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Lenin H. Balza
Laura Heras-Recuero
David Matias
Rigoberto Ariel Yépez-García

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Green or Growth? Understanding the Relationship between Economic Growth and CO_2 Emissions*

Lenin H. Balza[†] Laura Heras-Recuero[‡] David Matias[§] Ariel Yépez-García[¶]

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Abstract

The relationship between economic growth and environmental impact is a topic that has largely been studied through the framework of the Environmental Kuznets Curve (EKC), which posits an inverted U-shape relationship between the two. We examine this link by analyzing GDP and CO_2 emissions per capita from 1970 to 2020 using a panel of 136 countries. We estimate both the short- and long-run income elasticities of CO_2 emissions across various regions and for rolling time periods. The analysis focuses on Latin America and the Caribbean, aggregating and disaggregating data by region and introducing alternative measures of CO_2 emissions. Though our findings confirm the existence of the EKC at the global level, we do not find evidence of it for all regions. A monotonic positive relationship between income and emissions is observed for Latin America and the Caribbean. We also find that, in most cases, the income elasticity of production-based emissions is lower than that of consumption-based emissions. This distinction is particularly pronounced in the Latin American and Caribbean region, where the income elasticity of consumption-based emissions is estimated at 0.95, as opposed to 0.56 when using a production-based measure.

Keywords: CO_2 emissions, economic growth, environmental Kuznets curve, Latin America and the Caribbean.

JEL Classification: C33, O11, O13, O44.

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[†]Inter-American Development Bank. Infrastructure and Energy Sector. ✉: leninb@iadb.org

[‡]Inter-American Development Bank. Infrastructure and Energy Sector. ✉: laurahe@iadb.org

[§]Inter-American Development Bank. Infrastructure and Energy Sector. ✉: edilbertom@iadb.org

[¶]Inter-American Development Bank. Vice Presidency for Sectors and Knowledge. ✉: ariely@iadb.org

1 Introduction

The relationship between economic growth and CO_2 emissions has been a subject of particular interest in the context of the fight against climate change. In this, decarbonization has become a crucial issue, as countries strive to accomplish the 2030 Agenda for Sustainable Development and comply with the Paris Agreement, which aims to limit global warming to between 1.5°C and 2°C above pre-industrial levels, and requires reaching net zero CO_2 by around 2050. Yet attaining these goals poses particular challenges for developing countries, including many in Latin America and the Caribbean, as they seek to achieve sustained growth while also limiting emissions.

In order to build decarbonization strategies in Latin America and the Caribbean, a perspective that integrates both economic and social goals is key to ensuring that the process brings economic and development opportunities for the region (IDB and DDPLAC, 2019). The energy and transport sectors can play an important role in achieving this objective. However, this transformation will require massive capital mobilization.[1] This includes generation capacity, grid expansion and storage, the electrification of both the transportation and residential sectors, improvements in efficiency in end-use sectors, and policies to clean up the energy matrices. Increasing the share of renewable energy is also essential for ensuring energy security, reliable and affordable energy, and sustainable economic growth amidst the challenges posed by climate change.

In this paper, we examine the dynamics of CO_2 emissions in relation to economic growth through the lens of the Environmental Kuznets Curve (EKC).[2] Understanding this relationship is crucial for designing effective decarbonization strategies. We estimate the short- and long-run income elasticities of per capita CO2 emissions employing a series of annual data from 1970 to 2020 from a broad sample of developed and developing economies, grouped by region. Assessing an extensive time period is critical as the EKC describes a long-term

[1] To meet the infrastructure-related Sustainable Development Goals, the region will need to spend around US$185 billion per year until 2030 on new infrastructure and on the maintenance and replacement of existing facilities reaching the end of their useful life (Brichetti et al., 2021).

[2] The impact of economic growth on the environment, particularly as a source of CO_2 emissions, has been debated by academics and policy makers for decades. The Environmental Kuznets Curve (EKC) hypothesis, postulated by Grossman and Krueger (1991), has provided a leading theoretical framework to analyze this issue. The hypothesis postulates that the relationship between economic growth and environmental degradation changes throughout a country's development process. Under this view, the relationship is initially positive, meaning that growth is associated with an increase in environmental degradation. The trend is then reversed at a certain point on the development path, as countries become able to grow while increasing environmental quality. Changes in an economy's structure or technological development are implicit in the EKC since, in their absence, economic growth always leads to proportional environmental degradation, a phenomenon that some authors refer to as the scale effect (Stern, 2004).

phenomenon. This approach also allows us to examine elasticity estimates in Latin America and the Caribbean relative to the rest of the world. We use a primary measure of net CO_2 emissions that includes those from fossil fuels and industry measured on the production side, but complement this analysis with two other measures: a consumption-based measure that takes into account the emissions embedded in traded goods, and a production-based measure that adds to our primary measure the emissions generated by land-use activities (land-use change, deforestation, soils, or vegetation). In this way, we aim to achieve a comprehensive view of the relationship between growth and emissions by considering trade-embedded emissions and the emissions that come from both burning fossil fuels and land-use activities.

The results from our baseline measure of CO_2 emissions, production-based excluding land use, appear to confirm the EKC at the global level, with the turning point shifting over time to a lower level of GDP per capita. This means that the possibility of decoupling economic growth from environmental degradation emerges at an earlier stage of development. However, if a consumption-based measure of CO_2 emissions is introduced instead, the magnitude of the long-run elasticity (0.78) increases relative to the initial specification (0.64). Including emissions from land use shifts the income elasticity of CO_2 emissions with those from land use included to 0.65. While the magnitude of the change is small, this figure shows greater volatility over time. The situation of Latin America and the Caribbean in the global emissions scenario varies according to the measure of emissions used. We reject the existence of the EKC in the region and find a positive monotonic relationship between growth and emissions in all cases. However, the magnitude of the positive income elasticity varies considerably: it is 0.56 in the case of production-based emissions but rises to 0.95 in the case of consumption-based emissions. We do not find a significant relationship between economic growth and production-based CO_2 emissions in the region when land-use activities are included.

This study contributes to the literature by addressing some of the main methodological and theoretical criticisms of the EKC. From a methodological perspective, our analysis uses long time series as the EKC is by definition a long-run phenomenon, which using shorter time series may obscure (Brown and McDonough, 2016). Furthermore, we control for common factors to examine the possibility of cross-sections not being independent, a particularly relevant consideration in regional analyses (Jardón et al., 2017). On the theoretical side, we address the main criticisms of the EKC, which highlight the impact of globalization on the relationship between growth and emissions. First, globalization opens up the possibility of some countries relocating their more polluting industries or stages of production to other countries (Dinda, 2004; Levinson and Taylor, 2008); secondly, the measurement of emissions may be complicated due to the structure of global trade itself (Leal and Marques, 2022). To consider this dimension in the analysis, we employ a consumption-based measure of emissions. Our work is, to the best of our knowledge, the first examining the EKC for the entire region of Latin America and the Caribbean that incorporates a consumption-based measure into the analysis.[3]

The remainder of the paper is structured as follows. Section 2 provides an overview of global trends and regional variability in CO_2 emissions and describes the position of Latin America and the Caribbean in the global scenario. Section 3 introduces the dataset. Section 4 presents our methodology and Section 5 the results, including comparisons between different measures of CO_2 emissions. Conclusions and policy implications are discussed in Section 6.

2 Background

2.1 Global Trends and Regional Variability in CO_2 Emissions

CO_2 emissions are the main driver of climate change. Human activity, especially since the Industrial Revolution, has dramatically increased the concentration of CO_2 in the atmosphere. Global surface temperatures between 2011 and 2020 were 1.1°C higher than the 1900–1980 mean (IPCC, 2023). Figure 1 shows the evolution and regional composition of production-based emissions. The long-term trend in global annual CO_2 emissions shows a steady increase from about 14 billion tons in 1970 to more than 35 billion tons in 2021, with a recent drop in 2020 due to the COVID-19 pandemic.

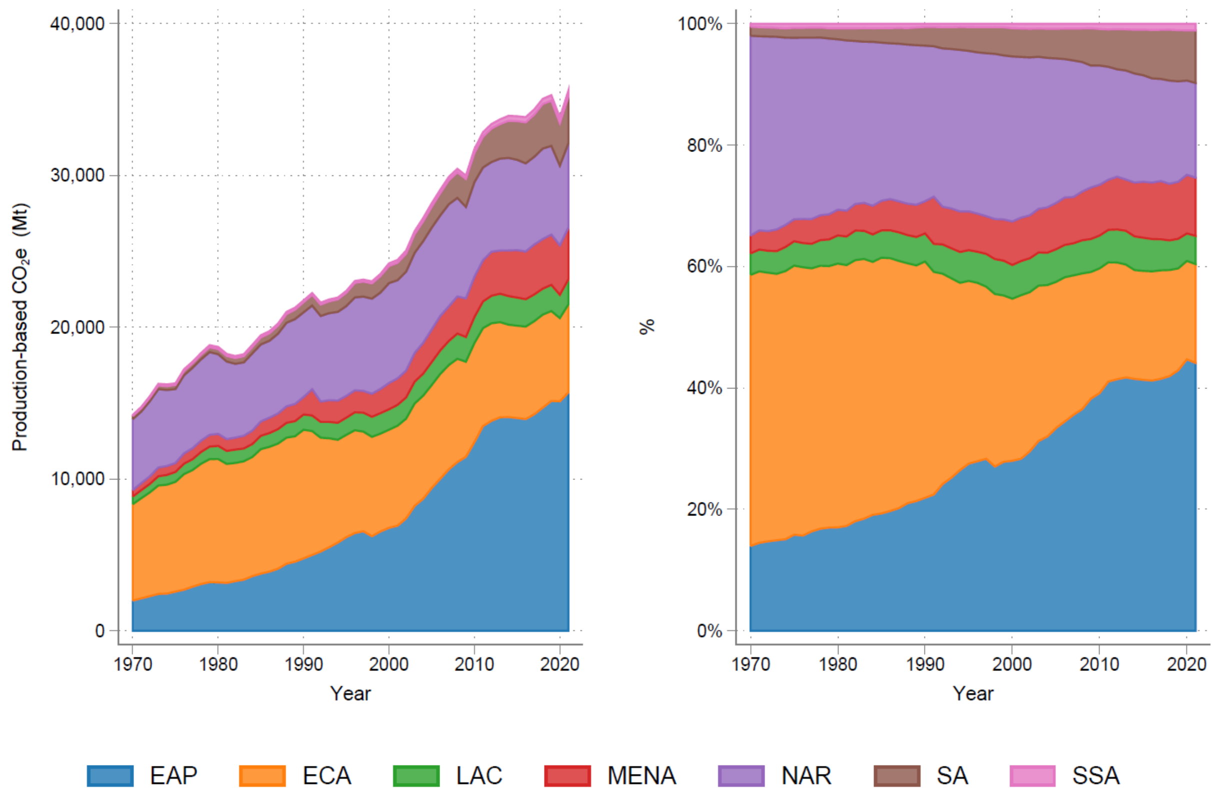
The regional composition of emissions has also changed over the last half century. In the 1970s, the main contributors to global CO_2 emissions were the high-income countries in Europe and Central Asia and North America. While these still account for a significant share of total emissions, their contribution has decreased over time. In 1970, Europe and Central Asia generated 44.7% of total emissions, while North America[4] 32.9% of the world's total; by 2021 these shares decreased to 16.3% and 15.6%, respectively. Meanwhile, middle-income regions have seen the greatest increase in their contribution to global emissions. East Asia and the Pacific stands out as the main CO_2 emitting region, with a share of 44.1% of total emissions in 2021, while South Asia has seen its share of global emissions rise steadily, as has the Middle East and North Africa. In contrast, Latin America and the Caribbean has

[3]Several studies have used consumption-based measures of CO_2 emissions in single-country analyses. For example Adebayo et al. (2021) focuses on the Chilean context, while Kirikkaleli and Oyebanji (2022) reviews the case of Bolivia.

[4]North America includes Canada and the United States.

maintained its share at around 5% over the same period.

Figure 1: Annual CO_2 emissions by region



Source: Authors' own elaboration based on Global Carbon Budget data.
Notes: Production-based CO_2 emissions exclude land-use change and forestry and waste. Regions: East Asia and the Pacific (EAP), Europe and Central Asia (ECA), Latin America and the Caribbean (LAC), the Middle East and North Africa (MENA), North America (NAR), South Asia (SA), and Sub-Saharan Africa (SSA).

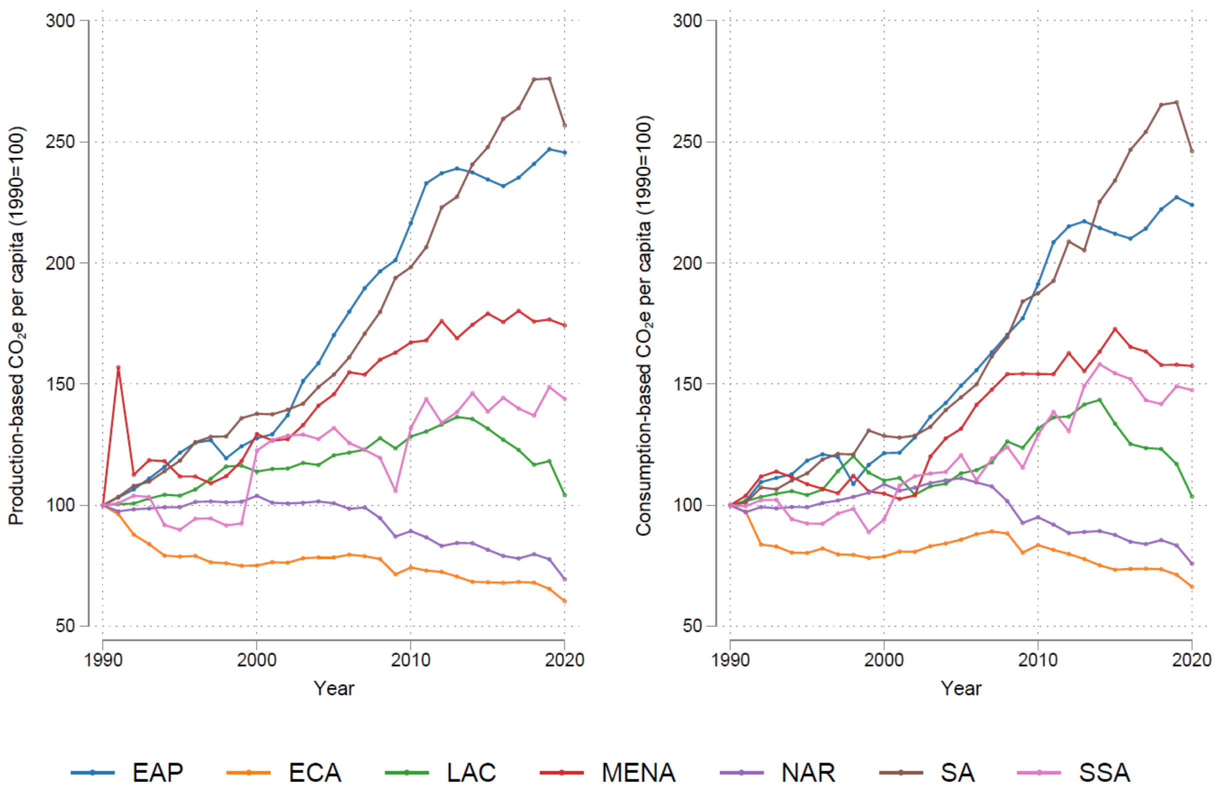
There are wide regional differences in how CO_2 emissions per capita have changed over time. Figure 2 shows both production- and consumption-based[5] emissions per capita by region[6]. North America and Europe and Central Asia are the only regions that have successfully reduced emissions over time. South Asia and East Asia and the Pacific have seen the largest increases in CO_2 emissions per capita, with an increase of 154% and 145%, respectively, between 1990 and 2020. While the main dynamics at the regional level are consistent across for both production-based and consumption-based emissions measures, there are some noteworthy differences. In South Asia, East Asia and the Pacific, and the Middle East and North Africa, production-based emissions have increased more than consumption-based emissions,

[5]Consumption-based emissions adjust production-based emissions to account for trade, meaning that emissions associated with the production of exported goods are subtracted from total production-based emissions and those associated with the production of goods imported into the country are added. Thus, a country or region where consumption-based emissions are greater than production-based emissions would be a net importer of CO_2.

[6]In addition, Figure A1 in the Appendix displays CO_2 emissions in tons per person by region.

while the opposite has ocurred in the other regions. In the case of Latin America and the Caribbean, emissions grew steadily until 2015 and have since declined, roughly in line with the end of the commodity price boom phase. In addition, the dynamics of consumption-based emissions have been more pronounced, with higher growth rates during the period of rising emissions and deeper declines in recent years.

Figure 2: Evolution of per capita CO_2 emissions by region



Source: Authors' own elaboration based on Global Carbon Budget data.
Notes: Production-based CO_2 emissions exclude land-use change and forestry and waste. Consumption-based emissions adjust production-based emissions to account for trade, meaning that emissions associated with the production of exported goods are subtracted and those associated with the production of goods imported into the country are added. Regions: East Asia and the Pacific (EAP), Europe and Central Asia (ECA), Latin America and the Caribbean (LAC), the Middle East and North Africa (MENA), North America (NAR), South Asia (SA), and Sub-Saharan Africa (SSA).

The relationship between economic growth and emissions has been studied since the second half of the 20th century. One of the most influential papers is that of Meadows et al. (1972), who used a computer simulation model to conclude that high growth rates were incompatible within a global context of limited natural resources. According to this theory, humanity would reach a point where the unsustainability of growth would lead to a decline in industrial production and population. This result is based on an assumption of limited technological growth. The EKC hypothesis, meanwhile, as proposed by Grossman and Krueger (1991), marked a turning point in the analysis of the relationship, which came to be considered as being non-monotonic.

The Kuznets curve, initially proposed by Kuznets (1955) to study the relationship between income per capita and inequality, posits an inverse U-shape to denote inequality rising with income growth until reaching an inflection point at a certain level of per-capita income, after which it decreases. Likewise, the EKC posits a relationship between growth and environmental degradation that changes over the course of economic development. Under this view, the relationship is positive in the early stages of development until the country reaches a certain level of income per capita. From that point on, income is decoupled from emissions, and countries manage to grow with a decreasing detrimental impact on the environment. The underlying rationale is that the development process achieves certain changes in productive structures, permits technological advances that enable cleaner production, and generates greater environmental awareness in society (World Bank, 1992; Panayotou, 1993). These technological advances and innovations include the ability to generate clean energy. Since the 1990s, the EKC has become the main framework for analyzing the relationship between economic growth and emissions, generating a substantial body of literature that has adopted this setup when modeling emissions and has investigated its validity using both time series and panel data (Cole et al., 1997; Dinda, 2004; Kijima et al., 2010; Stern, 2017; Leal and Marques, 2022).

Although the EKC has become the main theoretical and methodological framework for explaining the relationship between growth and environmental degradation, a body of literature has emerged that is critical of some aspects of this proposal. Most of these criticisms revolve around the methodology or theoretical aspects of the hypothesis. The methodological criticisms fall into a few main groups, which are worth discussing here. First, empirical analyses of this phenomenon – by definition, a long-term one (Brown and McDonough, 2016) – have tended to use relatively short time series. This may explain why some papers find no evidence for the existence of the relationship. Second, many panel data studies do not account for the possibility that their cross-sections may be interdependent. This is, however, a particularly relevant issue in regional analyses, where such interdependence is likely to exist. In the case of Latin America and the Caribbean, Jardón et al. (2017) show that the EKC hypothesis, which is supported under an assumption of cross-sectional independence, is not found when this issue is considered.

Other critiques focus on theoretical aspects of the EKC. First, in a scenario of globalized open economies, the curve's shape might be explained not only by countries' own development processes but also by the changing structure of trade. Specifically, there has been a tendency to shift more polluting industries or stages of production to developing countries, while developed countries focus more on less polluting sectors and cleaner technologies (Grossman and Krueger, 1991). The so-called pollution haven hypothesis suggests that this phenomenon is the result of differences in environmental regulations, which create incentives for firms to relocate to countries or regions with more lax regulations (Dinda, 2004; Levinson and Taylor, 2008; Sarkodie and Strezov, 2019). Evidence in support of this theory is, however, mixed (Bashir, 2022). Alternatively, the dynamics of the EKC may be explained by the structure of global trade itself, with developing countries specializing more in labor-intensive industries or stages of production while developed countries specialize in more technologically and capital-intensive industries or stages of production, in line with their comparative advantages (Leal and Marques, 2022). These considerations highlight the need to consider the trade dimension in the analysis of the relationship between emissions and economic growth, and has recently led to the inclusion of both production- and consumption-based measures of CO_2 emissions in the literature (Cohen et al., 2018; Hubacek et al., 2021; Hassan et al., 2022).

An additional critique is that the use of income as an explanatory variable represents a reduced-form formulation: since income is a variable that encompasses so many aspects of the economy, it makes it difficult for these analyses to generate policy proposals. The impact of the economies of scale, the structure of production, changes in the input mix, and other causes related to social and idiosyncratic characteristics of countries are thus obscured under the umbrella of income (Stern, 2017).

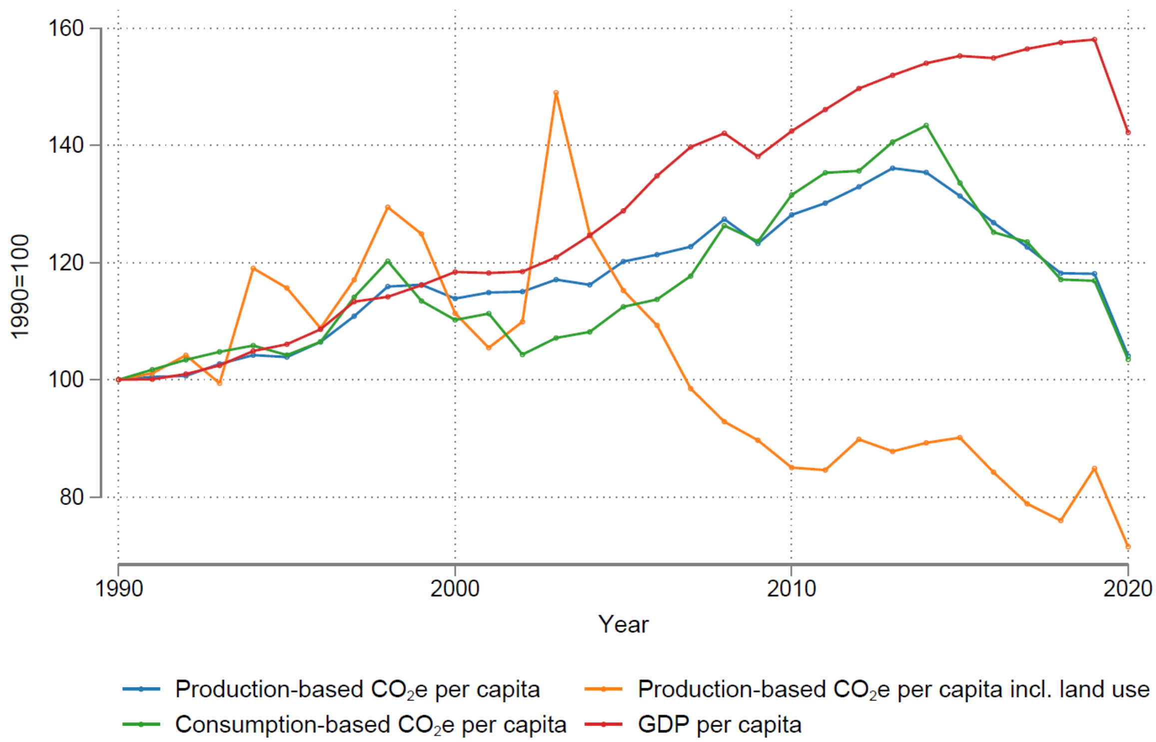
2.2 Latin America and the Caribbean in the Global Scenario of CO_2 Emissions

The "grow first, then clean up" paradigm of the EKC is difficult to justify in the current context of climate change. In the energy sphere, there is an urgent need for developing countries to leapfrog fossil fuels to renewable energy sources. Although there is evidence that countries are making their energy transitions at increasingly lower levels of GDP per capita (Marcotullio and Schulz, 2007), and development processes are therefore less polluting today than they used to be, economic growth in today's developing countries is no less energy intensive than past growth in industrialized countries (Benthem, 2015).[7] Despite improvements in energy efficiency, reducing emissions while ensuring economic growth is still a major challenge for developing countries. However, this can also be seen as an opportunity to

[7] Balza et al. (2024) explore the energy consumption-income growth relationship in Latin America and the Caribbean. Their findings reveal a robust positive correlation, which is more pronounced than in other country groups. This indicates that economic growth in the region remains significantly energy-intensive, challenging the notion of a less polluting development process in contemporary developing countries.

implement structural policies that ensure growth and achieve achieve climate goals, among other development objectives (IDB and DDPLAC, 2019). Environmental regulations are often lax in developing countries (Dasgupta et al., 2002) and production structures are more concentrated toward traditionally more polluting sectors such as agriculture and industry.[8] Therefore, there is ample scope for implementing policies and reforms that aim to attract the investments needed to meet climate goals.

Figure 3: CO_2 emissions and GDP in Latin America and the Caribbean



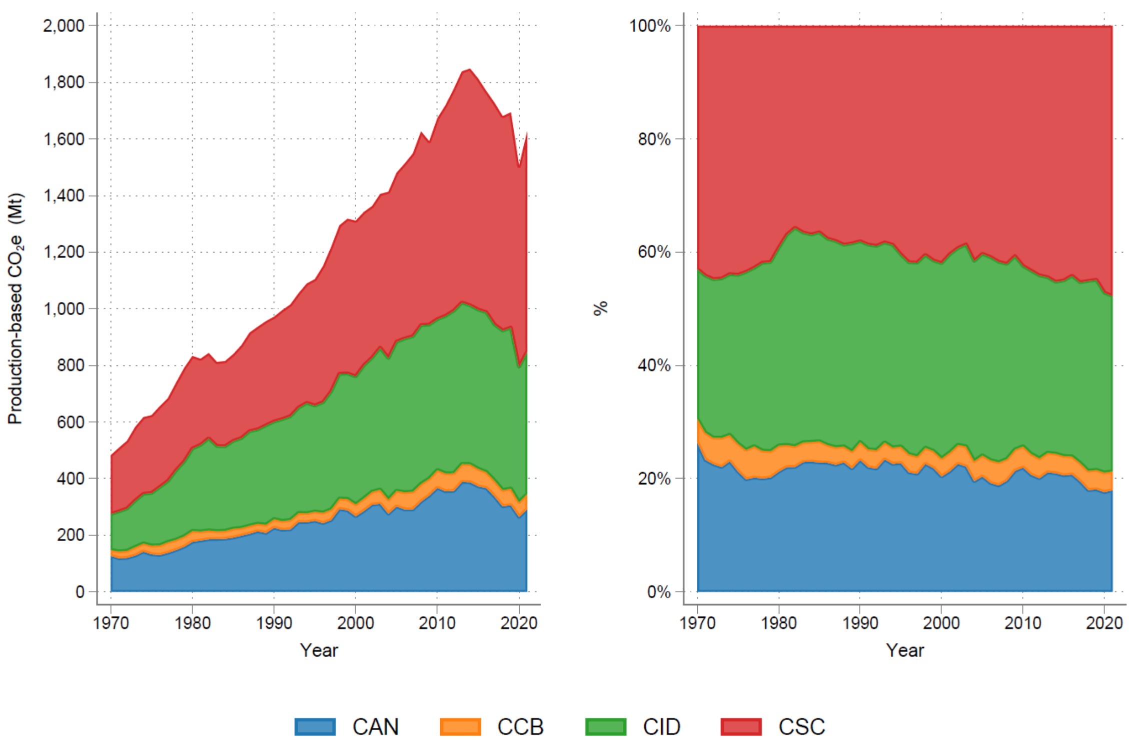
Source: Authors' own elaboration based on Global Carbon Budget data.
Notes: Production-based CO_2 emissions exclude land use change and forestry and waste. Consumption-based emissions adjust production-based emissions to account for trade, meaning that emissions associated with the production of exported goods are subtracted and those associated with the production of goods imported into the country are added. Latin America and the Caribbean includes the following countries: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Paraguay, Peru, Trinidad and Tobago, Uruguay, and Venezuela.

Latin American and Caribbean economies face a particularly complex situation in terms of reducing emissions and complying with the Paris Agreement. One of the main difficulties arises from the characteristics of the productive matrix of several countries in the region, which are oriented towards the extraction of raw materials to meet global demand, a process associated with high levels of CO_2 emissions. As shown in Figure 3, aggregate per capita CO_2

[8]According to data from Climate Watch and the World Resources Institute, 29% of global CO_2 emissions are generated by industrial activity and industrial energy use, while 18% are generated by agriculture, forestry, and land use. Moreover, low-technology manufacturing, highly concentrated mostly in developing countries, is associated with the highest emissions (Avenyo and Tregenna, 2022).

emissions began to decouple from economic growth starting in the early 2000s. Since then, GDP per capita grew faster than all three measures of emissions. However, while growth has slowed over time in production-based CO_2 emissions per capita including land use[9], this is not the case when measuring either production-based emissions excluding land use or consumption-based emissions; reductions in the growth rate of these emissions measures have only becoming apparent in recent years, particularly since 2014.

Figure 4: Production-based CO_2 emissions in Latin America and the Caribbean by subregion



Source: Authors' own elaboration based on Global Carbon Budget data.
Notes: Production-based CO_2 emissions exclude land use change and forestry and waste. We follow the IDB regional country composition for Latin America and the Caribbean: CAN (Bolivia, Colombia, Ecuador, Peru, and Venezuela), CCB (the Bahamas, Barbados, Guyana, Jamaica, Suriname, and Trinidad and Tobago), CID (Belize, Costa Rica, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, and Panama), and CSC (Argentina, Brazil, Chile, Paraguay, and Uruguay).

When looking at the trajectory of annual emissions levels, the picture is a somewhat more positive. Figure 4 shows annual production-based CO_2 emissions in million tons in Latin American and the Caribbean[10]. Annual emissions have increased over time in the region, reaching a maximum of 1.849 billion tons in 2014. They have followed a downward trend since, with a significant drop in 2020 associated with the impact of the COVID-19 pandemic and a subsequent recovery in 2021, though this increase still saw emissions return to a level

[9] The behavior of this measure of CO_2 emissions in the region closely mirrors the pattern of deforestation in the Brazilian Amazon, as can be seen in Appendix Figure A2.

[10] A complementary breakdown of energy-related CO_2 is shown in Appendix Figure A3.

lower than their pre-COVID figure. When disaggregated by subregion, the Southern Cone is the region's largest emitter, accounting for around 48% of total emissions in 2021. It is followed by Central America with 31% of total emissions, of which 25% are from Mexico, and by the Andean Group with 18% of total regional emissions. Emissions from the Southern Cone countries have been increasing their share of total emissions since the mid-1980s, while the shares of Central America and, to a lesser extent, the Andean Group have been decreasing over time.

The relationship between economic growth and environmental impact, approximated by various aggregates such as CO_2 emissions, has been studied in the Latin American and Caribbean context within the theoretical framework of the EKC. However, many of the criticisms leveled at this hypothesis in discussions of other regions or global trends are equally applicable to this area. There is no clear consensus on the matter among studies that use long time series to explore the existence of the EKC in a Latin American panel of countries. Some research finds evidence of a relationship between income per capita and CO_2 emissions consistent with the EKC hypothesis (Al-mulali et al., 2015; Sapkota and Bastola, 2017), including some evidence for the region as a whole (Sánchez and Caballero, 2019), while other studies conclude that the relationship between economic growth and CO_2 emissions in the region is linear and positive (Seri and de Juan Fernández, 2023). Yet other works observes an N-shaped relationship (Poudel et al., 2009).

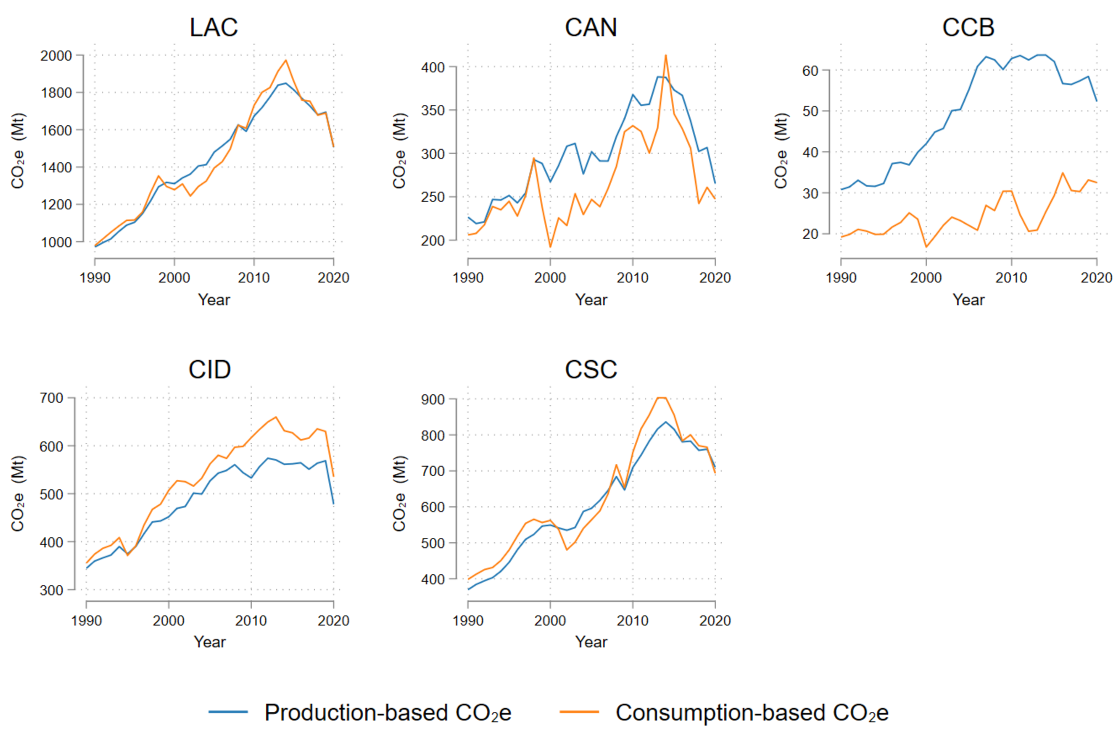
Scholars have also come to divergent conclusions on related issues. Pablo-Romero and De Jesús (2016) do not find that the EKC applies to the relationship between economic growth and energy consumption in the region, but Bhattarai and Hammig (2001) confirm the EKC relationship between income and deforestation. Differences in the estimation method, the period covered, the control variables, and the sample composition may lie behind these differences. Moreover, since most of Latin America comprises middle-income countries, it may be that these countries are close to the turning point of the relationship, possibly explaining the divergent results.

In the case of Latin America and the Caribbean, the behavior of the export sector is also particularly important for a complete overview of the relationship between income and emissions. The region's productive and export matrices, with a few exceptions, are dominated by commodities, while imports are mostly manufactured products.[11] Both industries are associated with high levels of CO_2 emissions. The extraction and processing of natural resources is responsible for approximately half of global greenhouse gas emissions, of which

[11] According to World Bank data (World Integrated Trade Solution), in 2020, 30% of total exports in Latin America and the Caribbean were raw materials and 70% of total imports were manufacturing products.

CO_2 is a major component. In the case of Latin America and the Caribbean, this figure rises to 60% for some South American countries (UNEP, 2019). The manufacturing sector is also a major source of CO_2 emissions (Sohag et al., 2017). Consumption-based emissions, which incorporate the structure of trade into the analysis, are therefore particularly relevant to the region's situation. In fact, as shown in Figure 5, there are significant differences in how the region's CO_2 emissions change over time depending on whether production- or consumption-based measurements are considered; these measurements also uncover differences within the region.[12] In general terms, the gap between production-based and consumption-based CO_2 emissions can be explained by the composition and behavior of the trade balance.

Figure 5: Production- and consumption-based CO_2 emissions in Latin America and the Caribbean by subregion



Source: Authors' own elaboration based on Global Carbon Budget data.
Notes: Production-based CO_2 emissions exclude land use change and forestry and waste. Consumption-based emissions adjust production-based emissions to account for trade, meaning that emissions associated with the production of exported goods are subtracted and those associated with the production of goods imported into the country are added. We follow the IDB regional country composition for Latin America and the Caribbean (LAC): CAN (Bolivia, Colombia, Ecuador, Peru, and Venezuela), CCB (the Bahamas, Barbados, Guyana, Jamaica, Suriname, and Trinidad and Tobago), CID (Belize, Costa Rica, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, and Panama), and CSC (Argentina, Brazil, Chile, Paraguay, and Uruguay).

[12] In Appendix Figure A4, we also compare these two emissions measures at the country level across nations for which data on both is available. In the case of Panama, although data are available for both measures, the consumption-based CO_2 emissions data series has missing values between 2002 and 2007 and 2010 and 2014; published data from the country uses linear interpolations for these periods. For this reason, we decide not to include Panama in this paper.

Moreover, until very recently, the literature on CO_2 emissions in the region has not considered these different methods of measuring emissions, and therefore a complete picture of the relationship between income and emissions is not available. Recent work has examined the phenomenon with consumption-based emissions measures for individual countries, such as Adebayo et al. (2021) for Chile and Kirikkaleli and Oyebanji (2022) for Bolivia. However, to the best of our knowledge, no regional study of the phenomenon has yet been conducted. This paper contributes to the literature by examining the relationship between economic growth and CO_2 emissions, including those from domestic production as well as emissions measures that incorporate the dynamics of the external sector.

3 Data

The dataset used in this paper consists of an unbalanced panel covering 136 countries, including 21 countries from Latin America and the Caribbean, with annual data for the period 1970–2020.[13] The dependent variable is a measure of annual production-based emissions of carbon dioxide ($CO2E$) in tons per person.[14] The measure does not include emissions embedded in traded goods and those derived from land use change. We also complement this measure of CO_2 emissions with two alternative metrics. The first is a consumption-based CO_2 emissions measure ($CCO2E$), in tons per person, which is adjusted for trade (i.e., production emissions within the country minus emissions embedded in exports, plus emissions embedded in imports). The second is a production-based CO_2 emissions measure ($LUCO2E$), in tons per person, which includes land use change.[15] All CO_2 metrics are derived from the Global Carbon Budget database.

The main explanatory variable is GDP per capita (GDP), in constant 2015 US dollars, from the World Bank World Development Indicators (WDI) database. Its relationship with per capita CO_2 emissions is modeled in this paper following the EKC hypothesis, i.e., as a quadratic relationship. As Figure 6 shows, this form is supported by a first exploratory analysis

[13]Specifically, Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Paraguay, Peru, Suriname, Trinidad and Tobago, and Uruguay.

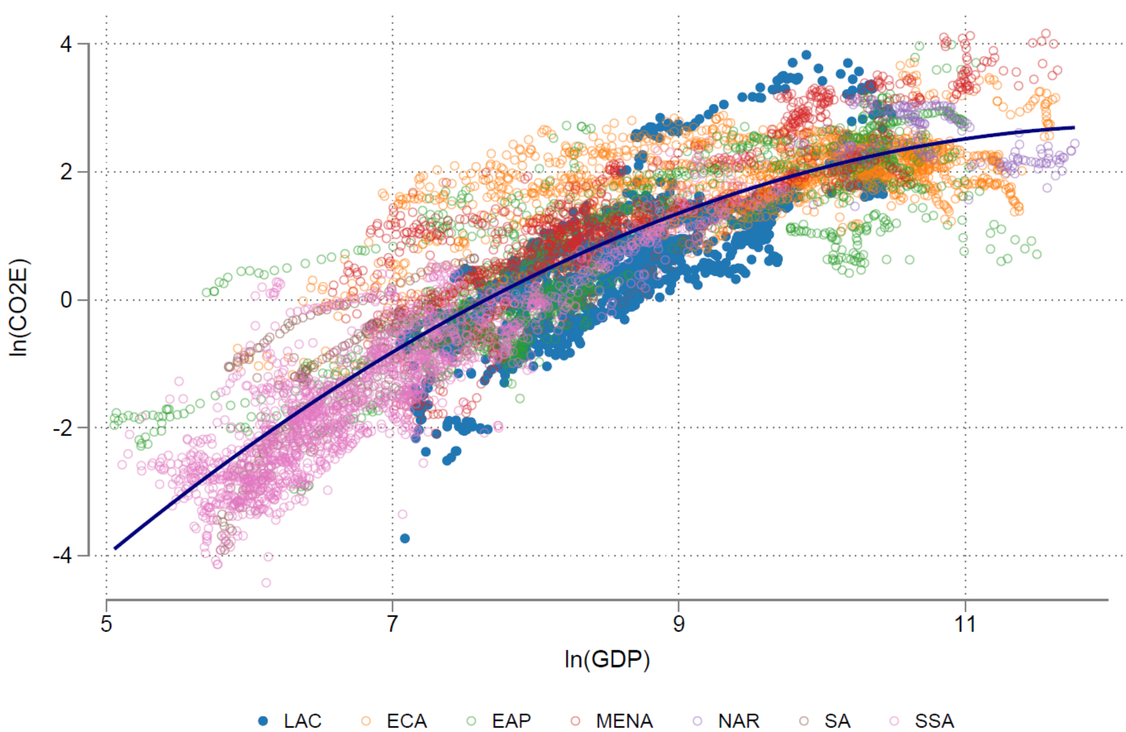
[14]CO_2 emissions include the oxidation of fossil fuels through both combustion and chemical oxidation activities, and the decomposition of carbonates in industrial processes. They also include CO_2 uptake from the cement carbonation process as explained in Friedlingstein et al. (2022).

[15]This includes CO_2 emissions from deforestation, afforestation, logging and forest degradation (including harvest activity), shifting cultivation (cycles of cutting forests for agriculture followed by abandonment of the fields), and regrowth of forests (following wood harvest or agriculture abandonment). It also incorporates emissions from peat burning and drainage (Friedlingstein et al., 2022).

of the data, at least at the global level.

We also include other regressors in the specifications to control for some relevant factors identified in the literature. These include the value added of agriculture ($AGRIC$), manufacturing ($MANUF$), and services ($SERV$), respectively, expressed as a percentage of GDP from the WDI database. Including these variables allows us to control for varying GDP compositions across countries, which has been identified in the literature as a driver of CO_2 emissions. For instance, the industrial sector— comprising manufacturing, mining, and energy production— has repeatedly been identified as a major contributor to CO_2 emissions (Sohag et al., 2017). Meanwhile, agriculture stands out as a particularly important driver of emissions in Latin America and the Caribbean (Seri and de Juan Fernández, 2023). Processes of structural transformation, which involve changes in the sectoral composition of GDP, have likewise been found to have a positive impact on CO_2 emissions (Mehmood Mirza et al., 2022).

Figure 6: CO_2 emissions per capita and GDP per capita by region



Source: Authors' own elaboration based on Global Carbon Budget data.
Notes: Production-based CO_2 emissions do not include land use change and forestry and waste. Regions: East Asia and the Pacific (EAP), Europe and Central Asia (ECA), Latin America and the Caribbean (LAC), Middle East and North Africa (MENA), North America (NAR), South Asia (SA), and Sub-Saharan Africa (SSA).

We furthermore consider the percentage of renewable sources in the energy matrix (RE) from the International Energy Agency World Energy Balances 2022. The rationale for including this stems from an extensive literature showing that increasing the share of renewables in the energy matrix has a significant impact on reducing CO_2 emissions (Yuping et al., 2021; Kirikkaleli et al., 2022). This impact is particularly large in the case of Latin America and the Caribbean (Dong et al., 2018). Appendix Table 1A presents some descriptive statistics for the data.

4 Empirical Strategy

The EKC describes a long-term phenomenon that relates the trajectory of environmental degradation, in this case measured by CO_2 emissions, to countries' development processes, usually captured by GDP per capita (Brown and McDonough, 2016). We accordingly estimate it with a methodological framework that distinguishes between the short and long term. In order to be consistent with the EKC, we model the relationship in a quadratic form, an approach supported by the preliminary exploration of the data. The long-run income elasticity of CO_2 emissions can be represented by the following equation:

$$\ln(CO2E_{it}) = \beta_0 + \beta_1 In(GDP_{it}) + \beta_2 In(GDP_{it})^2 + \varepsilon_{it} \tag{1}$$

Equation (1) represents the long-run relationship between CO_2 emissions and GDP per capita. However, different short- and long-run coefficients can be modeled when adding the first-order lag of the dependent variable to the specification as in Koyck (1954). Model (1) then becomes:

$$\ln(CO2E_{it}) = \beta_0 + \gamma In(CO2E_{i,t-1}) + \beta_1 In(GDP_{it}) + \beta_2 In(GDP_{it})^2 + \varepsilon_{it} \tag{2}$$

The emergence of different short- and long-run coefficients comes from the adjustment mechanism given by γ. By bringing the lag of the endogenous variable to the right side of the equation, model (2) can be represented as:

$$(1-\gamma L)\ln(CO2E_i) = \beta_0 + \beta_1 In(GDP_{it}) + \beta_2 In(GDP_{it})^2 + \varepsilon_{it} \tag{3}$$

where $(1-\gamma L)$ is the lag operator and the coefficients on the right side of the equation represent the short-run dynamics. This means that the total income elasticity of $CO2E$ in the same period can be calculated as $\beta_1 + 2\beta_2 In(GDP)$. The long-run total income elasticity, which indicates the cumulative effect of a sustained 1 percentage point increase in GDP, is given by the following expression:

$$\delta_{gdp} = \frac{\beta_1 + 2\beta_2 ln(GDP)}{1-\gamma} \tag{4}$$

In our analysis, we start from the framework established by the EKC but extend it by taking into account suggestions from the literature related to the use of this analytical framework. First, we address the possibility that the cross-sections are not independent by including a common factor—the oil price—that would serve to approximate global economic conditions (Mohaddes and Pesaran, 2017). This factor is particularly relevant at the regional level, especially in Latin America, as shown by Jardón et al. (2017). Second, we control for relevant factors in the regression. Specifically, we account for the productive structure by including the value added of agriculture, manufacturing, and services, each calculated as a percentage of GDP. We also include a proxy for the weight of clean energy in the energy matrix, i.e., the percentage of renewables in the total energy mix.

Given the above information, the previous setup can be extended by including the relevant control variables and fixed effects:

$$\ln(CO2E_{it}) = \beta_0 + \gamma ln(CO2E_{i,t-1}) + \beta_1 ln(GDP_{it}) + \beta_2 ln(GDP_{it})^2 + A\theta_i + \alpha_i + \alpha_i xOILP_t + t + t^2 + \varepsilon_{it} \tag{5}$$

where i and t refer to country and year dimensions, respectively. The long-run CO_2 emissions ($CO2E$) are a function of income per capita (GDP) and its square. A is a matrix of relevant controls, including the sectoral composition of GDP and the share of renewable sources in the energy matrix. α_i represents country fixed effects, and $\alpha_i xOILP_t$ denotes an interaction between country fixed effects and a common factor, namely the evolution of oil prices, allowing us to account for the differential impact of oil prices at the country level. $t + t^2$ is a quadratic time trend, and ε_{it} represents the error term.

We estimate equation (5) using a country fixed effects (FE) estimator with Driscoll-Kraay standard errors that are robust to heteroskedasticity and general forms of serial correlation and cross-sectional ("spatial") dependence. The country fixed effects allow us to capture country-specific factors that may explain CO_2 emissions, while the interaction of oil prices with country dummies allows us to control for common global economic factors that may affect each country differently. The time trend captures the dynamics of emissions, which are expected to increase with marginal returns over time given the earth's environmental limits.[16]

We complement the analysis with production-based CO_2 emissions as the explanatory variable, with consumption-based CO_2 emissions (to account for the behavior of the external

[16]We also test the stability of the estimates when employing different types of fixed effects, see the results in Appendix Figure A5.

sector) and production-based CO_2 emissions (including emissions generated by land use, forestry, and waste, as dependent variables. Although the latter two measures would, in principle, offer better approximations of the phenomenon, the data cover a smaller temporal range and the literature on this approach is limited. This leads us to consider them as alternative approaches to the use of production-based CO_2 emissions as the main measure of pollution in this paper.

5 Results

Table 2 presents the results of the estimation of equation (5). The first column reports the estimates for a global sample that includes both developed and developing countries, the second column refers to the estimates for the Latin America and the Caribbean region, and the remaining columns those of other geographic regions with more than 10 countries. The first part of each column shows the short-run estimates, with the last row containing the lag of the dependent variable (the adjustment term). The second part of each column presents the long-run coefficients. We introduce a quadratic relationship between GDP and CO_2 emissions, following the EKC hypothesis, only in those cases where it turns out to be significant. When this is the case, we also include the turning point, which indicates the level of GDP per capita, in constant 2015 US dollars, where the relationship between CO_2 emissions per capita and GDP per capita changes its sign from positive to negative. This is the specific value of GDP per capita at which the decoupling process between CO_2 and economic growth would occur.

While the controls have the expected signs, there are regional differences in terms of significance. The share of manufacturing in GDP is positively associated with emissions at the global level and for the Middle East and North Africa. The share of agriculture in GDP is significant for Latin America and the Caribbean, where it has a negative sign. Tachega et al. (2021) also capture this mitigating effect of the agricultural share in some regions, although note that agriculture has a positive sign for Europe and Central Asia. The share of renewables in the energy matrix is significant in all regions, suggesting that an increase in the share of renewables is associated with lower emissions. The negative impact is also particularly large in the case of Latin America and the Caribbean, where a 1% increase in renewables is associated with a long-term impact of –0.36% in emissions. This is consistent with previous findings (Dong et al., 2018) and is indicative of the potential for renewable resources to reduce emissions in the region.

Table 1: FE estimates of CO_2 emissions by region

Dependent variable	*ln(CO2E$_{it}$)*						
	World	LAC	No LAC	EAP	ECA	MENA	SSA
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ln(GDP$_{it}$)	0.748***	0.181**	0.726***	1.468***	0.701***	0.088*	1.247***
	(0.084)	(0.064)	(0.119)	(0.422)	(0.208)	(0.048)	(0.246)
ln(GDP$_{it}$)^2	-0.036***		-0.034***	-0.073**	-0.027**		-0.073***
	(0.005)		(0.007)	(0.025)	(0.011)		(0.017)
ln(MANUF$_{it}$)	0.040***	0.062	0.039***	-0.046	0.027	0.053**	0.032
	(0.009)	(0.042)	(0.014)	(0.075)	(0.038)	(0.025)	(0.039)
ln(AGRIC$_{it}$)	-0.015	-0.071*	0.001	-0.006	0.041*	-0.010	-0.035
	(0.019)	(0.038)	(0.016)	(0.063)	(0.022)	(0.020)	(0.047)
log(SERV$_{it}$)	-0.007	-0.029	-0.006	-0.065	0.037	-0.038	-0.101*
	(0.018)	(0.043)	(0.023)	(0.050)	(0.081)	(0.041)	(0.056)
ln(RE$_{it}$)	-0.043**	-0.115***	-0.036***	-0.047***	-0.033**	-0.024*	-0.511***
	(0.014)	(0.030)	(0.009)	(0.015)	(0.014)	(0.014)	(0.096)
ln(CO2E$_{it-1}$)	0.769***	0.678***	0.778***	0.784***	0.706***	0.712***	0.662***
	(0.028)	(0.072)	(0.025)	(0.045)	(0.033)	(0.044)	(0.042)
Long-run coefficients							
ln(GDP$_{it}$)	3.232***	0.563***	3.267***	6.798***	2.385***	0.307*	3.687***
	(0.589)	(0.167)	(0.553)	(2.179)	(0.546)	(0.168)	(0.664)
ln(GDP$_{it}$)^2	-0.154***		-0.152***	-0.336**	-0.090***		-0.215***
	(0.032)		(0.032)	(0.131)	(0.031)		(0.050)
ln(MANUF$_{it}$)	0.173***	0.193	0.176***	-0.214	0.093	0.183**	0.093
	(0.034)	(0.123)	(0.063)	(0.373)	(0.130)	(0.087)	(0.124)
ln(AGRIC$_{it}$)	-0.064	-0.219**	0.004	-0.026	0.139*	-0.031	-0.102
	(0.079)	(0.094)	(0.073)	(0.292)	(0.076)	(0.067)	(0.140)
ln(SERV$_{it}$)	-0.028	-0.091	-0.027	-0.301	0.126	-0.130	-0.300**
	(0.077)	(0.138)	(0.105)	(0.204)	(0.275)	(0.147)	(0.151)
ln(RE$_{it}$)	-0.184***	-0.356***	-0.161***	-0.217**	-0.113***	-0.082*	-1.510***
	(0.044)	(0.080)	(0.038)	(0.089)	(0.040)	(0.047)	(0.244)
Turning point	$ 36,198	-	$ 46,477	$ 24,737	$ 568,070	-	$ 5,294
R-squared	0.900	0.868	0.907	0.931	0.874	0.895	0.877
Observations	4,486	902	3,584	501	1,259	663	832
Number of countries	136	21	115	17	43	23	24

Notes: All estimations include country fixed effects, an interaction term between country and oil prices, and a quadratic time trend. Driscoll-Kraay standard errors in parentheses. A quadratic relationship between ln(GDP) and ln(CO2E) is considered when it is significant. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

The relationship between growth and emissions takes different functional forms for different regions. We confirm the EKC hypothesis at the global level – with a turning point around $36,198 per capita – as well as for East Asia and the Pacific, Europe and Central Asia, and Sub-Saharan Africa. This means there is a certain development threshold above which these countries can achieve growth while reducing emissions. However, the threshold value in Europe and Central Asia ($568,070) is higher than the region's maximum level of GDP per capita ($112,418), meaning that this decoupling between emissions and economic growth has not been reached in any country in the region.

In contrast, we reject the EKC hypothesis in the case of Latin America and the Caribbean and the Middle East and North Africa. In these two regions, we find a positive linear relationship between growth and emissions; our results suggest that it is not currently possible to sustain growth – at any income level – without also increasing emissions. The long-run income elasticities for these two regions are 0.57 and 0.31, respectively, meaning that a 1% increase in per capita GDP is associated with a 0.57% increase in per capita CO_2 emissions in Latin America and the Caribbean and a 0.31% increase in emissions in the Middle East and North Africa.

The overall magnitude of the elasticities is difficult to observe a priori when a quadratic relationship is imposed, since their value changes at different levels of GDP per capita. Therefore, Table 3 presents short- and long-run income elasticities calculated at each region's median level of GDP per capita in the cases where we find a significant quadratic relationship between income and emissions. To analyze the stability of the elasticities over time, we calculate elasticities by region and by income group, as well as for overlapping time periods with respect to the full sample, the full sample without Latin America and the Caribbean, and Latin America and the Caribbean alone.

As the table shows, the estimated global long-run income elasticity is around 0.69, with large differences across regions. The Middle East and North Africa has the lowest elasticity (0.31), followed by Latin America and the Caribbean (0.57) and Europe and Central Asia (0.61). East Asia and the Pacific has the highest elasticity, which, at 1.29, is also greater than 1, meaning that the rate of GDP growth is associated with an even higher increase in emissions (i.e., a 1% growth in GDP is associated with a 1.29% growth in emissions in the long run).

Analyzing the elasticities by dividing the sample by countries' GDP per capita is also particularly instructive, since the EKC can be seen as an expression of the process of development. Indeed, the results of the long-run income elasticities indicate differences across income levels. High and upper middle income countries account for the lowest income elasticities (0.62 and 0.60, respectively), while lower middle income countries have the highest income elasticity (0.78). While the elasticities are positive at the median of all income groups, the results also indicate that income elasticity increases up to a lower-middle-income level, decreasing at higher levels of GDP per capita while remaining positive.

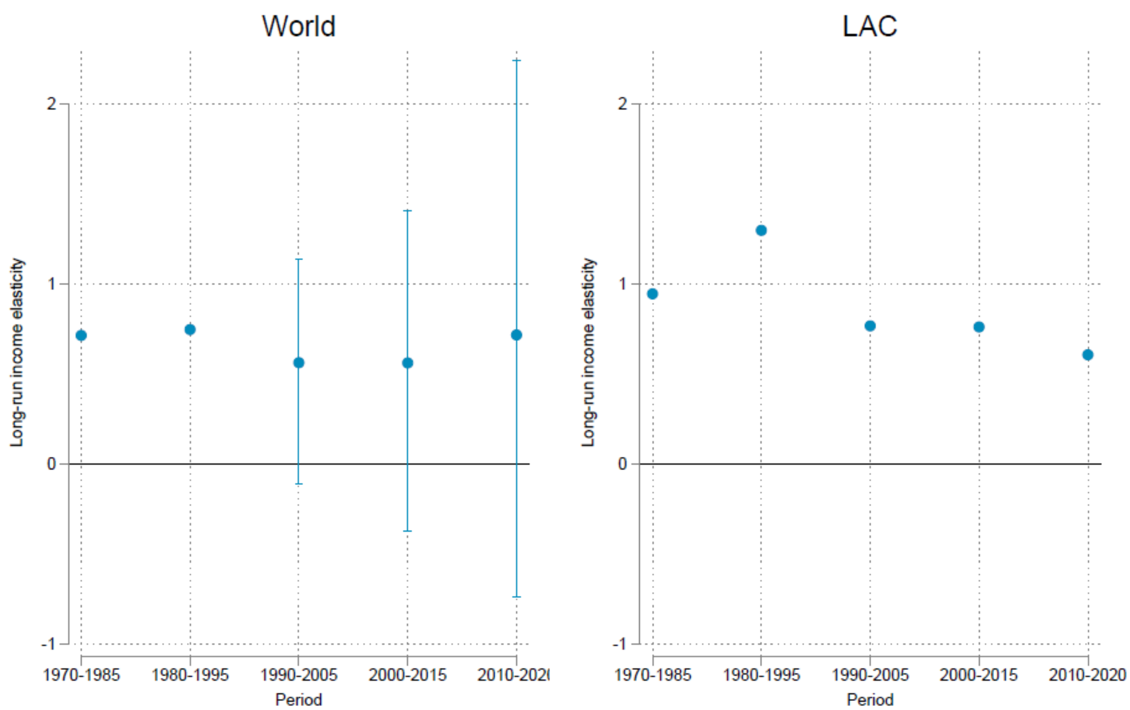
Table 2: Long-run income elasticity of CO_2 emissions

	ln($CO2E_{it}$)	
	SR	LR
World†	0.159***	0.686***
LAC	0.181**	0.563***
No LAC†	0.171***	0.769***
EAP†	0.279***	1.293***
ECA†	0.179***	0.609***
MENA	0.088*	0.307*
SSA†	0.258***	0.763***
Low income	0.187**	0.649***
Lower middle income†	0.214***	0.777***
Upper middle income	0.144*	0.596***
High income†	0.149***	0.619***
World		
1970-1985	0.341*	0.712***
1980-1995	0.422**	0.745***
1990-2005†	0.277***	0.561***
2000-2015†	0.238**	0.560**
2010-2021†	0.331***	0.715***
LAC		
1970-1985	0.588***	0.943***
1980-1995	0.894	1.296**
1990-2005	0.469***	0.765***
2000-2015	0.400***	0.760***
2010-2021	0.383***	0.605***
No LAC		
1970-1985	0.280	0.584*
1980-1995	0.366*	0.677***
1990-2005†	0.265***	0.567***
2000-2015†	0.235**	0.571**
2010-2021†	0.344***	0.770***

Notes: A quadratic relationship between ln(GDP) and ln(CO2E) is considered when it is significant, and it is indicated with †. In such cases, the predicted income elasticity is calculated at the median value of ln(GDP). All estimations include country fixed effects, an interaction term between the country and oil prices, and a quadratic time trend. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

The bottom part of the table shows income elasticities for different rolling time periods, calculated separately for the full sample, the full sample without Latin America and the Caribbean, and Latin America and the Caribbean alone. At the global level, the long-run income elasticity shows a U-shaped pattern, with a decrease until 2000–2015, when it stood at 0.56, followed by an increase to its maximum value in the last decade (0.72). The functional form of the relationship has also changed over time, as shown in Figure 7. We find a positive linear relationship between growth and emissions in the first decades of the period analyzed, which becomes quadratic around the 1990s, when the possibility of a decoupling of emissions and growth emerges. Thus, income elasticity changes along the distribution of GDP per capita, opening up the possibility of becoming negative, as the figure shows. Moreover, the level of GDP per capita at which the relationship turns from positive to negative has shifted to the left. That is, the point at which the sign is reversed has been moving earlier in the development process over time, consistent with the results of other empirical research (Dasgupta et al., 2002).

Figure 7: Long-run income elasticity for different rolling time periods



Notes: A quadratic relationship between ln(GDP) and ln(CO2E) is considered when it is significant. In cases where a quadratic relationship was confirmed, the dot represent the income elasticity at the median, and the dispersion interval represents the income elasticities at all points of the distribution of ln(GDP), with the income elasticity at the maximum and minimum of the distribution, respectively, in the extremes of the interval.

The picture is somewhat different in the case of Latin America and the Caribbean, where we find a linear relationship between growth and emissions. The long-run income elasticity, although consistently positive, has decreased from its peak in 1980–1995 to its lowest value of 0.61 in the last decade. However, this analysis should be treated with caution as changes in the the sample's composition over time due to data availability may have influenced the measures of elasticity at various points in time, especially in terms of their magnitude, given the small number of cross-sections.[17]

[17]This is certainly the reason why the elasticity for Latin America and the Caribbean is lower for the whole period than for the different sub-periods.

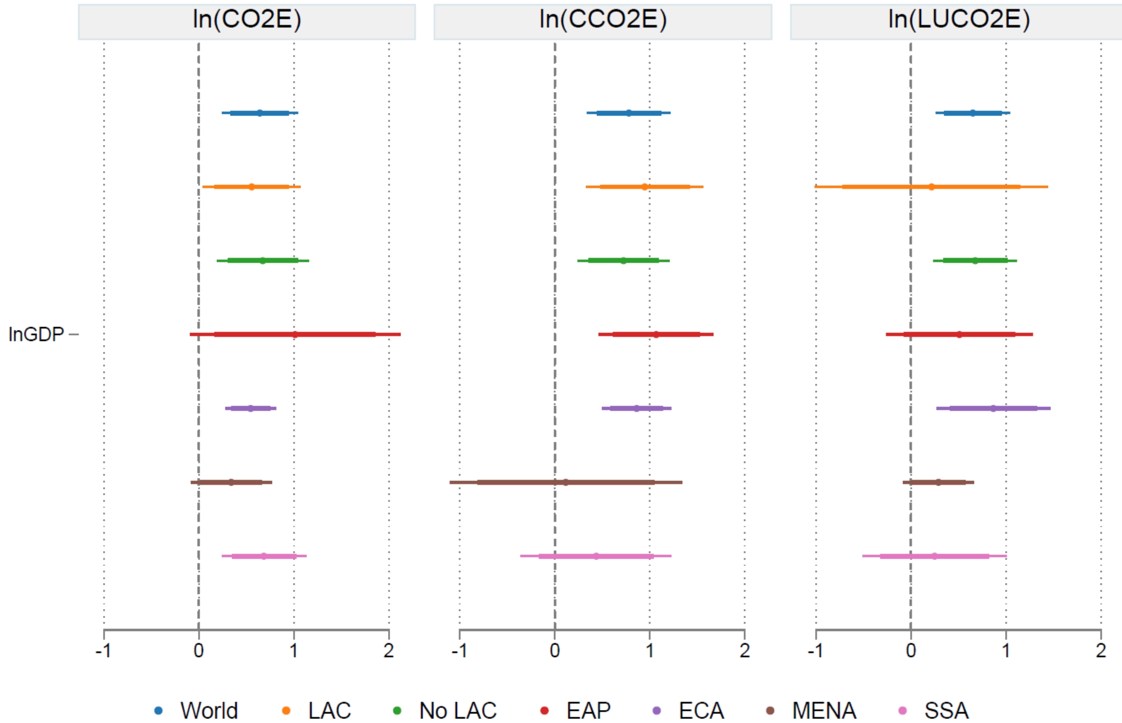
5.1 Comparison with other Measures of CO_2 Emissions

So far, we have examined the relationship between GDP per capita and CO_2 emissions per capita, measured on the production side and excluding emissions from land use. However, considering other emissions measures can help to provide a more complete picture of the relationship. In this section, we introduce two alternative measures into the analysis. The first is a consumption-based CO_2 emissions measure, which accounts for the behavior of the external sector by accounting for emissions embedded in imports and subtracting those generated domestically to produce exports. The second is a production-based CO_2 emissions measure that includes land use. Using a consumption-based measure is particularly relevant for analyses at the regional level. Doing so enables the analysis to consider channels such as the most polluting production being relocated to countries with less stringent environmental regulations (Dinda, 2004; Levinson and Taylor, 2008) and the impact of the emissions from extractive industries (Zheng et al., 2023), which are mostly oriented to supply foreign markets. Meanwhile, including emissions from land use change makes it possible to capture the emissions generated by the deforestation processes and other activities related to land exploitation.

Figure 8 shows the long-run elasticities for the full sample and disaggregated by region. Our main measure of emissions, production-based CO_2 emissions, is shown in the left panel. The middle panel shows the elasticities for consumption-based emissions and the right panel lists the same figures using production-based emissions. To compare the magnitude of the elasticities across measures, we limit the period of analysis to 1990–2020 because our consumption-based emissions data begins in 1990. At the aggregate level, the results suggest that the long-run global income elasticity for emissions measured on the consumption side is significantly higher (0.78) than for emissions measured on the production side (0.64), our baseline measure. The income elasticity of production-based emissions including those from land use change (0.65) is almost the same as our baseline emissions measure.

In the case of Latin America and the Caribbean, we find that income elasticity using the consumption-based measure of emissions is significantly higher (0.95) than when it is calculated using the production-based measure of emissions (0.56). Many regional factors may explain this result, including the impact of changes in income distribution on imports or external energy dependence. There is no statistically significant relationship when the calculations are carried out using emissions including land use.

Figure 8: Long-run income elasticity of different measures of CO_2 emissions by region



Notes: A quadratic relationship between ln(GDP) and ln(CO2E) is considered when it is significant. This is the case for the World, No LAC, EAP, and SSA for all measures of CO_2 emissions, and is true for ECA for production-based CO_2 emissions only. In these cases, the predicted income elasticity is calculated at the median value of ln(GDP). Regions: Latin America and the Caribbean (LAC), East Asia and the Pacific (EAP), Europe and Central Asia (ECA), Middle East and North Africa (MENA), and Sub-Saharan Africa (SSA). Both 90% and 95% confident intervals are displayed.

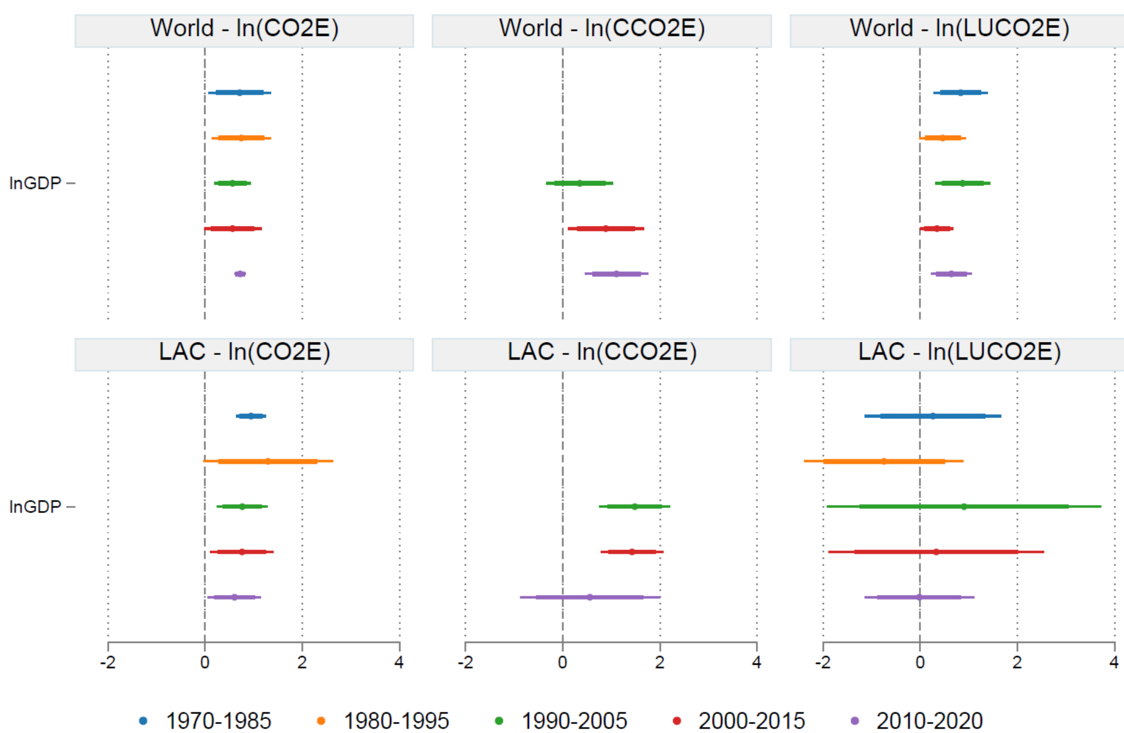
The picture for the remaining regions is heterogeneous. In general, we find relatively small differences between the elasticities of production- and consumption-based emissions measures at the regional level. The latter are higher than the former in East Asia and the Pacific (1.07 and 1.01, respectively) and in Europe and Central Asia (0.86 and 0.55, respectively). In other words, these regions have higher income elasticity when emissions are adjusted to account for the dynamics of the external sector. However, the rise is minimal for East Asia and the Pacific, suggesting that changes in the external sector have only a small impact as drivers of emissions. Moreover, in this region we find elasticities greater than 1. This indicates that economic development, manifested as an increase in GDP per capita, is associated with a larger increase in emissions. In the case of the regions of Middle East and North Africa and Sub-Saharan Africa, we find no significant relationship between GDP per capita and consumption-based emissions.

Including land-use emissions in calculations of income elasticities under production-based emissions measurements appears to reduce income elasticities in the cases of East Asia and the Pacific (0.51 from 1.01) and the Middle East and North Africa (0.29 from 0.34).

Conversely, Europe and Central Asia see a substantial increase in income elasticity—from 0.55 to 0.87—when including land use. Lastly, for sub-Saharan Africa, the income elasticity of production-based emissions including land use is not significant.

Figure 9 shows the long-run income elasticity of emissions over time. The top panels present data for the full sample, while the bottom panels focus on Latin America and the Caribbean. The income elasticity of CO_2 emissions varies depending on the emissions measures used. Specifically, for the full sample, the U-shaped form observed with our main emissions measure disappears when we include land-use emissions. In this case, the elasticity does not show a clear trend; however, it is significantly lower in 2010–2020 (0.64) than in 1970–1985 (0.83). There is an increasing trend in the elasticity of both production- and consumption-based emissions since the 1990s, but this increase is much greater for consumption-based emissions. In the most recent period, the elasticity was even higher than 1 at the global level (1.11).

Figure 9: Long-run income elasticity of different measures of CO_2 emissions for different time periods



Notes: A quadratic relationship between ln(GDP) and ln(CO2E) is considered when it is significant. This is the case for the global production-based emissions for the period 1990-2020, the period 2010-2020 for global consumption-based emissions, and the period 2000-2015 for global production-based emissions including land use. In the case of LAC, a quadratic relationship is considered only for the period 2000-2015 for consumption-based emissions. In all cases where a significant relationship exists, the predicted income elasticity is calculated at the median value of ln(GDP). Both 90% and 95% confidence intervals are displayed.

The declining pattern in income elasticity found in Latin America and the Caribbean when using our standard production-based measure of emissions is not replicated when emissions are measured from the consumption side, taking into account the dynamics of the external sector. Rather, we find a sustained elasticity greater than 1 over time, but we do not find a significant relationship between economic growth and CO2 emissions in the most recent subperiod, between 2010 and 2020. For production-based emissions, which include emissions from land use activities, we do not find a significant relationship between economic growth and emissions.

6 Conclusions

In this paper, we explore the relationship between growth and CO_2 emissions through the lens of the EKC hypothesis. At the global level, our results confirm the EKC hypothesis, revealing a leftward shift in the curve's turning point, in line with existing research (Dasgupta et al., 2002). This suggests that it is becoming possible to decouple emissions from economic growth at earlier stages of development. However, when using a consumption-based measure, the income elasticity of emissions varies significantly in both magnitude and shape. Specifically, the EKC holds true for the entire period but, when shorter time frames are considered, only materializes since 2010. In addition, the magnitude of the income elasticity calculated with consumption-based emissions is higher than when a production-based measure is used.

These differences highlight the need to broaden the EKC analysis, which often relies on production-based emissions measures, to include metrics that take into account external sector dynamics. In particular, our results suggest that using a production-based measure tends to downwardly bias income elasticity in most cases. This is the case for both measures of production-based emissions, but the measure that includes land-use emissions shows elasticities with greater variability over time. We also find significant differences at the regional level when different alternative emissions measures are employed. East Asia and the Pacific stands out as having the highest income elasticity of production-based emissions, but Latin America and the Caribbean has the highest income elasticity of consumption-based CO_2 emissions. Meanwhile, the highest income elasticity when measured using production-based emissions including those from land use economic activities is observed in Europe and Central Asia.

The role of Latin America and the Caribbean in global emissions varies widely when different emissions measures are used. When using production-based emissions as a baseline measure, the region has a lower income elasticity than the global average. However, when we adjust these emissions to account for external sector dynamics, the region's income elasticity appears to be higher. Furthermore, in both cases we reject the existence of an EKC for the region; rather, economic growth dynamics is always associated with higher emissions in the region, in line with the findings of Seri and de Juan Fernández (2023). While both income elasticities of emissions have decreased over time, the region has not yet succeeded in decoupling emissions from growth. Additionally, we find no significant relationship between growth and emissions over the full period when emissions from land-use changes are included.

Our results show that it is possible to shift the threshold at which the relationship between economic growth and emissions reverses. In this sense, there is a wide range of policies that could help to transition to the decoupling phase to an earlier stage of development. On the energy side, investment in renewable energy stands out as a clear option. Our results, which show that increasing the share of renewables in the energy mix has a significant negative impact on CO_2 emissions in all regions – in some places with considerable magnitude, as is the case in Latin America and the Caribbean – support the potential of renewables to fight climate change, in line with other work (Yuping et al., 2021; Kirikkaleli et al., 2022; Dong et al., 2018).

Decoupling growth from emissions is urgently needed to comply with climate agreements and slow climate change. Economic growth is compatible with emissions reductions, as our findings show. Some regions, such as East Asia and the Pacific, have shown that this is possible, with some countries in the region managing to leapfrog towards less emissions-intensive development. The regions that are not yet on this path should prioritize moving to the sustainable corridor shown in Appendix Figure A6. In other words, their long-term green growth strategies must aim to achieve growth without increasing emissions. In this sense, Latin American and Caribbean countries need to step up their efforts to decouple emissions from growth, on both the production and trade spheres. Though, securing adequate financing to achieve the same level of emission reductions as high-income economies presents a major challenge for developing countries, and without it, they may struggle to implement effective climate change policies and transition to more sustainable practices.

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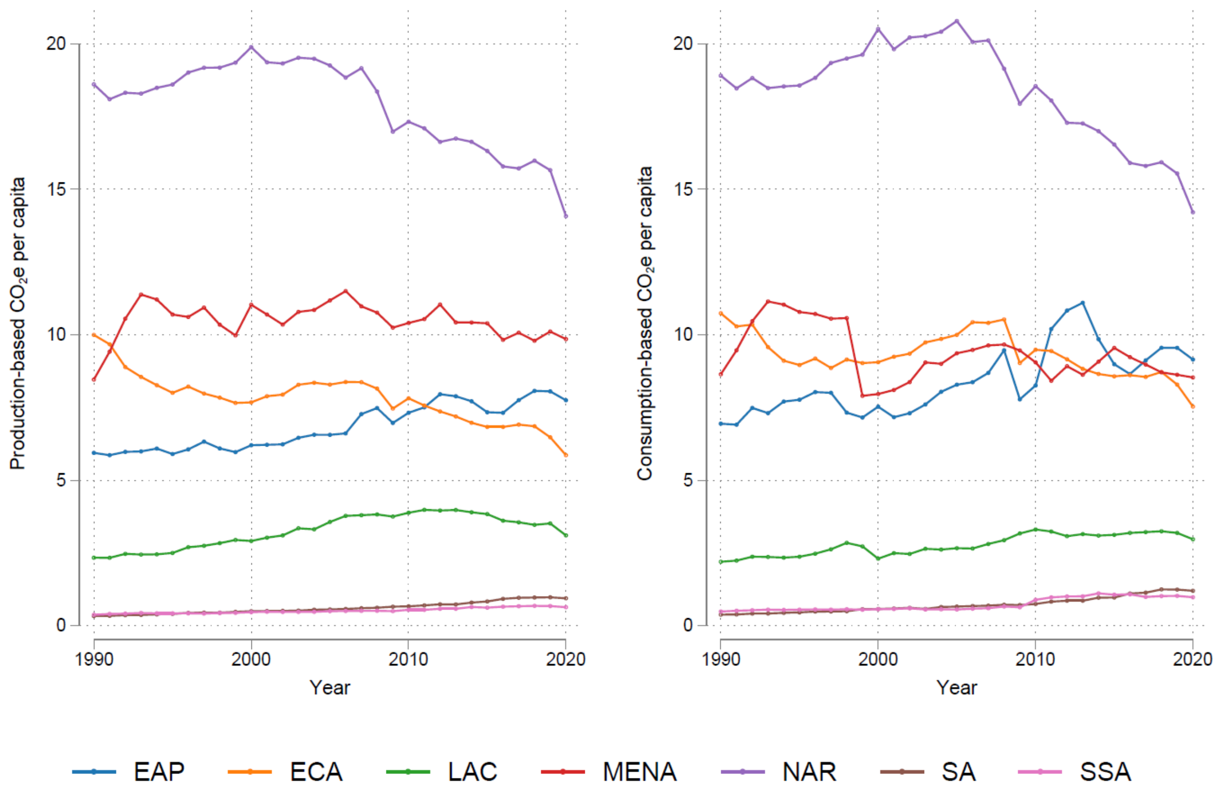
Appendix

Table A1: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
CO2E	6,912	5.81	8.74	0.00	367.93
CCO2E	3,378	6.72	7.18	0.00	56.14
LUCO2E	6,912	7.38	8.87	0.00	367.96
GDP	6,010	12566.5	17149.4	154.45	114047.9
AGRIC	5,330	13.33	12.23	0.01	73.66
MANUF	4,983	14.49	6.37	0.00	49.88
SERV	5,076	50.60	12.17	8.15	94.15
RE	6,265	30.46	30.98	0.00	99.54

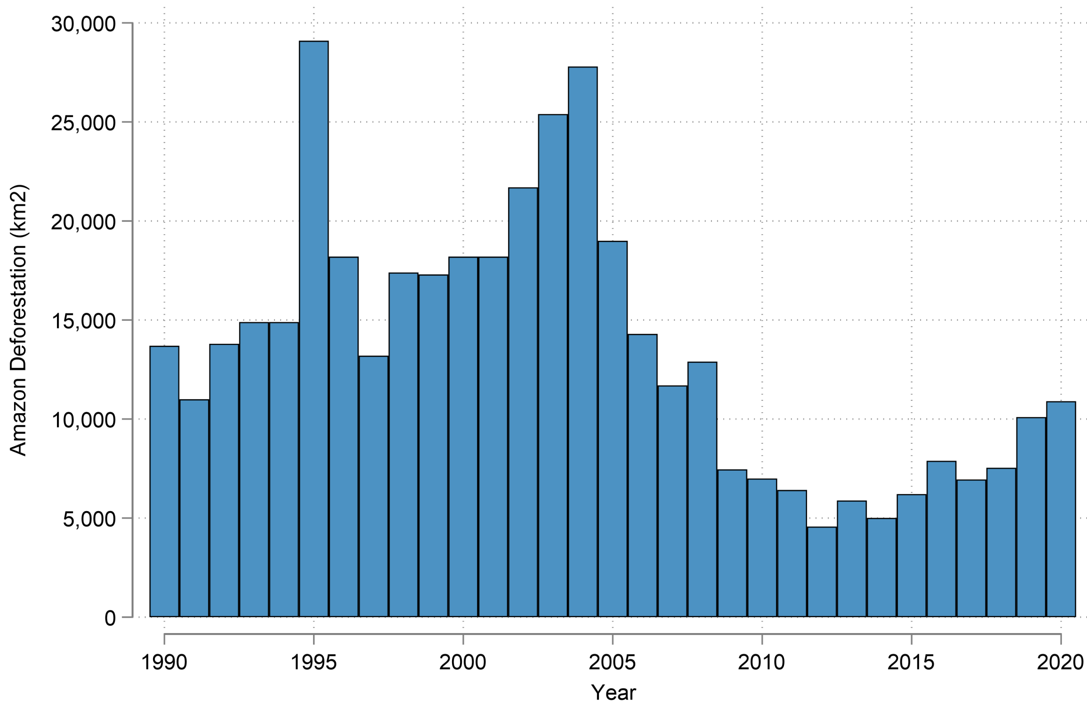
Notes: This table presents the number of observations, mean, standard deviation, maximum, and minimum for all variables, including annual production-based CO_2 emissions ($CO2E$), trade-adjusted consumption-based CO_2 emissions ($CCO2E$), production-based CO_2 emissions including land use ($LUCO2E$), GDP per capita (GDP), agricultural value added ($AGRIC$), manufacturing value added ($MANUF$), services value added ($SERV$), and the percentage of renewable energy sources in the energy matrix (RE).

Figure A1: Annual CO_2 emissions per capita by region



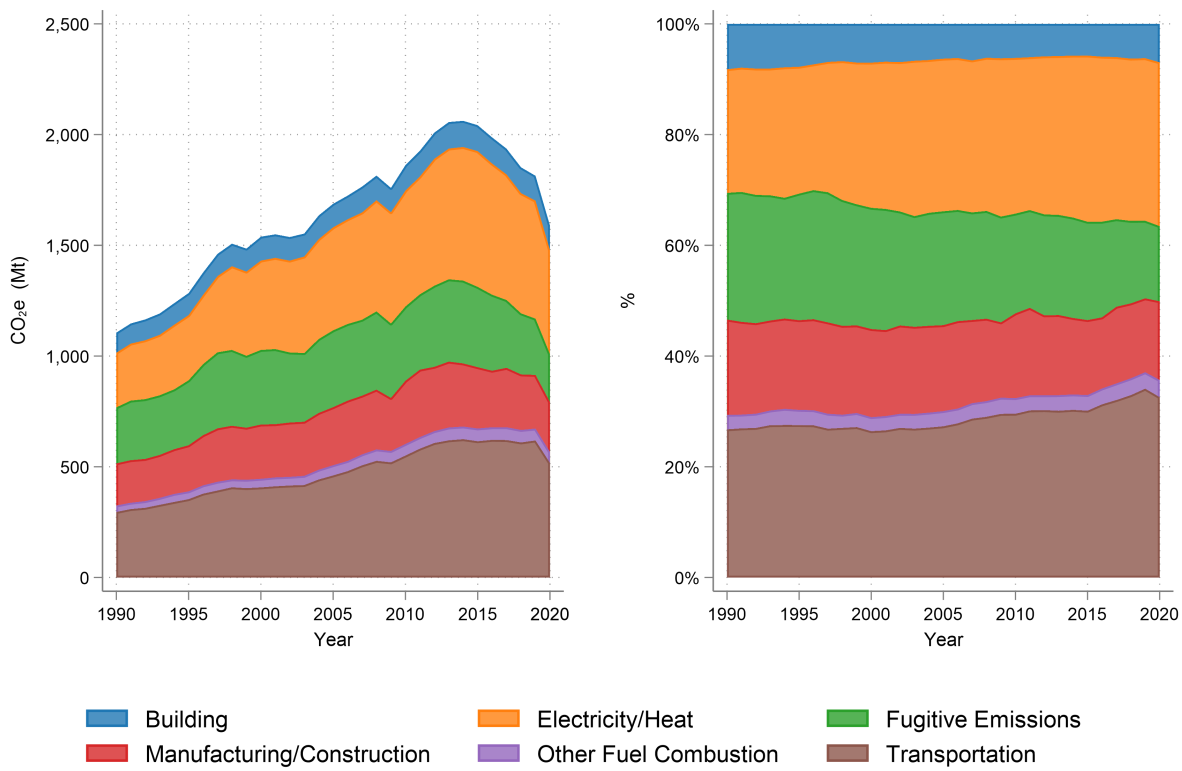
Source: Authors' own elaboration based on Global Carbon Budget data.
Notes: Production-based CO2 emissions exclude land-use change and forestry and waste. Consumption-based emissions adjust production-based emissions to account for trade, meaning that emissions associated with the production of exported goods are subtracted and those associated with the production of goods imported into the country are added. Regions: East Asia and the Pacific (EAP), Europe and Central Asia (ECA), Latin America and the Caribbean (LAC), the Middle East and North Africa (MENA), North America (NAR), South Asia (SA), and Sub-Saharan Africa (SSA).

Figure A2: Brazilian Amazon deforestation



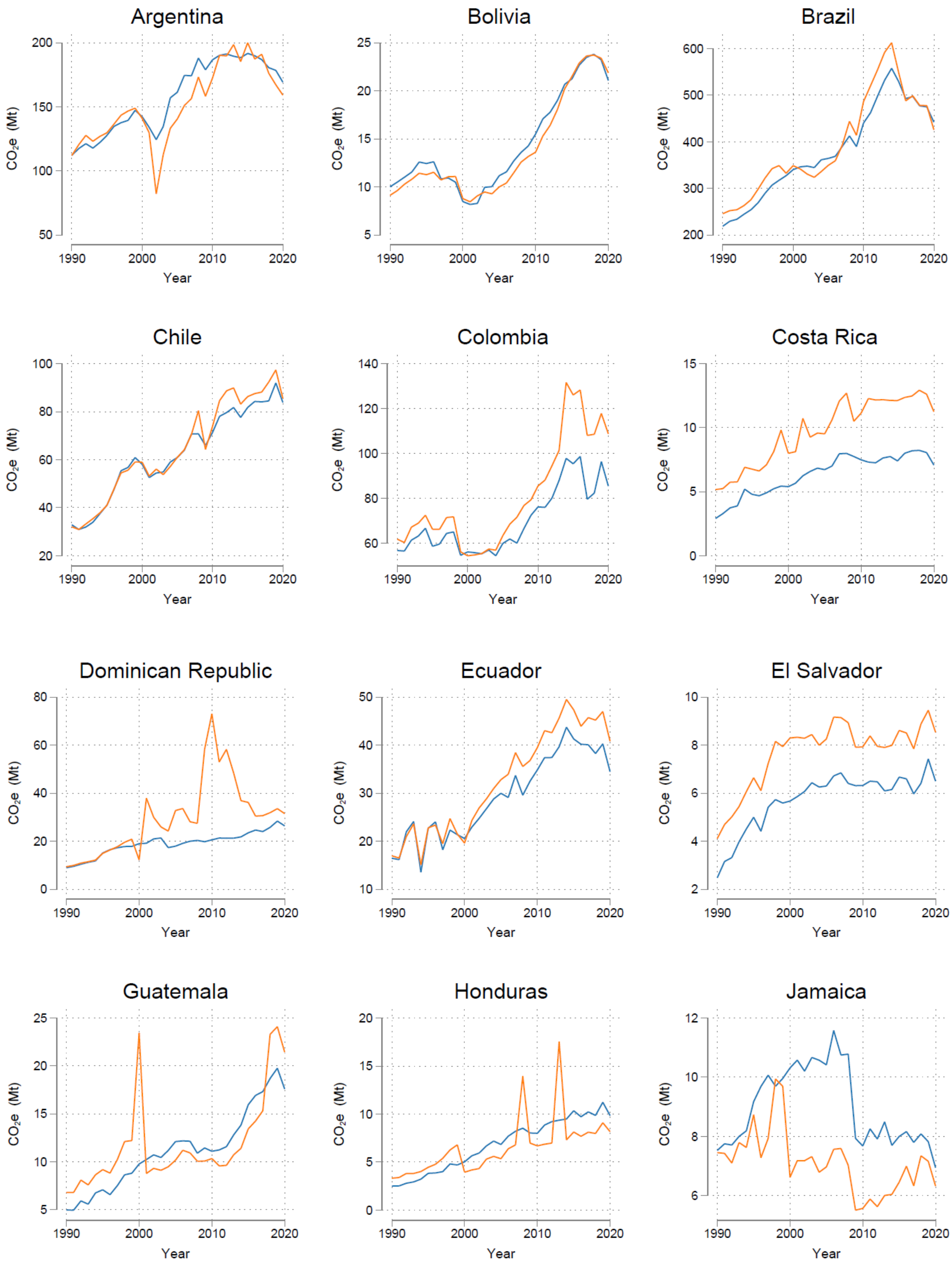
Source: Authors' own elaboration based on PRODES data.
Notes: Data extracted from PRODES (Program for the Calculation of Deforestation in the Amazon), an official source of deforestation statistics recognized by the Brazilian government. Calculations are made through the use of satellite image analysis.

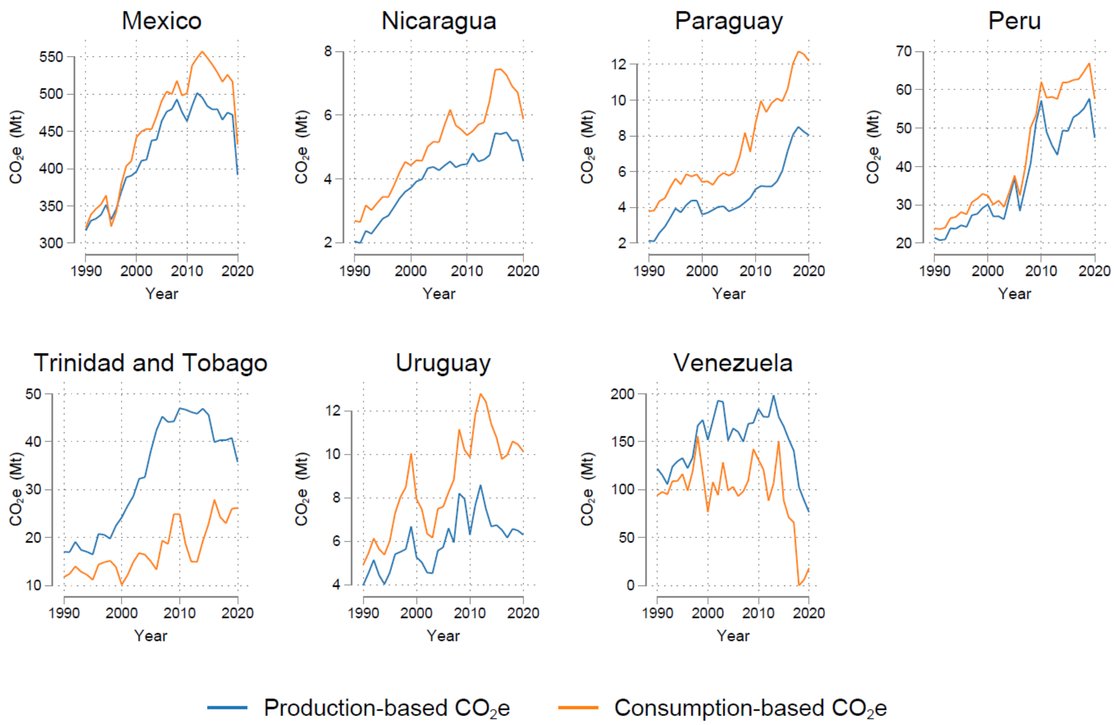
Figure A3: Annual energy-related CO_2 emissions in Latin America and the Caribbean



Source: Authors' own elaboration based on Climate Watch data.
Notes: Energy production-based CO2 emissions exclude land-use change and forestry and waste, agriculture, bunker fuels, and industrial processes.

Figure A4: Production-based and consumption-based CO_2 emissions in Latin America and the Caribbean by country

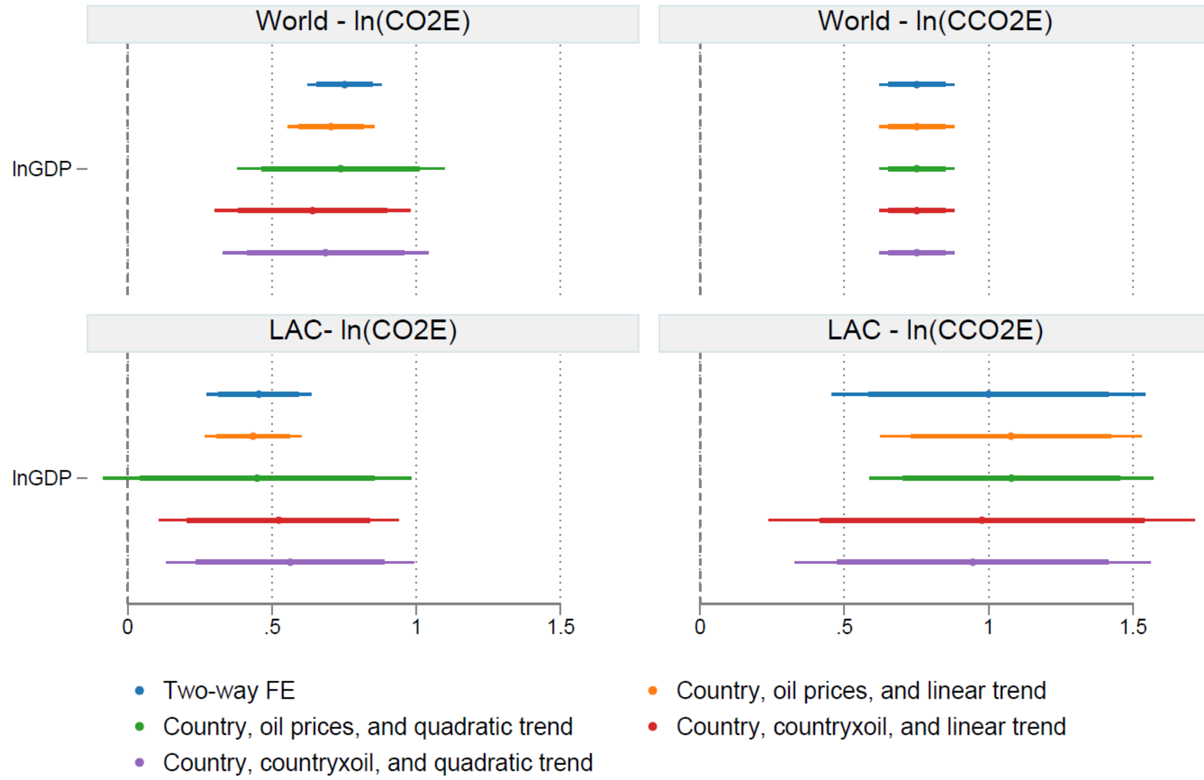




Source: authors' own elaboration based on Global Carbon Budget data.

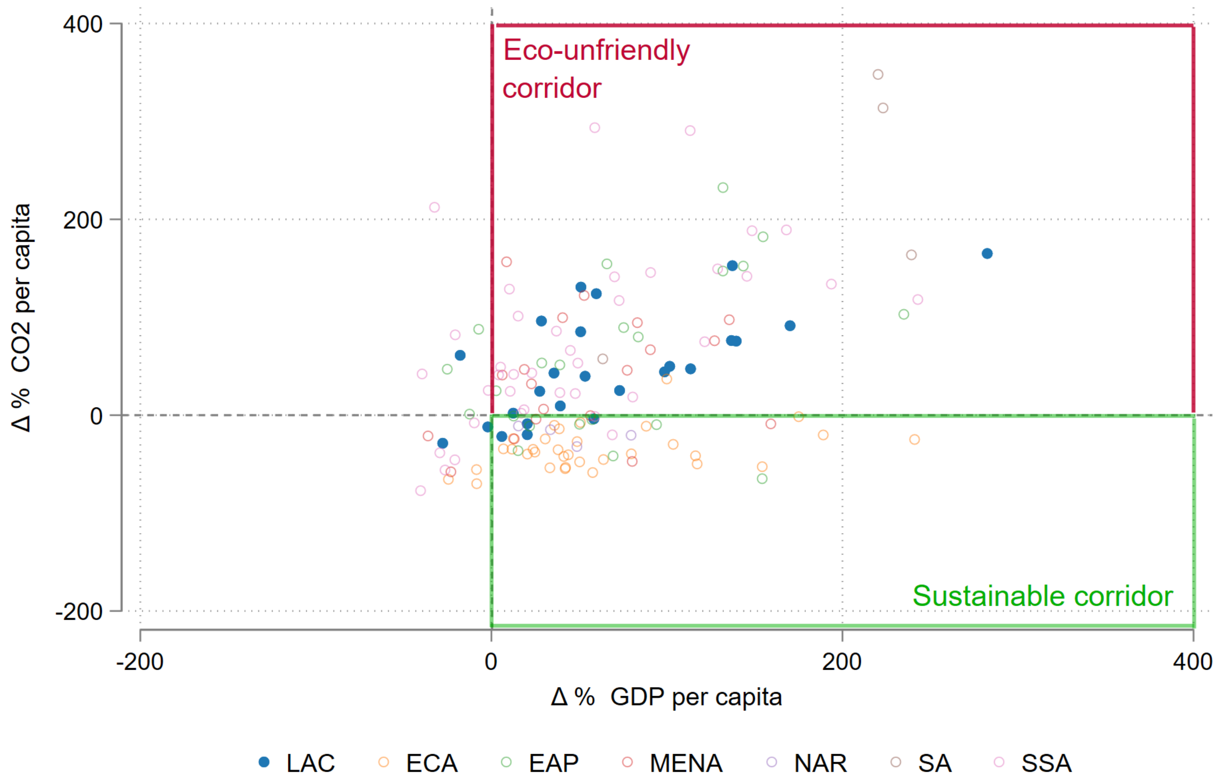
Notes: Only LAC countries with available data for both measures of emissions are shown. Countries are listed alphabetically. Production-based CO_2 emissions do not include land use change and forestry and waste. Consumption-based emissions adjust production-based emissions to account for trade. This means emissions associated with the production of exported goods are subtracted, and those associated with the production of goods imported into the country are added.

Figure A5: Long-run income elasticity with different types of FE



Notes: A quadratic relationship between ln(GDP) and ln(CO2E) is considered where significant. In those cases, the predicted income elasticity is computed in the median value of ln(GDP). 90% and 95% confident intervals are displayed.

Figure A6: Δ CO_2 emissions and Δ GDP per capita by region between 1990 and 2020



Source: Authors' own elaboration based on Global Carbon Budget and World Development Indicators data.
Notes: Each data point represents the percentage difference between a country's per capita emissions and per capita GDP between 1990 and 2020. CO_2 emissions are production-based and exclude land use change and forestry and waste. The presented regions are Latin America and the Caribbean (LAC), Europe and Central Asia (ECA), East Asia and the Pacific (EAP), Middle East and North Africa (MENA), North America (NAR), South Asia (SA), and sub-Saharan Africa (SSA).