2	8.5	9.1	9.6	8.5	8.7	8.9
	V	11.2	10.4	10.1	9.3	9.9	9.4	9.6	9.8	10.5	10.8	9.7	9.8	9.9
	VI	12.9	11.9	11.7	10.6	11.5	10.8	11.0	10.9	11.8	12.1	10.8	11.1	11.0
	VII	15.3	13.8	13.5	12.3	13.2	12.7	12.8	12.9	13.6	13.6	12.4	12.7	12.3
	VIII	17.8	16.4	15.9	14.6	15.7	15.1	15.3	15.0	16.0	15.8	14.5	14.9	14.4
	IX	21.9	21.1	20.6	18.2	19.6	19.0	19.2	19.4	19.9	19.8	18.0	18.7	17.8
	X	40.1	37.1	37.6	31.3	34.3	37.9	35.5	35.0	36.1	32.4	29.7	30.3	31.3
	Total	14.9	13.8	13.6	12.1	13.0	12.9	12.9	12.9	13.6	13.5	12.2	12.5	12.5
0.9	*I*	4.1	3.5	3.5	3.4	3.4	3.1	3.3	3.8	4.0	4.6	4.3	4.5	4.4
	II	6.2	5.5	5.2	5.0	5.1	4.8	5.1	5.3	5.8	6.4	5.7	6.0	6.1
	III	7.5	6.9	6.6	6.2	6.5	6.2	6.4	6.7	7.2	7.7	6.8	7.0	7.2
	IV	8.9	8.3	8.0	7.4	7.9	7.4	7.6	7.8	8.5	9.0	8.0	8.2	8.3
	V	10.5	9.8	9.5	8.8	9.3	8.8	9.0	9.2	9.9	10.3	9.3	9.4	9.4
	VI	12.3	11.4	11.1	10.2	11.0	10.3	10.5	10.4	11.3	11.7	10.4	10.7	10.6
	VII	15.0	13.4	13.1	12.0	12.9	12.3	12.4	12.6	13.2	13.4	12.2	12.4	12.0
	VIII	17.7	16.4	15.8	14.6	15.7	14.9	15.2	14.9	16.0	15.8	14.5	14.9	14.3
	IX	22.4	21.7	21.1	18.7	20.1	19.3	19.7	19.9	20.4	20.4	18.6	19.3	18.2
	X	44.2	40.9	41.6	34.4	37.8	42.0	39.2	38.7	39.8	35.4	32.6	33.2	34.5
	Total	14.9	13.8	13.6	12.1	13.0	12.9	12.9	12.9	13.6	13.5	12.2	12.5	12.5
1.0	*I*	3.4	2.9	2.9	2.9	2.9	2.6	2.7	3.2	3.4	4.0	3.7	3.9	3.8
	II	5.4	4.8	4.5	4.5	4.5	4.2	4.5	4.6	5.1	5.7	5.1	5.4	5.5
	III	6.7	6.2	5.9	5.6	5.8	5.5	5.7	6.1	6.5	7.1	6.2	6.4	6.6
	IV	8.1	7.6	7.3	6.9	7.3	6.8	6.9	7.2	7.8	8.4	7.5	7.6	7.8
	V	9.8	9.1	8.9	8.3	8.7	8.1	8.4	8.6	9.3	9.8	8.8	8.9	8.9
	VI	11.8	10.8	10.6	9.8	10.5	9.7	10.0	9.9	10.7	11.3	10.0	10.3	10.2
	VII	14.6	13.0	12.7	11.7	12.6	11.8	12.0	12.2	12.9	13.1	11.9	12.2	11.7
	VIII	17.6	16.2	15.6	14.5	15.6	14.7	15.1	14.7	15.8	15.8	14.5	14.8	14.2
	IX	22.7	22.1	21.5	19.1	20.5	19.5	20.0	20.3	20.8	20.9	19.0	19.8	18.6
	X	48.5	44.8	45.7	37.6	41.3	46.3	43.1	42.5	43.7	38.6	35.5	36.1	37.7
	Total	14.9	13.8	13.6	12.1	13.0	12.9	12.9	12.9	13.6	13.5	12.2	12.5	12.5

e	decile/Ano	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014
0.7	*I*	1.3	1.2	1.3	1.2	1.3	1.3	1.4	1.6	1.7	1.9	1.8	2.0	1.9
	II	1.8	1.6	1.5	1.5	1.6	1.5	1.8	1.9	2.1	2.1	2.0	2.2	2.2
	III	1.9	1.8	1.8	1.7	1.8	2.0	2.0	2.1	2.3	2.4	2.3	2.4	2.4
	IV	2.2	2.1	2.1	1.8	2.2	2.1	2.1	2.3	2.5	2.6	2.4	2.5	2.5
	V	2.4	2.3	2.4	2.2	2.5	2.4	2.4	2.5	2.8	2.8	2.6	2.7	2.7
	VI	2.5	2.6	2.6	2.4	2.7	2.6	2.6	2.7	3.0	3.0	2.7	2.9	2.9
	VII	2.9	2.8	2.8	2.6	3.1	3.2	3.0	3.1	3.2	3.2	3.0	3.3	3.0
	VIII	3.4	3.3	3.2	3.0	3.3	3.4	3.4	3.4	3.6	3.6	3.4	3.6	3.4
	IX	4.1	4.3	4.1	3.7	4.1	4.2	4.2	4.1	4.5	4.3	4.0	4.4	4.1
	X	7.4	7.2	7.7	6.4	7.3	8.0	7.8	7.7	8.0	6.7	6.5	7.0	7.4
	Promedio	3.0	2.9	3.0	2.7	3.0	3.1	3.1	3.2	3.4	3.4	3.2	3.4	3.3
0.8	*I*	1.1	1.0	1.1	1.0	1.1	1.1	1.2	1.4	1.5	1.6	1.6	1.8	1.7
	II	1.6	1.4	1.4	1.3	1.5	1.3	1.6	1.7	1.8	1.9	1.9	2.0	2.0
	III	1.7	1.7	1.6	1.5	1.7	1.8	1.8	1.9	2.1	2.3	2.1	2.2	2.2
	IV	2.0	1.9	2.0	1.7	2.0	2.0	2.0	2.2	2.3	2.5	2.3	2.4	2.4
	V	2.3	2.1	2.2	2.1	2.3	2.2	2.2	2.3	2.6	2.7	2.5	2.6	2.6
	VI	2.5	2.5	2.5	2.3	2.6	2.5	2.5	2.6	2.8	2.9	2.7	2.8	2.8
	VII	2.9	2.7	2.7	2.5	3.0	3.1	2.9	3.0	3.1	3.2	2.9	3.3	2.9
	VIII	3.4	3.3	3.2	3.1	3.4	3.4	3.4	3.4	3.6	3.6	3.4	3.6	3.4
	IX	4.2	4.4	4.2	3.9	4.2	4.3	4.3	4.2	4.6	4.5	4.1	4.5	4.2
	X	8.2	8.0	8.6	7.1	8.1	9.0	8.7	8.5	8.9	7.4	7.1	7.7	8.2
	Promedio	3.0	2.9	3.0	2.7	3.0	3.1	3.1	3.2	3.4	3.4	3.2	3.4	3.3
0.9	*I*	1.0	0.9	0.9	0.9	0.9	0.9	1.0	1.2	1.3	1.4	1.4	1.5	1.5
	II	1.4	1.3	1.2	1.2	1.3	1.2	1.4	1.5	1.6	1.8	1.7	1.8	1.8
	III	1.5	1.5	1.5	1.4	1.5	1.6	1.6	1.7	1.9	2.1	2.0	2.0	2.1
	IV	1.8	1.8	1.8	1.6	1.9	1.8	1.8	2.0	2.2	2.3	2.1	2.2	2.2
	V	2.1	2.0	2.1	2.0	2.2	2.1	2.1	2.2	2.5	2.5	2.4	2.4	2.4
	VI	2.4	2.3	2.4	2.2	2.5	2.4	2.4	2.5	2.7	2.9	2.6	2.7	2.7
	VII	2.8	2.6	2.6	2.5	2.9	3.0	2.9	2.9	3.1	3.1	2.9	3.2	2.9
	VIII	3.4	3.3	3.2	3.1	3.4	3.3	3.4	3.3	3.6	3.6	3.4	3.6	3.4
	IX	4.3	4.5	4.3	4.0	4.4	4.4	4.4	4.4	4.7	4.6	4.2	4.7	4.3
	X	9.0	8.8	9.5	7.8	8.9	9.9	9.6	9.4	9.8	8.1	7.8	8.4	9.0
	Promedio	3.0	2.9	3.0	2.7	3.0	3.1	3.1	3.2	3.4	3.4	3.2	3.4	3.3
1.0	*I*	0.8	0.7	0.8	0.7	0.8	0.7	0.8	1.0	1.1	1.2	1.2	1.3	1.3
	II	1.2	1.1	1.0	1.0	1.1	1.0	1.2	1.3	1.5	1.6	1.5	1.6	1.7
	III	1.4	1.4	1.3	1.3	1.3	1.4	1.5	1.6	1.8	1.9	1.8	1.8	1.9
	IV	1.7	1.6	1.7	1.5	1.7	1.6	1.7	1.8	2.0	2.2	2.0	2.1	2.1
	V	2.0	1.9	1.9	1.8	2.1	1.9	2.0	2.1	2.3	2.4	2.3	2.3	2.3
	VI	2.2	2.2	2.2	2.1	2.4	2.2	2.3	2.4	2.6	2.7	2.5	2.6	2.6
	VII	2.7	2.5	2.6	2.4	2.8	2.9	2.8	2.8	3.0	3.1	2.8	3.1	2.8
	VIII	3.3	3.2	3.2	3.0	3.3	3.3	3.3	3.3	3.6	3.6	3.4	3.6	3.4
	IX	4.3	4.6	4.4	4.1	4.4	4.4	4.5	4.4	4.8	4.7	4.4	4.8	4.4
	X	9.9	9.6	10.4	8.6	9.7	11.0	10.5	10.3	10.8	8.8	8.5	9.2	9.9
	Promedio	3.0	2.9	3.0	2.7	3.0	3.1	3.1	3.2	3.4	3.4	3.2	3.4	3.3

Table AIII.
Per capita CO_2 emissions by income group in Mexico, 1990-2014 (tCO_2)