Emissions and Global Development: Evidence from the Environmental Kuznets Curve

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Abstract

The global sustainable development agenda indicates that countries must achieve a rapid reduction in greenhouse gases emissions (decarbonization) while sustaining economic growth to continue improving living standards -especially in developing countries-. The relationship between emissions and economic growth is complex. One of the most widely used tools to model this relationship is the so-called Environmental Kuznets curve (EKC). The EKC suggests the existence of an inverted-U relationship between greenhouse gases (GHG) emissions and economic growth. In this work, we estimate the EKC for a broad panel of countries spanning the last three decades (1990-2019), using a panel regression with fixed effects. We find a positive relationship between GHG emissions and growth. Emissions eventually turn with income when we narrow down the analysis to carbon dioxide excluding land use, land use change and forestry, supporting the EKC hypothesis. These results are robust when decomposing by emitting activities (energy and industrial processes) and sub-activities (electricity, transportation and buildings), but they are not robust to decomposition by regions. In the 1990-2019 sample, we find no relationship between emissions and growth in the Latin American and the Caribbean, as well as some other regions. We use the results to assess the level of income at which emissions eventually decouple from growth. Even though we show some disperse results, which are common in the literature, we recommend cautiousness and deeper research in fostering growth hoping emissions will eventually turn. Therefore, decarbonization efforts should not be diminished.

Keywords: greenhouse gases emissions, growth, Environmental Kuznets Curve

JEL Codes: Q56, O13

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1. Introduction

The climate change agenda call for early and fast decarbonization (reduction of greenhouse gases, GHG), based on the main concern that under current actions temperature level will exceed 2° the preindustrial levels. Under this path, global warming and related climate effects are a serious risk to life. However, combined with the sustainable development agenda, this goal cannot be pursued without taking into consideration that growth and development must be also pursued to continue improving living standards. This situation is more critical in developing countries.

The decarbonization efforts imply different strategies depending on the economic sector: in Energy, the emphasis is on the replacement of fossil fuels for renewable energies; on the demand side, decarbonization policies aim for changing consumption patterns by substituting away the consumption of oil derivatives, such as electrification of transport. In agricultural and forest activities, strategies focus on land use, and natural carbon capture. These relationship between productive activities, consumption activities and emission patterns is complex.

One of the main concerns related to the emission-reduction target is whether it can be met by sacrificing growth (i.e., a trade off), or they could be achieved together (i.e., a complementarity). The literature over the last three decades both elaborated on the conceptual issues and raised a lot of evidence. A long-used tool to explain the key drivers of environmental degradation is the environmental Kuznets curve (EKC). The EKC suggest that there exists an inverted-U relationship between emissions and growth. Starting from low levels of income, growth and emissions increase simultaneously. However, when a certain threshold is achieved, emissions decouple from growth. Stern (2017) presents an interesting work that reviews the alternative hypothesis: scale effects, output mix, input mix, technological changes, and emission-specific technological changes.

This paper assesses the EKC hypothesis using a panel of countries covering the period 1990-2019. The first goal is to identify heterogeneity in the emission-growth relationship among economic sectors. For this purpose, we estimate an EKC equation by source of emission (energy, agriculture, and industrial processes). The second goal is to identify regional heterogeneities. Given the level of development of the North American or European regions vis a vis Latin America or Africa the difficulties that countries face in the pursue of decarbonization may be different.

We find a positive relationship between GHG emissions and growth. Emissions eventually turn with income when we narrow down the analysis to carbon dioxide excluding land use, land use change and forestry, supporting the EKC hypothesis. These results are robust when decomposing by emitting activities (energy and industrial processes) and sub-activities (electricity, transportation and buildings), but they are not robust to decomposition by regions. In the 1990-2019 sample, we find no relationship between emissions and growth in the Latin American and the Caribbean, as well as some other regions. We use the results to assess the level of income at which emissions eventually decouple from growth. Even though we show some disperse results, which are common in the literature, we recommend cautiousness and deeper research in fostering growth hoping emissions will eventually turn. Therefore, decarbonization efforts should not be diminished.

The paper is organized as follows. Section 2 presents the background, introducing main concepts and related literature. Section 3 introduces the model and data. Section 4 presents the main results. Finally, Section 5 concludes.

2. Background

The EKC-literature is so vast in quantity and variety. For this reason, this paper will not cover it completely and will focus mainly in those studies which use Latin America and Caribbean (LAC) data and/or whose models include energy variables. There are papers that has the only purpose to review the bibliography on this topic and they can complement this section (Stern, 2004, 2017; Kaika and Zervas, 2013a y 2013b; Sarkodie y Strezov, 2019; Al Khars et al. 2022).

The inverted U-shaped relationship between two variables was firstly identified by Kuznets (1955), whose hypothesis was the existence of this type of relationship between economic growth and income inequality. A few decades later, Grossman and Krueger (1991) found a similar reversed U-shaped relationship between the economic growth and the environment degradation, mainly focused on variables that represent air pollution (sulfur dioxide, “smoke”, and suspended particulate matter) and justified their findings with three possible explanatory mechanisms: scale, composition, and technical effects.

The works that evolved after Grossman and Krueger evaluated the existence of this type of relationship between different environmental outputs and their possible drivers. These studies arrived at various conclusions depending on the regions or countries analyzed, the period considered, the model specifications, the explanatory variables, and the dependent variable which was object of study. For example, Sarkodie and Strezov (2019) classified the EKC-studies in: atmospheric indicators; land indicators; oceans, seas, coasts and biodiversity indicators; and freshwater indicators. Likewise, Kaika and Zervas (2013a) organized the studies according to the main drivers: income distribution inequality, international trade (pollution haven hypothesis), structural change and technical progress, energy intensity, institutional framework and governance, and consumers’ preferences.

Given the wide range of studies, one is not surprised to find evidence that support the EKC hypothesis (Lean and Smyth, 2010; Arouri et al., 2012; Heidari et al., 2015; Manta et al. 2020; Tenaw and Beyene, 2021), while others find a monotonically increasing, U-shaped, N-shaped, or inverted N-shaped relationship (Pablo-Romero and De Jesús, 2016; Özokcu and Özdemir, 2017; Antonakakis et al., 2017; Nguyen et al., 2021), or find mixed results. For example, Bibi and Jamil (2021) found the EKC relationship only for regions where some countries have exceeded a turning point (being the Sub-Saharan Africa region the exception). Similarly, Kattak et al. (2020) study the EKC hypothesis in BRICs economies and find that it does not hold for India and South Africa. Kais and Sami (2016) found an inverted U-shaped correlation in Europe and North Asia, and in the Middle Eastern, North Africa, and sub-Saharan Africa regions, but found a U-shaped relationship in LAC region.

Focusing on the LAC region, the results are diverse too. Bibi and Jamil (2021) study several regions in the world (including LAC) during 2000-2018, using a panel data model with fixed and random effects. They conclude that the EKC hypothesis is support for the LAC region and its turning point is US$ 36.316. They argue that, given that many LAC economies belong to high-income and upper middle-income countries, according to the World Bank, their income levels reached the turning point. Likewise, Al-Mulali et al. (2015) support the EKC-hypothesis in LAC (with using data from 1980 to 2010).

On the other hand, Elmarzougui et al. (2016) study the EKC hypothesis for the period 1960-2007 for different regions, and do not find evidence for LAC. Moreover, they find that carbon emissions grow at an increasing rate as income per capita increases in Central America and the Caribbean.

The other classification that is relevant for this paper is emission-generating activities. One set of papers analyze energy variables as key drivers. Most of them include the energy consumption (in some cases electricity consumption or other source of energy) as an explanatory variable (Hossain, 2011; Lean and Smyth, 2010; Acaravci and Ozturk, 2010; Arouri et al., 2012; Heidari et al., 2015; Özokcu and Özdemir, 2017; Antonakakis et al., 2017; Manta et al., 2020; Khattak et al., 2020; Rahman et al., 2021) and conclude that there is a positive correlation between energy use and carbon emissions. Rahman et al. (2021), for example, find that, in the long run, the carbon intensity increases with the energy use and the industrialization, while it decreases with the renewable energy use and the urbanization. Antonakakis et al. (2017) disaggregate the “energy consumption” explanatory variable by source (renewable energy, electricity, oil consumption, natural gas and coal) and find heterogeneous results.

Heidari et al. (2015) conclude that the energy consumption increases the carbon emission in the ASEAN region. Hossain (2011) quantifies this relationship for newly industrialized countries and report a short-run elasticity of energy consumption over carbon emissions of 0,60 and a long-run elasticity of 1,2.

Also, there are papers that study both the energy variable and the LAC region. For example, Apergis and Payne (2009) focus on 6 Central American countries for the period 1971-2004 and both confirm the EKC hypothesis and a relative relationship between energy consumption and emissions. Pablo-Romero and De Jesús (2016) investigate the relationship between energy consumption and economic growth using the EKC hypothesis for 22 LAC countries over the years 1990-2011. Unlike other papers, this model includes the energy consumption as the dependent variable of the income. These authors reject the EKC hypothesis and state that the energy consumption increases exponentially with the gross added value. Kais and Sami (2016) find that the energy use has a positive impact over the emissions in all the regions. For the LAC case, a 1% raise in energy use increase carbon emissions increase in 0,74%.

Regarding the turning point, Sarkodie and Strezov (2019) estimate a threshold of US$ 8,910 per capita, from a meta-analysis of previous works. However, the evidence is mixed on the subject. Recent literature reviews indicate a lack of consent about the direction and magnitude of the relationship between growth and emissions. Differences may be due to the geographic coverage, time analysis, estimation method, control variables included in the analysis, and so on (Aslam et al., 2021; Alkhars et al., 2022).

Given this context, the following sections introduce the methodology, data used, and results.

3. Data and methodology

3.1. Information

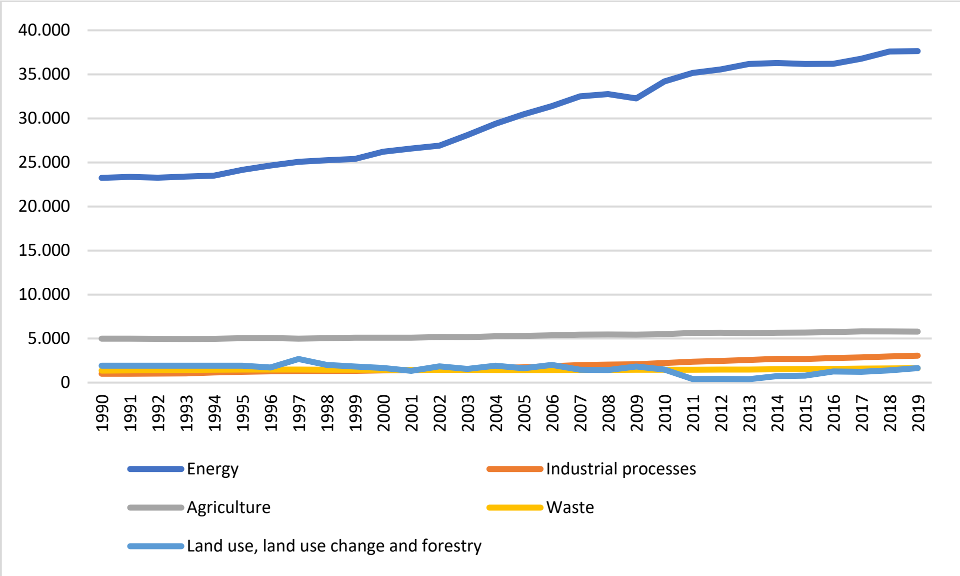
We combine two sources of information: records of greenhouse gases emissions (GHG), disaggregated by gas, country, sector and year, from the Climate Watch database, and development indicators -including economic growth- from World Development Indicators (World Bank).

Climate Watch records are available on an annual basis since 1990. Total emissions can be disaggregated by sources of emissions: Energy, Agriculture, Industrial processes, Land use, land use change and forestry (LULUCF), Waste and Bunker fuels, and by gas type (mainly, carbon dioxide -CO_2-, methane -CH_4-, nitrous oxide -N_2O-, and fluorinated gases). Emissions attributed to Bunker fuels are excluded from the analysis due to the impossibility of adequately allocating the sector's emissions among countries.[1] In the case of Energy, GHG can be disaggregated into transport, buildings, electricity/heat, furtive emissions and other fuels.

Graph 1 presents the evolution of global emissions by sector during the last three decades. Worldwide, the Energy sector is responsible for most of the emissions (75.6% in 2019), followed by Agriculture (11.6% in 2019). In addition, despite the growing concern about climate change and the commitments towards mitigation, the increasing trend in GHG has not yet changed.

[1] This source includes emissions from aircraft and ships used in international transport. These emissions can be attributed to the country in which the port or airport where refueling (fuel loading) takes place is located. However, this criterion does not necessarily accurately reflect the economic activity (and associated emissions) of each country. In this regard, the guidelines for reporting greenhouse gas emissions of the United Nations Framework Convention on Climate Change (n.d.) recommends that emissions from this sector be excluded from national totals and reported separately. In any case, Bunker fuels represent just 2.6% of global emissions in 2019.

Graph 1. Global greenhouse gases emissions by sector (1990-2019)



Source: Own elaboration based on Climate Watch. Note: values in million tons of CO2eq (MtCO_2e).

The most relevant gas is carbon dioxide, which represents 72% of total GHG emissions, followed by methane (19%). Also, the different regions contributed to global warming at different rates. Table 1 shows that the East Asia and Pacific region is the largest contributor, with a share that increased from 25% in 1990-99 to 38% in 2010-19. LAC decreased the share from 12% to 9%, while Europe and East Asia share decreased from 26% to 16%. This change in contributions is most driven by carbon dioxide. Regarding methane, the most noticeable change is a 5% reduction (between 1990-99 and 2010-19) in Europe and East Asia, which was taken by MENA (+2%) and the other regions (approximately +1% each).

As regions specialize in diverse activities, sources of emissions also differ. Table 2 shows GHG and CO2 emissions during the last decade (2010-2019) by source. All regions contribute to emissions through economic activities that use energy, and also directly in agricultural activities and industrial process. But they took different paths regarding the use of land: while Europe and Central Asia, and North America reduce emissions by managing land, Latin America and Sub-Saharan Africa contribute the most. CO_2 consumption patterns also differ. In all countries it concentrates on economic activities that use energy: electricity consumption is responsible of about 50% of CO_2 emissions, while transport and manufacturing industries take another 40%.

Table 1. GHG and gases by region

GHG				
	1990-19	1990-99	2000-09	2010-19
EAP	32%	25%	30%	38%
ECA	20%	26%	19%	16%
LAC	11%	12%	11%	9%
MENA	7%	5%	6%	8%
NA	17%	20%	19%	15%
SA	7%	5%	6%	8%
SSA	7%	8%	7%	8%
CO_2				
	1990-19	1990-99	2000-09	2010-19
EAP	34%	25%	32%	41%
ECA	20%	27%	20%	15%
LAC	9%	11%	10%	7%
MENA	6%	5%	6%	7%
NA	20%	23%	22%	16%
SA	5%	3%	5%	7%
SSA	6%	6%	6%	6%
CH_4				
	1990-19	1990-99	2000-09	2010-19
EAP	26%	25%	25%	26%
ECA	19%	22%	19%	17%
LAC	14%	14%	15%	14%
MENA	9%	8%	10%	10%
NA	10%	11%	10%	9%
SA	11%	11%	11%	11%
SSA	10%	10%	10%	11%

Source: Own elaboration based on Climate Watch. EAP: East Asia and Pacific; ECA: Europe and Central Asia; LAC: Latin America and Caribbean; MENA: Middle East and North Africa; NA: North America; SA: South Asia; SSA: Sub-Saharan Africa.

Data on economic activity comes from World Development Indicators records published by the World Bank. Following standard practice, we compare economic activity in constant dollars of year 2015.

To control for drivers that affect emissions for reasons other than growth, we consider net inflow of direct foreign investment as a percentage of GDP, trade openness -exports and imports as a percentage of GDP- and the urbanization rate -proportion of urban population- (World Development Indicators). These controls are frequent in the literature on this topic.

Table 2. GHG and CO2 by source of emission. Period 2010 – 2019.

	GHG									
	Agriculture	Industrial processes	LULUCF	Waste	Energy					
					Total	Electricity	Manuf.	Transport	Building	Others
World	**56.830**	**26.592**	**9.743**	**15.326**	**344.647**	**149.876**	**62.437**	**65.765**	**29.749**	**36.820**
EAP	14.548	14.052	2.640	4.187	135.084	65.612	35.597	15.727	7.917	10.231
ECA	7.459	3.331	-11.858	3.204	68.464	28.386	8.544	13.850	9.355	8.329
LAC	10.126	1.483	8.232	2.182	18.985	5.682	2.753	6.069	1.170	3.313
MENA	1.358	2.366	-62	1.862	28.742	10.039	3.881	5.606	2.103	7.113
NA	4.337	2.401	-2.279	1.543	59.888	24.934	5.120	19.282	6.010	4.543
SA	10.072	1.607	-93	1.154	23.871	11.567	5.661	3.306	1.917	1.420
SSA	8.931	1.352	13.163	1.194	9.613	3.656	883	1.925	1.277	1.872
	CO_2									
	Agriculture	Industrial processes	LULUCF	Waste	Energy					
					Total	Electricity	Manuf.	Transport	Building	Others
World	**0**	**14.415**	**7.491**	**0**	**311.133**	**149.213**	**62.001**	**63.942**	**27.073**	**8.905**
EAP	0	8.990	1.813	0	125.964	65.306	35.397	15.313	7.200	2.748
ECA	0	1.536	-11.919	0	61.227	28.263	8.500	13.512	9.058	1.894
LAC	0	713	8.069	0	16.132	5.646	2.702	5.885	1.042	858
MENA	0	1.124	-63	0	22.709	10.019	3.873	5.462	2.082	1.272
NA	0	438	-2.307	0	55.374	24.833	5.079	18.670	5.931	862
SA	0	1.316	-158	0	22.409	11.507	5.587	3.222	1.356	737
SSA	0	298	12.055	0	7.317	3.639	864	1.876	404	534

Source: Own elaboration based on Climate Watch. EAP: East Asia and Pacific; ECA: Europe and Central Asia; LAC: Latin America and Caribbean; MENA: Middle East and North Africa; NA: North America; SA: South Asia; SSA: Sub-Saharan Africa.

3.2. Estimation Strategy

The estimation strategy is based on a panel regression with fixed effects as follows from equation (1):

$$ln(Em_{it}) = \alpha + \beta . ln(GDP_{it}) + \gamma . ln^2(GDP_{it}) + \Delta . X_{it} + \varphi_i + \delta_t + \mu_{it} \qquad (1)$$

where Em refers to per capita greenhouse gases, CO_2 or CH_4 emissions ($MtCO_2e$) and GDP refer to the per capita GDP. The vector X_{it} includes covariates that may have effect on emissions (foreign direct investment, trade openness, and urbanization rate). The $ln(.)$ transformation applies to emissions, GDP and covariates (whenever it corresponds). The panel structure is organized according to country (i) and time (year t). Finally, φ_i and δ_t are geographic and temporal fixed effects, respectively, and μ_{it} is the model error term.

Equation (1) makes it possible to quantify the relationship between economic growth and greenhouse gases emissions. The threshold, whenever exists, is found by calculating the GDP level at which $GDP = e^{-\frac{\beta}{2\gamma}}$. In line with most of the previous literature and considering the parsimony of the model, in this work we consider a quadratic specification of equation 1 and not a higher order specification.

We estimate Equation (1) by considering the total emissions, but also the disaggregated emissions arising from different activities (including transport), and by regions (in this case, we focus on specificities corresponding to the LAC region).

The panel regression approach allows us to control for unobserved heterogeneity that differs across countries but not over time (geographical fixed effects) and for that which differs over time, but not across countries (time fixed effects). This is a clear advantage over time series or cross section specifications. In addition, the combined use of geographic and temporal fixed effects (two-way fixed effects) has become standard among econometric tools.

4. Results

Table 3 below presents the results that arise from estimating equation (1) considering global emissions under different specifications. When simultaneously considering all sectors and gases, there is a positive relationship between activity (per capita GDP) and emissions (column I). This result holds for carbon dioxide and methane emissions (columns II and III).[2]

Table 3. Growth and Global Emissions

	(I)	(II)	(III)	(IV)	(V)
Emissions by gas	**GHG emissions**	**CO_2 emissions**	**CH_4 emissions**	**GHG emissions w/o LULUCF**	**CO_2 emissions w/o LULUCF**
GDP	0.588*	1.674**	0.621**	0.467*	3.584***
	(0.353)	(0.839)	(0.261)	(0.263)	(0.475)
GDP^2	-0.006	-0.073	-0.019	-0.001	-0.206***
	(0.022)	(0.051)	(0.016)	(0.016)	(0.029)
FDI (% of GDP)	0.000	0.000	0.000	0.000	0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Trade openness (% of GDP)	-0.000	-0.000	-0.000	-0.000	-0.001
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
Urban pop (%)	-0.003	0.005	-0.005	0.006	0.025***
	(0.006)	(0.012)	(0.006)	(0.005)	(0.006)
Fixed effects	Yes	Yes	Yes	Yes	Yes
N	4,532	4,453	4,621	4,486	3,647
R^2	0.941	0.910	0.954	0.977	0.987

Source: own elaboration based on Climate Watch and World Development Indicators. Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

When the environmental variable narrows down to CO_2 emissions excluding those related to land use (LULUCF), Table 1 shows a EKC relationship, that is, emissions grow with GDP to a level, after which they decrease with GDP (column V). Other authors (Grossman and Krueger, 1991; Fodha and Zaghdoud, 2010) have found a EKC relationship for specific gases or pollutants. In the case of CO_2 emissions, Arouri et al.

[2] In this paper we do not analyze F-gases and and N2O separately.

(2012) obtain this result when relating with energy consumption and real GDP, and Apergis and Payne (2009) obtain it when studying causal relationship between emissions, energy consumption and output.

The results also show that LULUCF emissions, which are negative in several regions, as well as methane emissions, of which the agricultural sector is a main contributor, follow different and specific processes. Regarding the LULUCF emissions, data is lost through the logarithm transformation. For this reason, we re-estimated equation (1) considering emissions on a linear scale (Table A.1 in the Appendix). The relationship between per capita GDP and LULUCF emissions is positive. This result may contrast with Watcharaanantapong (2016), although the author focuses only on a set of -developed- countries.

Control variables present, in general, statistically insignificant coefficients and therefore are not of great interest. Table 3 excludes coefficients, but they are available upon request.

The aggregate result -either GHG or CO_2 emissions at a global level- may be pooling, and hence hiding, sector o regional differences. Some of them may be captured in the country fixed effects, but others may be omitted. We consider three cases. First, regions are positioned in different levels of the development path, with some of them having reached development levels in “environment” conditions which are different from those that less developed countries must face throughout the development phase. Second, countries may engage in different emission paths depending on their commitment to environment (e.g., if they signed the Kyoto Protocol).[3] Third, there may be a specific trend that all countries follow, independently of their level of economic activity. In this section we check equation (1) for the second and third alternatives and defer the first alternative to the next subsection.

When we consider the time trend terms (linear and quadratic), the estimated coefficients do not change significatively (see Table 4). That is, the EKC hypothesis is not rejected for CO_2 emissions excluding LULUCF. Regarding the time trend, two results emerge. Firstly, depending on the equation GHG emissions seem to have been decreasing over time (or follow no temporal trend). But CO_2 emissions without LULUCF increased over time or follow an inverted-U pattern. Secondly, for these specific emissions, the time trend does not cancel out the EKC effect.

Next, we introduce a variable to identify countries that may have engaged in mitigation actions at early stages. The dummy variable pools countries that committed to the Kyoto Protocol in 2005. Table 5 shows that there is a reduction in emissions in the committing countries. In general, this result is accompanied by a loss of significance of the activity coefficient, except for the result with CO_2 emissions excluding LULUCF. In this case, the EKC result is robust, although the level of per capita income at the turning point increases from US$ 6,000 to US$ 7,800.

[3] Surely, a differentiation of this kind will emerge in the future as countries develop their National Determined Contributions following the Paris Agreement.

Table 4. Growth and Global Emissions – time trend

	(I)		(II)		(III)		(IV)	
Emissions by gas	**GHG**		**GHG w/o LULUCF**		**CO_2**		**CO_2 w/o LULUCF**	
GDP	0.588*	0.588*	0.467*	0.467*	1.674**	1.674**	3.584***	3.584***
	(0.353)	(0.353)	(0.263)	(0.263)	(0.839)	(0.839)	(0.475)	(0.475)
GDP^2	-0.006	-0.006	-0.001	-0.001	-0.073	-0.073	-0.206***	-0.206***
	(0.022)	(0.022)	(0.016)	(0.016)	(0.051)	(0.051)	(0.029)	(0.029)
Linear trend	-0.009***	-0.002	-0.007***	0.005	-0.006	0.006	0.017***	0.035***
	(0.003)	(0.007)	(0.002)	(0.006)	(0.004)	(0.009)	(0.004)	(0.008)
Quadratic trend		-0.000		-0.000**		-0.000*		-0.001***
		(0.000)		(0.000)		(0.000)		(0.000)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	4,532	4,532	4,486	4,486	4,453	4,453	3,647	3,647
R^2	0.941	0.941	0.977	0.977	0.910	0.910	0.987	0.987

Source: own elaboration based on Climate Watch and World Development Indicators. Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

This separation between economic activity and commitments through the Kyoto Protocol was analyzed by Carvalho and Almeida (2011) and by Bozkurt and Okumuş (2019), under different contexts (the first paper sook a N-relationship between GDP and emissions, while the second paper rejected the EKC relationship but focused on EU countries).

Table 5. Growth and Global Emissions – differential mitigation actions

	(I)	(II)	(III)	(IV)	(V)
Emissions by gas	**GHG**	**GHG w/o LULUCF**	**CO_2**	**CO_2 w/o LULUCF**	**CH_4**
GDP	0.247	-0.151	1.446	2.526***	0.291
	(0.358)	(0.220)	(0.898)	(0.467)	(0.253)
GDP2	0.015	0.027**	-0.059	-0.141***	0.002
	(0.022)	(0.014)	(0.055)	(0.028)	(0.015)
Kyoto Protocol	-0.140***	-0.145***	-0.093	-0.379***	-0.135***
	(0.048)	(0.036)	(0.064)	(0.051)	(0.047)
Controls	Yes	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes	Yes
N	4,532	4,398	4,453	3,647	4,621
R2	0.942	0.983	0.910	0.989	0.955

Source: own elaboration based on Climate Watch and World Development Indicators. Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

As we discussed in Section 2, the literature on the relationship between economic activity and environmental degradation is vast. Results can vary for pollutants, groups of countries, specifications, and empirical strategies. Two decompositions are of interest in this paper: emissions by regions and by activities. The next subsections analyze these cases in detail.

Decomposition by emission activities

We decompose emissions by sector to test whether certain kind of emissions follow different patterns or relationships between emissions and growth. Table 6 shows the regression results for GHG in Energy, Agriculture, and Industrial Processes, including three subdivisions in Energy (Building, Electricity / Heath, and Transportation). By 2019, these sectors combined accounted for about 95% of total emissions. **Table 7** presents the same results for CO_2 emissions (Agriculture and Waste do not emit CO_2 directly, but indirectly through energy consumption). Column IV in Table 3 showed an increasing relationship between growth and emissions, with a statistically non-significant quadratic effect. When decomposing all GHG emissions by activity, an interesting result is the emergence of an EKC relationship for many emitting activities (except for emissions in buildings).[4]

Table 6. Growth and Global GHG Emissions by activity

	(I)	(II)	(III)	(IV)	(V)	(VI)
Emissions by sector	**Energy**	**Agriculture**	**Industrial processes**	**Building**	**Electricity / Heat**	**Transport -ation**
GDP	2.083***	0.963***	5.362***	1.113*	2.639***	2.830***
	(0.348)	(0.260)	(0.867)	(0.657)	(0.803)	(0.410)
GDP^2	-0.100***	-0.049***	-0.309***	-0.052	-0.147***	-0.134***
	(0.021)	(0.016)	(0.053)	(0.043)	(0.048)	(0.024)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Number of cod_pais	4,610	4,586	4,354	4,402	4,372	4,568
R^2	0.986	0.981	0.924	0.926	0.958	0.972

Source: own elaboration based on Climate Watch and World Development Indicators. Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Emissions by waste is omitted: the results are qualitatively like those in the reported sectors.

Table 7 confirms the result from Column V in Table 3 for Energy and Industry emissions, and also for the subdivisions in Electricity, Transportation and Building. However, the turning points for different activities (between USD 18,000 and USD 22,800) are larger than the turning point at the aggregate level (between USD 6,000 and USD 7,800).

Other authors take the approach of disaggregating emissions by sectors, but at a country or group level. Wang et al. (2017) investigate the relationship between income / urbanization and the disaggregated industrial carbon emissions for China, considering three subsectors: mining, manufacturing, and electricity and heat production. The EKC is supported only in this third subsector. Similarly, Moutinho et al. (2017) study the EKC hypothesis for Portugal and Spain, using data from 13 activity sectors (agriculture and forestry, extractive, food and drinks, among others). This general sectoral analysis

[4] There are different strategies to incorporate GDP in a EKC sectoral analysis. Some papers introduce the income variable using the sectoral GVA according to the emitting activity (Moutinho et al., 2017; Moutinho et al., 2020) and other authors include a common measure -GDP- for all emissions (Wang et al., 2017; Fujii and Managi, 2013). We follow the second approach because emissions are disaggregated by activities that do not necessarily coincide with sectoral GVA (for example, industrial process and manufacturing consumption of energy).

concludes that an EKC relationship exists between the gross value added (GVA) and sectoral environmental CO_2 emissions. On the other hand, Fujii and Managi (2013), for OECD countries, find that total CO_2 emissions from nine industries evidence a N-shaped relationship with income. At sector-level, these authors find that the EKC hypothesis is supported in the following sectors: wood and wood products; paper, pulp, and printing; and construction industries.

Table 7. Growth and Global CO2 Emissions by activity

	(I)	(II)	(III)	(IV)	(V)
Emissions by sector	**Energy**	**Industrial processes**	**Building**	**Electricity / Heat**	**Transport-ation**
GDP	2.551***	5.560***	2.262***	2.651***	2.818***
	(0.361)	(0.751)	(0.799)	(0.800)	(0.409)
GDP^2	-0.130***	-0.277***	-0.114**	-0.148***	-0.133***
	(0.022)	(0.047)	(0.051)	(0.048)	(0.024)
Fixed effects	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes
N	4,610	3,645	4,391	4,369	4,568
R^2	0.984	0.926	0.940	0.957	0.972

Source: own elaboration based on Climate Watch and World Development Indicators. Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Decomposition by regions

We also decompose emissions by regions to test whether certain kind of emissions follow regional patterns or relationships between emissions and growth. We consider the seven regions proposed by the World Bank (see Table 2) and present the results for both GHG (Table 8) and CO_2 emissions (Table 9), excluding LULUCF.

We repeat Column (IV) of Table 3 as Column (I) in Table 8. The main observation is that the increasing relationship found at worldwide level is a combination of emissions unrelated to income in several regions (in ECA and LAC, the linear coefficients are positive but non significative) and a EKC relationship in North America and South Asia (EKC).

Also, we repeat Column (V) of Table 3 as Column (I) in Table 9. The main observation is that the EKC relationship found at the aggregate level is a combination of a strong EKC in North America and emissions unrelated to income in all regions (in ECA and LAC, the linear coefficients are positive but non significative). The results in Tables 8 and 9 may be explained by the reduced variability in per capita income within each region -in relation to the global comparison that includes all countries-.

The grouping of countries has also been a strategy in the empirical literature. The possible decompositions found in the literature are by income / development level (Özokcu and Özdemir, 2017; Antonakis et al., 2017; Allard et al., 2018) and by region (Bibi and Jamil, 2021; Kais and Sami, 2016). A common result is the validity of the EKC hypothesis for specific, but not necessarily the same, regions. Bibi and Jamil (2021) find the EKC relationship only for some regions (Latin America and the Caribbean, Europe and Central Asia, East Asia and the Pacific, Middle East and North Africa, and South Asia, excluding Sub-Saharan Africa region), concluding that this type of relationship does not exist in regions characterized by low-income countries so that their income level is below the turning point. Kais and Sami (2016) found an inverted U-shaped correlation in Europe and North Asia, and in the Middle Eastern, North Africa, and sub-Saharan Africa regions, and a U-shaped relationship in LAC region.

Table 8. Growth and GHG emissions, excluding LULUCF, by Region

	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
Emissions by region	**World**	**EAP**	**ECA**	**LAC**	**MENA**	**NA**	**SA**	**SSA**
GDP	0.467*	-0.121	0.477	1.054	-0.417	12.178***	1.218**	-0.662
	(0.263)	(0.315)	(0.355)	(1.715)	(1.038)	(0.000)	(0.608)	(0.580)
GDP^2	-0.001	0.030	-0.001	-0.035	0.060	-0.529***	-0.074**	0.082**
	(0.016)	(0.020)	(0.020)	(0.095)	(0.056)	(0.000)	(0.037)	(0.040)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	3,647	611	1,253	708	505	53	180	1,176
R^2	0.987	0.992	0.970	0.913	0.986	0.990	0.970	0.970

Source: own elaboration based on Climate Watch and World Development Indicators. Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. EAP: East Asia and Pacific; ECA: Europe and Central Asia; LAC: Latin America and Caribbean; MENA: Middle East and North Africa; NA: North America; SA: South Asia; SSA: Sub-Saharan Africa.

Table 9. Growth and GO_2 emissions, excluding LULUCF, by Region

	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
Emissions by region	**World**	**EAP**	**ECA**	**LAC**	**MENA**	**NA**	**SA**	**SSA**
GDP	3.584***	3.493**	0.528	2.262	0.777	12.802***	2.996	0.715
	(0.475)	(1.454)	(0.619)	(1.442)	(1.659)	(0.000)	(3.204)	(1.949)
GDP^2	-0.206***	-0.173**	-0.007	-0.097	-0.042	-0.549***	-0.171	0.011
	(0.029)	(0.082)	(0.038)	(0.080)	(0.090)	(0.000)	(0.197)	(0.139)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	3,647	377	1,276	596	475	53	173	697
R^2	0.987	0.995	0.989	0.991	0.985	0.990	0.997	0.969

Source: own elaboration based on Climate Watch and World Development Indicators. Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. EAP: East Asia and Pacific; ECA: Europe and Central Asia; LAC: Latin America and Caribbean; MENA: Middle East and North Africa; NA: North America; SA: South Asia; SSA: Sub-Saharan Africa.

In the special case the LAC region, the results are diverse too. Al-Mulali et al. (2015) support the EKC hypothesis in LAC by using data from 1980 to 2010. Apergis and Payne (2009) find an EKC result for 6 Central American countries during period 1971-2004. On the other hand, Elmarzougui et al. (2016) focus on Central America and the Caribbean region and find that carbon emissions grow at an increasing rate as income per capita increases, while there is no statistical relationship between the variables in South America.

Turning points

Our estimation strategy allows us to identify turning points, i.e., the level of per capita income at which the growth and emissions decouple. This is especially important given that it makes it possible to know in which section of the EKC each country is located by comparing its per capita income with that arising from these estimates and, with this, achieve a better targeting of decarbonization efforts for each case.

Table 10 presents the results for the robust cases of CO2 emissions without LULUCF by emitting activities. Energy emissions turn at US$ 18,000 (with differences between US$ 7,800 and US$ 40,000 depending on the sub activity). That is, based on current income levels, only developed countries would be in the declining tranche of the EKC for Energy and Industrial emissions, and middle to high income in the case of Electricity-based emissions.

These turning points are consistent with the values reached by other authors although these are widely range. In Bibi and Jamil (2020), the turning points for the different regions are in the range of $12,000-$90,000. Sarkodie and Strezov (2019) estimate a threshold of $ 8,910 per capita, from a meta-analysis of previous works.

The result may or may not be worrisome, depending on its robustness. Given the evidence collected here, we prefer to be cautious and rely on the disaggregated results rather than trust a low level of turning point and foster growth. The most recurrent evidence is that per capita income in most countries is substantially lower than those necessary to decouple growth from emissions. This requires further analysis.

Table 10. Income per capita at the turning point of the EKC – CO2 without LULUCF

Sector	Turning point ($)	Subsector (Energy)	Turning point ($)
Energy	18,243	Building	20,354
		Electricity/Heat	7,755
		Transportation	39,894
Industrial processes	22,836		

Source: own elaboration based on Tables 3 to 9.

5. Conclusions

Throughout this work we have examined the relationship between growth and greenhouse gases, and carbon dioxide, emissions for a wide panel of countries with a scope of three decades. We find a positive relationship between GHG emissions and growth. Emissions eventually turn with income -the Environmental Kuznets Curve result- when we narrow down the analysis to carbon dioxide excluding land use, land use change and forestry, supporting the EKC hypothesis. These results are robust when decomposing by emitting activities (energy and industrial processes) and sub-activities (electricity, transportation and buildings), but they are not robust to decomposition by regions. In the 1990-2019 sample, we find no relationship between emissions and growth in the Latin American and the Caribbean, as well as some other regions. We use the results to assess the level of income at which emissions eventually decouple from growth. Even though we show some disperse results, which are common in the literature, we recommend cautiousness and deeper research in fostering growth hoping emissions will eventually turn. Therefore, decarbonization efforts should not be diminished.

We studied the relationship between activity and emissions with a focus on decarbonization, but we did not study related climate issues such as resiliency and adaptation to climate change, which are relevant in the sustainable development agenda.

On another hand, given the regional differences discussed in the paper, a specific literature studies emissions convergence, along the paths of the economic convergence in the 90s. This is a next step (see Brock and Taylor, 2010; and the review by Petterson et al., 2013). Finally, given the cautiousness emphasized in this paper, it is important to continue in decarbonization efforts. In the energy sector, for example, this can be achieved by migrating to a greener energy matrix, both through supply-led and demand-led policies. One specific demand measure is energy efficiency to reduce energy intensity. The analysis of the successfulness and determinants of energy efficiency policies is also left to future research.

Appendix

Table A.1. LULUCF growth and emissions (linear scale)

Emissions by sector	LULUCF
GDP	1.65e-06***
	1.65e-06
GDP^2	-5.59e-08
	1.04e-07
Controls	Yes
Fixed effects	Yes
N	4,272
R^2	0.637

Source: own elaboration based on Climate Watch and World Development Indicators. Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

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