

The effect of environmental tax and economic complexity on environmental sustainability in Latin America (1995-2020)

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ABSTRACT

This paper studies the influence of economic complexity, environmental tax, renewable energy, and foreign direct investment on environmental sustainability for selected Latin American countries from 1995 to 2020. Panel data analysis was used in the study. In addition, the moment quantile regression method was applied. The results demonstrate evidence of at least a cointegration relationship between the variables. The relationship between economic complexity and sustainability is U-shaped and is confirmed in the quantiles in the upper part of the distribution (0.6, 0.7, 0.8, and 0.9). The Load Capacity Curve (LCC) hypothesis is validated. Similarly, renewable energy and FDI have a positive relationship with sustainability and are confirmed in most distribution quantiles. The Pollution Halo hypothesis is validated: Foreign Direct Investment (FDI) helps reduce pollution. The environmental tax also has a positive relationship and is confirmed in the 0.9 quantile.

Keywords: economic complexity, environmental tax, environmental sustainability, quantile regression, panel data.

JEL classification: E60, C20, O30, Q40, Q50.

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RESUMEN

El efecto del impuesto ambiental y la complejidad económica sobre la sostenibilidad ambiental en América Latina (1995-2020)

Este trabajo estudia la influencia de la complejidad económica, el impuesto ambiental, las energías renovables y la inversión extranjera directa en la sostenibilidad ambiental para países seleccionados de América Latina de 1995 a 2020. En el estudio se utilizó el análisis de datos de panel. Además, se aplicó el método de regresión cuantil de momentos. Los resultados demuestran evidencia de al menos una relación de cointegración entre las variables. La relación entre la complejidad económica y la sostenibilidad tiene forma de U y se confirma en los cuantiles de la parte superior de la distribución (0.6, 0.7, 0.8 y 0.9). Se valida la hipótesis de la Load Capacity Curve (LCC). En este sentido, las energías renovables y la IED tienen una relación positiva con la sostenibilidad y se confirman en la mayoría de los cuantiles de la distribución. Se valida la hipótesis del Halo de la Contaminación: la Inversión Extranjera Directa (IED) ayuda a reducir la contaminación. El impuesto ambiental también tiene una relación positiva y se confirma en el cuartil 0.9.

Palabras clave: complejidad económica, impuesto ambiental, sostenibilidad ambiental, regresión cuantil, datos panel.

Clasificación JEL: E60, C20, O30, Q40, Q50.

INTRODUCTION

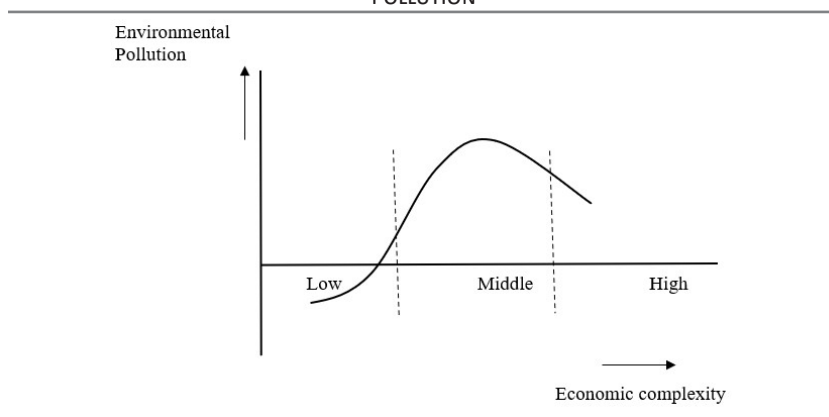
The inverted U-shaped relationship between various indicators of environmental pollution and economic development has received much attention since the seminal work of Grossman and Krueger (1991). These authors determined that the inverted U-shaped relationship (Environmental Kuznets Curve, EKC) is valid for some indicators of environmental degradation, i.e., that ecological pollution increases at first as the level of development increases, up to a certain threshold or inflection point, after which economic development reduces environmental degradation. In economic development, the productive structure has had structural changes, moving from agriculture to industry and from this last to the service sector, where the use of fossil fuels has affected the environment for decades (Dinda, 2004). Economic structure can explain and predict important macroeconomic outcomes,

from economic growth to greenhouse gas emissions intensity (Hidalgo, 2023). The complexity metrics estimate the value or sophistication of specialization patterns and their ability to predict future economic growth (Hidalgo, 2023). Economic complexity can help predict growth and reflect societies' knowledge and the economy's productive structure (Hausmann *et al.*, 2014). In this sense, economic complexity can indicate the productive structure (You *et al.*, 2022) and each nation's technological and productive capabilities (Hidalgo *et al.*, 2007). Therefore, economic complexity can be understood as the amount of hidden knowledge in the productive structure of an economy (Hausmann *et al.*, 2011), which can be a function or depend on the level of technological development (Nan *et al.*, 2022). Complexity considers the sophistication of its exported goods compared to other countries' exports, reflecting the differences in industrial structures between countries (Nan *et al.*, 2022). Recently, some studies have emphasized that the environment is also related to economic complexity, which measures a country's sophistication and knowledge-based production structure (Nan *et al.*, 2022). According to Neagu (2019), the economic complexity indicator measures how a country can produce and export a complex product. Higher economic complexity reflects a greater capacity to produce and export complex products with higher added value.

According to Rafei *et al.* (2022), economic complexity is highly intertwined with countries' economies and can affect environmental quality differently. On the one hand, improving countries' production and manufacturing requires the extraction, exploitation, and utilization of natural resources and energy (Abumunshar *et al.*, 2020). In refining and diversifying exported goods, the demand for energy increases, increasing energy intensity and emissions (Li *et al.*, 2017). On the other hand, economic complexity can also boost R&D activities that help firms innovate and improve efficiency, causing structural changes in economies and contributing to sustainable development (Can and Gozgor, 2017). R&D contributes to technological advances, stimulates economic growth, and moves countries to use clean energy (Pata, 2021). Recently, some researchers, such as Pata (2021), have included the Economic Complexity Index (ECI) as an indicator of economic development in the analysis of the EKC hypothesis. According to Pata (2021), economic complexity and environmental degradation may have an EKC relationship.

This relationship can be shown in Figure 1.

FIGURE 1
ENVIRONMENTAL KUZNETS CURVE. ECONOMIC COMPLEXITY AND ENVIRONMENTAL POLLUTION



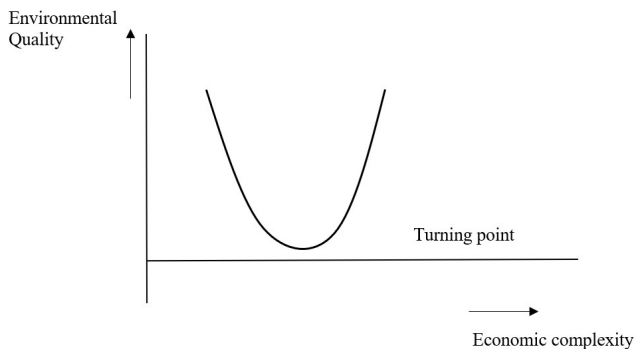
Source: Pata (2021).

At the beginning of the first stage of economic development, the production process in simple agricultural economies creates less environmental pollution, i.e., at low levels of economic complexity, it is associated with products that are peripheral in the product space since these are products that are less connected to other products, limiting opportunities for different economic activities and therefore limiting the impact on the environment. At the end of this first stage and the beginning of the second stage of economic development, economies become more complicated with increasing industrialization and product diversity, which affects environmental degradation (Swart and Brinkmann, 2020). However, new technologies emerging with structural change in this process replace old ones that cause environmental pollution when medium and high economic complexity provides cleaner technologies and knowledge needed to improve environmental standards (Pata, 2021). Therefore, once a certain threshold is exceeded, increasing complexity can reduce environmental degradation by increasing manufacturing based on the development of technology, knowledge, and human capital (Pata, 2021; Swart and Brinkmann, 2020).

This increase in economic complexity provides the knowledge and, therefore, the technology needed for economies to become cleaner, such as the production of energy-efficient goods and electric cars; the generation of energy with renewable resources such as photovoltaics,

wind, or biomass; or innovations such as recycling (Swart and Brinkmann, 2020). However, recent literature has considered environmental sustainability a more complete measure of environmental quality since it considers both the demand and supply sides. Siche *et al.* (2010) propose the low-capacity factor (LoCaFa) as an environmental indicator measured by the biocapacity/ecological footprint ratio. This factor represents the sustainability of a country's lifestyle as follows: the lifestyle is unsustainable when the ratio is less than one, while it is sustainable when it is greater than one (Siche *et al.*, 2010). Recent literature has made use of this new environmental quality indicator; see, for example, the works of Djedaïet *et al.* (2024), Gómez and Rodríguez (2024), and Fang (2024). Following the proposal of Dogan and Pata (2022), the relationship between LoCaFa and income can be nonlinear, similar to the context of the EKC hypothesis; however, now considering economic complexity instead of income level. Assuming that LoCaFa is an indicator of environmental quality, the relationship between sustainability and economic complexity should be U-shaped, as shown in Figure 2. This figure shows that LoCaFa decreases in the early phase of economic development, but environmental quality improves when economic complexity exceeds a certain threshold. Following Dogan and Pata (2022), this relationship can be interpreted as the low-capacity curve (LCC) hypothesis, and its validity implies that once a country reaches a certain level of economic complexity, it can reduce its carrying capacity and increase its biocapacity.

FIGURE 2
LCC HYPOTHESIS



Source: Based on Dogan and Pata (2022).

Another variable that affects environmental degradation is foreign direct investment (FDI). Some of the studies have investigated the impacts of FDI flows on carbon emissions and their effect on climate change. With the acceleration of economic globalization, the flow of international capital, especially the FDI, promotes economic growth in host countries and increases carbon emissions (Hayat, 2019; Huang *et al.*, 2022). FDI can contribute to new technologies, expertise, and infrastructure in the host country and generate greater productivity and competition in the local market, which can be reflected in better consumer products and services (Chirilu and Costea, 2023).

On the one hand, it is argued that FDI inflows negatively affect developing host countries, based on the Pollution Haven Hypothesis (PHavenH) (Yi *et al.*, 2023). This theory was developed by Walter and Ugelow (1969) and refined by Baumol and Oates (1988) to examine whether FDI transfers pollution-intensive industries to the host country and thus leads to increased local carbon emissions. The PHavenH suggests that pollution-intensive industries will migrate from countries with high levels of environmental cost internalization to countries with low levels, thus turning countries with lower environmental standards into a haven for pollution-intensive industries (Yi *et al.*, 2023). FDI inflows into pollution-intensive domestic industries in developing economies are higher than in developed economies, facilitating economic expansion mainly among developing countries (Agozie *et al.*, 2022). The FDI can increase environmental pollution in the host country because when firms from developed countries invest in developing countries, they may relocate their manufacturing operations to take advantage of lower costs and less stringent environmental conditions, resulting in the transfer of pollution from developed to developing countries (Vu Hoang *et al.*, 2023).

On the other hand, the Pollution Halo Hypothesis (PHaloH) conjectures that foreign investments help reduce pollution. The PHaloH assumes foreign firms save energy and have cleaner manufacturing processes than domestic firms. Moreover, due to technological spillovers, foreign firms will likely transfer environmentally friendly technology to the host country (Vu Hoang *et al.*, 2023). This effect was introduced by Birdsall and Wheeler (1993) and suggests that FDI brings advanced equipment and cutting-edge technology to the host country, saving resources and factor inputs through technology spillovers and improving environmental quality (Li *et al.*, 2017). Furthermore, FDI

may positively affect the environmental consciousness of the investment location. Therefore, FDI may not increase local pollution and instead have a halo effect on local environmental improvements. Bird-sall and Wheeler (1993) questioned the PHavenH, explicitly arguing that the liberalization of trade regimes and increased foreign investment in Latin America have not been associated with pollution-intensive industrial development. The PHaloH occurs when foreign companies establish themselves in developing countries and exhibit superior environmental performance compared to national companies. That is, by introducing better technology than national companies and new knowledge, they improve processes, reducing CO₂ emissions compared to the processes of national companies (Xie *et al.*, 2020).

According to the Economic Commission for Latin America and the Caribbean (ECLAC, 2023), the global outlook for FDI in 2022 was mixed, as flows increased in some regions, such as Latin America and the Caribbean, while they decreased in others, such as in the United States and some countries in the European Union. According to this report, for 2022, almost all Latin America and the Caribbean countries received more foreign direct investment, reaching historic records. Specifically, in 2022, US\$224,579 millions of FDI entered the region, with 55.2% more than in 2021. If we analyze by country, Brazil leads the list with 41% of the regional total, followed by Mexico, Chile, Colombia, Argentina, and Peru with 17, 9, 8, 7 and 5%, respectively (ECLAC, 2023). This increased investment reflected a marked interest in investments in services, a renewed interest in investments in hydrocarbons, and the continuity of investments in manufacturing in countries where greater capacities have been accumulated (ECLAC, 2023).

In this sense, this paper aims to study the influence of economic complexity, environmental tax, foreign direct investment, and renewable energy on environmental quality in 14 selected Latin American countries (1995-2020). This research is different from the existing literature in the following points: 1) It is the first paper that studies the LCC Hypothesis for 14 Latin American countries; 2) it takes into account novel variables such as environmental tax and economic complexity in the study for this region; 3) it applies novel techniques, such as the quantile regression method, to analyze the effects of the determinants of environmental quality in the entire distribution; 4) it applies the Granger causality test for heterogeneous panels as proposed by Juodis

et al. (2021). Specifically, this research is different from Gomez and Rodriguez (2024) mainly in the following terms: 1) this research tests the LCC Hypothesis and the PHaloH for 14 Latin American countries; 2) it includes three different explanatory variables such as environmental tax, FDI and economic complexity; 3) this study includes 14 Latin American countries, while the study by Gomez and Rodriguez (2024) comprises seven countries of the Americas including the United States and Canada; 4) in addition, this research includes the ARDL method and the quantile regression.

1. LITERATURE REVIEW

This section first reviews the literature linking economic complexity and environmental degradation. The nexus between economic complexity and the environment is a growing interest among scholars and policy-makers. While economic complexity has been found to have positive and negative impacts on sustainability, the literature remains divided on the general relationship between the two. Some of the most relevant and recent works by authors are mentioned below. Alvarado *et al.* (2021) find that the impact of economic complexity and natural resource rents is heterogeneous across the distribution of the ecological footprint in Latin America. Shahzad *et al.* (2021) show that economic complexity and fossil fuel energy consumption significantly increase the ecological footprint and deteriorate environmental quality in the United States. You *et al.* (2022) find that the magnitudes of the effects are heterogeneous, as in low-income countries, economic complexity has a positive relationship with CO₂ emissions while increasing economic complexity for high-income countries could reduce CO₂ emissions. Rafei *et al.* (2022) find that economic complexity (118 countries) positively impacts the ecological footprint. Sun *et al.* (2022) show the mitigating effects of economic complexity and renewable energy on emissions, mainly in higher emission quantiles for BRICS countries. Empirical results by Hassan *et al.* (2023) reveal that high scores on the economic complexity index increase the pressure on the ecological footprints of OECD countries. Similarly, Wang *et al.* (2024) indicate that renewable energy consumption significantly reduces the ecological footprint in countries with lower quantiles, while its effect is not prominent in countries with higher quantiles. Economic complexity has a negative

impact on the ecological footprint, and this impact becomes stronger as the ecological footprint quantile increases for G20 countries.

Another part of the literature has attempted to test the validity of the EKC, considering economic complexity and some indicators of environmental degradation. Among the first works, Can and Gozgor (2017) validate the EKC hypothesis for France, and it is observed that a higher level of economic complexity suppresses the level of CO₂ emissions in the long term. In this same sense, Neagu (2019) shows a relationship according to the inverted U-shaped curve for the entire panel (25 selected countries) and six countries (Belgium, France, Italy, Finland, Sweden, and the United Kingdom). Similarly, Ahmad *et al.* (2021) find evidence of the validity of the EKC using the variables of economic growth and economic complexity in emerging countries. Pata (2021) validates the inverted U-shaped EKC relationship between economic complexity and environmental pollution in the USA. Taghvaei *et al.* (2022) confirm the EKC hypothesis, which implies that economic structure and complexity have an influential role in socioeconomic development in OECD countries. In Adebayo *et al.* (2022)], the EKC is validated at each quantile in the most economically complex economies. For Agozie *et al.* (2022), the empirical result shows both U-shaped and inverted N-shaped EKC relationship between ECI and CO₂ emissions (Brazil, Russia, India, China, and South Africa). For BRICS countries, Balsalobre-Lorente *et al.* (2023), the EKC holds a positive but decreasing contribution of economic development to environmental deterioration. In Tchouto (2023), the EKC hypothesis is not significantly valid for the whole sample (Nordic and non-Nordic European countries). Balsalobre-Lorente *et al.* (2024a) support the inverted U-shaped EKC linkages between economic complexity and ecological footprint, carbon footprint, and carbon dioxide emissions for G-20 countries. Finally, in Balsalobre-Lorente *et al.* (2024b), the G-7 countries support the validity of the inverted U-shaped EKC hypothesis for an ecological footprint.

Furthermore, a small part of the literature has sought the validity of the LCC hypothesis. Dogan and Pata (2022) used LoCaFa to examine the factors that determine environmental quality and hypothesized LCC, contributing to the existing environmental literature. This study confirms the U-shaped relationship between environmental quality and income, i.e., the LCC hypothesis is validated. Djedaiet *et al.* (2024) suggest the validity of the LCC hypothesis with a turner point ranging between \$6674 and \$7623 per capita in seven African oil-producing OPEC countries.

On the other hand, another part of the literature also links FDI and environmental degradation. There is no consensus on the impact, whether positive or negative. Some work, such as that of Huang *et al.* (2022), for the G20 economies. The results indicate that FDI inflows are positively associated with carbon emissions and increasing environmental degradation. Similar results are found in Agozie *et al.* (2022), where the economies of Brazil, Russia, India, China, and South Africa are analyzed. The empirical findings also support the PHavenH, which suggests that FDI inflow contributes to environmental degradation in these countries. Tsoy and Heshmati (2023) investigate the effects of FDI inflow on environmental sustainability at the global level (for 100 countries). The results of the dynamic panel model do not validate the PHavenH, i.e., FDI inflow had no statistically significant effect on environmental sustainability.

Meanwhile, Yi *et al.* (2023) show a negative relationship between FDI and CO₂ emissions. FDI reduces carbon emissions in capital-, technology- and labor-intensive manufacturing industries (China). In the same way, Vu Hoang *et al.* (2023) show that a percentage increase in FDI inflows, in the long run, reduces CO₂ emissions and environmental pollution in 47 middle-income countries. Balsalobre-Lorente *et al.* (2023) confirm the PHavenH in the BRICS economies.

Finally, environmental tax is another variable that can help improve environmental quality due to its effect on environmental degradation in recent years. For example, Wolde-Rufael and Mulat-Weldemeskel (2022) investigated the impact of environmental tax and renewable energy to mitigate CO₂ emissions in 18 Latin American and Caribbean (LAC) countries. The evidence shows that the effects of environmental tax and renewable energy on CO₂ are heterogeneous, with significant negative impacts in countries with higher emissions but insignificant in countries with lower emissions. The results show that environmental taxes and renewable energy can reduce CO₂ emissions, with the mitigation effect of renewable energy being considerably more significant than that of environmental tax. However, LAC countries have been slow to implement environmental taxes. They are still at a rate well below that of OECD countries and lower than that proposed by the World Bank to meet global CO₂ emission reduction targets (Wolde-Rufael and Mulat-Weldemeskel, 2022). For their part, Saqib *et al.* (2023), in the short and long-term projections, it is

observed that increased use of environmentally friendly technology, economic complexity, environmental tax, and renewable electricity generation help reduce carbon emissions.

2. MATERIALS AND METHODS

Considering that in panel data analysis, there is a possibility of cross-sectional dependence due to integration across countries, four following tests are applied: Breusch-Pagan LM, Pesaran scaled LM, Bias-corrected scaled LM, and Pesaran CD. In addition, the Karavias and Tzavalis (KT) (2014) unit root test is also applied, and it is robust to cross-sectional dependence. In addition, the CADF test proposed by Pesaran (2007) is also used, which is also appropriate when there is cross-sectional dependence in the variables. In addition, Pedroni (1999, 2004) and Westerlund (2005) cointegration tests are applied to verify the cointegration relationship between the variables.

Panel-Corrected Standard Errors (PCSE) and Feasible Generalized Least Squares (FGLS) methods are used to estimate long-run parameters in the presence of cross-dependence in this research to verify the robustness of the results. The Moment Quantile Regression Method (MMQR) (Machado and Silva, 2019) with fixed effects is also applied. According to the literature, this method has the following advantages. First, it estimates more robust results for outliers emanating from the dependent variable (Koenker, 2004). Second, it represents the impact of independent variables on dependent ones across the distribution (Ike *et al.*, 2020). It is considered the most appropriate technique that incorporates asymmetric and nonlinear linkages by simultaneously dealing with heterogeneity and endogeneity (An *et al.*, 2020). Third, the stages of economic development across Latin American and Caribbean countries may differ, as well as their emissions and sustainability levels, so pressure levels may also be heterogeneous across these countries (Wolde-Rufael and Mulat-Weldemeskel, 2022). The MMQR method considers the conditional heterogeneous effects of the independent variables on the entire distribution instead of the average parameter estimation with traditional methods (Gómez and Rodríguez, 2020; Wolde-Rufael and Mulat-Weldemeskel, 2022). In addition, the Granger heterogeneous causality test of Juodis *et al.* (2021) is applied, which is robust to cross-sectional dependence and cross-sectional heteroscedasticity (Xiao *et al.*, 2023).

The selected countries include the main economies in the region and countries for which complete data availability was found for the sample period for all variables: Argentina, Bolivia, Brazil, Chile, Colombia, the Dominican Republic, Ecuador, Guatemala, Honduras, Mexico, Panama, Paraguay, Peru, and Uruguay. The Economic Complexity Atlas (2024) was used as the Economic Complexity Index (ECI) source. The Global Footprint Network (2024) source was used to calculate the load capacity factor (LoCaFa, calculated as biocapacity/ecological footprint). The FDI and renewable energy consumption (REC, % of total final energy consumption) were obtained from the World Bank (2024). The environment tax was taken from the Organization for Economic Co-operation and Development (OECD, 2024).

3. ANALYSIS AND DISCUSSION OF RESULTS

In panel data analysis, it is essential to verify whether the variables present cross-sectional dependence and determine the order of integration of the variables. To do so, in this research, four cross-sectional dependence tests are first applied, and the results are presented in Table 1. The null hypothesis of cross-sectional independence is rejected for all variables except for the Pesaran CD test on the variable ECI2 (ECI square). Therefore, it can be concluded that all variables show evidence of dependence, which is explained because today, in this globalized world, in the variables of these countries, many of the effects are common in the region.

TABLE 1
RESULTS OF CSD TESTS

<i>Tests</i>	<i>ECI</i>	<i>ECI2</i>	<i>REC</i>	<i>FDI</i>	<i>LoCaFa</i>	<i>TAX</i>
Breusch-Pagan LM	394.903***	364.877***	573.779***	565.158***	960.437***	394.474***
Pesaran scaled LM	22.526***	20.301***	35.786***	35.146***	64.446***	22.495***
Bias-corrected scaled LM	22.246***	20.021***	35.506***	34.866***	64.166***	22.215***
Pesaran CD	2.947***	-0.033	6.425***	16.654***	16.948***	7.021***

Note: *** denotes rejecting the null hypothesis at a 1% level.

Source: The authors' calculation using EViews 10.

Given the above, we apply the unit root tests that allow cross-section dependence, such as the CADF and KY, whose results are presented in Table 2. In levels, in the case of the CADF test, the FDI is stationary with a significance level of 1%, while for the KT test, the variables ECI, ECI2, and TAX would be stationary at the same significance level. The evidence is not conclusive. In the first difference, all variables reject the null hypothesis of unit root at 1% significance in both tests. Therefore, some variables are stationary in levels, and others are most integrated of order 1. The panel autoregressive distributed lag (ARDL) model may be appropriate even if the variables follow different integration orders, between $I(0)$ and $I(1)$ or a mixture of both but not of order $I(2)$ (Pesaran *et al.*, 1999).

TABLE 2
RESULTS OF THE UNIT ROOT TEST

<i>Results of CSD tests</i>	<i>CADF</i>	<i>KT</i>
LoCaFa	-2.573	-2.450
ECI	-2.056	-5.940***
ECI2	-2.047	-3.915***
REC	-2.659	-1.889
FDI	-3.285***	-5.841
TAX	-2.419	-5.310***
<i>Variable (first difference)</i>	<i>CADF</i>	<i>KT</i>
Δ LoCaFa	-3.897***	-46.748***
Δ ECI	-4.742***	-34.120***
Δ ECI2	-4.356***	-33.111***
Δ REC	-3.928***	-31.500***
Δ FDI	-4.300***	-33.258***
Δ TAX	-3.878***	-28.643***

*** and ** reject the null hypothesis at 1 and 5% levels, respectively.

Source: The authors' calculation using Stata 16.0.

Based on these results, the ARDL panel model is estimated (Table 3). The long-term results show evidence of a U-shaped relationship between economic complexity and sustainability. A statistically significant positive relationship exists between REC and TAX on sustainability. In the short term, the positive effect of REC on sustainability is confirmed, while FDI has a negative impact. The error correction term is negative and statistically significant, which indicates the speed of adjustment towards equilibrium and infers the long-term equilibrium or cointegration relationship between the variables.

TABLE 3
ARDL MODEL

	<i>Long Run Coefficient</i>	<i>t-Statistic (Prob)</i>
ECI	-0.483*	-1.932 (0.054)
ECI2	0.764**	2.527 (0.012)
REC	0.047***	4.948 (0.000)
FDI	3.87E-07	0.077 (0.937)
TAX	0.293***	2.922 (0.003)
	<i>Short Run Coefficient</i>	<i>t-Statistic (Prob)</i>
COINTEQ01	-0.105***	-2.621 (0.009)
D(ECI)	-0.430	-1.156 (0.248)
D(ECI2)	-0.363	-1.028 (0.304)
D(REC)	0.016**	2.240 (0.025)
D(FDI)	-2.34E-05*	-1.916 (0.056)
D(TAX)	-0.046	-0.734 (0.453)
Constant	-0.024	-0.905 (0.365)

Note: ***, **, and * reject the null hypothesis at 1, 5, and 10% levels, respectively.

Source: The authors' calculation using Stata 16.0.

In addition, Pedroni (1999, 2004) and Westerlund (2005) cointegration tests are applied to verify the cointegration relationship between the variables. All statistics show a long-run equilibrium relationship between the variables (Table 4).

TABLE 4
RESULTS OF THE COINTEGRATION TESTS

<i>Pedroni test</i>	<i>Westerlund test</i>
Modified Phillips-Perron t	Statistic
-2.022**	3.548***
Phillips-Perron t	
-3.176***	
Augmented Dickey-Fuller t	
-3.372***	

Note: *** and ** reject the null hypothesis at 1 and 5% levels, respectively.

Source: The authors' calculation using Stata 16.0.

Because there is cross-sectional dependence between the variables, the FGLS and PCSE methods will be applied to estimate the long-term parameters. The results of the first two methods are presented in Table 5. In both cases, there is evidence of a U-shaped relationship between economic complexity and sustainability, i.e., in the early stages, higher economic complexity reduces sustainability, but after a certain level, there is a turning point, and the relationship becomes positive; higher

levels of economic complexity increase environmental sustainability. These results are similar to those found in Dogan and Pata (2022) for the G7 countries and in Djedaïet *et al.* (2024) for seven African OPEC-producing countries, where in both studies, the relationship between income level and sustainability is considered, and not economic complexity. The same is true for RE for both methods; higher renewable energy consumption improves sustainability. Similar results are found in Dogan and Pata (2022) for the G7 countries and Wolde-Rufael and Mulat-Weldemeskel (2022) for 18 Latin American and Caribbean (LAC) countries, where a positive relationship between renewable energy and environmental quality is demonstrated.

On the other hand, the effect of FDI is minimal, close to 0, but statistically significant, so that FDI positively affects environmental sustainability in the selected Latin American countries. The PHaloH is validated. These results are in line with those of Vu Hoang (2023) for 47 middle-income countries (1991-2018) where FDI reduces environmental pollution and are different from those found by Balsalobre-Lorente *et al.* (2023) for the BRICS countries for the period (1995 to 2020) where FDI deteriorates environmental sustainability.

TABLE 5
LONG-TERM COEFFICIENTS RESULTS

Variable	FGLS Coefficients	PCSE Coefficients
ECI	-0.743***	-0.790***
ECI2	0.343***	0.353**
REC	0.015***	0.015***
FDI	0.000***	0.000**
TAX	0.103***	0.103
Constant	1.050***	1.054***

Note: *** and ** reject the null hypothesis at 1% and 5% levels, respectively.

Source: The authors' calculation using Stata 16.0.

In the TAX case, the FGLS method confirms a positive and statistically significant relationship: a higher regional tax rate improves environmental sustainability. These results are similar to those reported by Wolde-Rufael and Mulat-Weldemeskel (2022) for 18 Latin American and Caribbean (LAC) countries and Saqib *et al.* (2023) in the G-10 countries; in both cases, the environmental tax rate reduces carbon dioxide emissions and increases environmental sustainability.

TABLE 6
QUANTILE ESTIMATION RESULTS

Variable	Quantiles								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
ECI	-0.189	-0.312**	-0.416***	-0.461***	-0.720***	-0.862***	-1.004***	-1.190***	-1.583***
ECI2	-0.529***	-0.3478*	-0.195	-0.130	-0.249	0.458*	0.667**	0.941***	1.517***
REC	0.005	0.007*	0.009**	0.009*	0.014***	0.016***	0.018***	0.021***	0.027**
FDI	0.000***	0.000**	0.000***	0.000***	0.000***	0.000***	0.000***	0.000*	0.000
TAX	-0.292**	-0.211*	-0.142	-0.113	0.057	0.151	0.245	0.367	0.626**
Constant	0.734***	0.800***	0.855***	0.879***	1.017***	1.092***	1.168***	1.267***	1.476**

Note: ***, **, and * reject the NH at 1%, 5%, and 10% levels, respectively.

Source: The authors' calculation using Stata 16.0.

The long-term parameters are also tested by the quantile regression method of moments (Table 6). The relationship between economic complexity and environmental sustainability is confirmed in the sixth to ninth quantile in the upper part of the distribution. That is, at the top of the distribution, greater economic complexity contributes to higher environmental quality in the selected Latin American countries. Higher levels of economic complexity generate greater capacity to produce and export complex products with higher added value in these countries. In this sense, new technologies emerge with structural change due to replacing old technologies that cause environmental pollution since medium and high economic complexity provide cleaner technologies and the knowledge necessary to improve environmental standards (Pata, 2021). In the case of REC, the positive impact on sustainability is confirmed from the second to the ninth quantile. These results confirm the importance of supporting the production and consumption of renewable energy in the region. In the case of FDI, a minimal effect close to 0 but statistically significant is also confirmed. It implies that the impact of FDI has not significantly contributed to improving quality in Latin America. Believing that FDI alone can solve the environmental problem is a mistake. More comprehensive and strict environmental policies are needed to help reduce environmental degradation. In the case of taxes, the relationship seems negative in the lower part of the distribution in the first and second quantiles. In contrast, in the upper part of the distribution (ninth quantile), the relationship is positive on sustainability. It confirms what Wolde-Rufael and Mulat-Weldemeskel (2022) pointed out: LAC countries have been slow to implement environmental taxes. Because of this, the effects of their sustainability improvement are not

clear in the quantile regression. The environmental tax in LAC is lower than that of OECD countries and the one proposed by the World Bank to meet global CO₂ emissions reduction targets (Wolde-Rufael and Mulat-Weldemeskel, 2022).

TABLE 7
CAUSALITY TEST RESULTS

Variables	LoCaFa	ECI	REC	FDI	TAX
LoCaFa	-	2.620***	1.470	-0.440	-2.700***
ECI	3.330***	-	-2.680***	-4.720***	-1.150
REC	2.230**	0.510	-	-0.450	-0.450*
FDI	-0.280	-0.280	-0.940	-	-3.650***
TAX	6.250***	-2.060**	0.260	-0.270	-

Note: ***, **, and * denote rejecting the null hypothesis at the 1, 5, and 10% levels, respectively.

Source: The authors' calculation using Stata 16.0.

The new Granger causality test proposed by Juodis *et al.* (2021) is also applied, presented in Table 7.

The results show evidence of a bidirectional causal relationship between sustainability and economic complexity, and between environmental tax and sustainability; these variables are complementary. The importance of the predictive power of economic complexity and environmental tax on environmental sustainability is highlighted. In addition, there are unidirectional causal relationships from renewable energy and FDI on economic complexity; that is, any movement of these variables has a predictive power on sustainability. Also, there is evidence of causality from the environmental tax and sustainability on renewable energy consumption, and from the environmental tax on FDI. In addition, there is a causal relationship from economic complexity on the environmental tax.

CONCLUSIONS

This paper studies the influence of economic complexity, environmental taxes, renewable energy, and foreign direct investment on environmental sustainability in 14 Latin American countries selected from 1995 to 2020. Cross-sectional dependence, unit root, cointegration, and causality tests were applied, and long-term parameters were estimated with methods robust to cross-sectional dependence. In addition, the moment quantile regression method was used. The results show evidence of cross-sectional dependence; the series are stationary in first

differences, and the variables show a long-term equilibrium relationship. In the long term, with the FGLS and PCSE methods, the relationship between economic complexity and sustainability is U-shaped. It is confirmed in the quantiles in the upper part of the distribution. The LCC hypothesis is validated. In this same sense, renewable energy and FDI have a positive relationship with sustainability and are confirmed in most of the quantiles of the distribution. The PHaloH, which postulates that FDI helps reduce pollution, is also validated. The tax rate also has a positive relationship and is only confirmed at the 0.9 quantile. These results are essential for these countries' governments and economic and environmental policymakers. Economic complexity, renewable energy, and environmental tax rates can help improve environmental sustainability in these countries. In these countries, it is important that environmental policies promote the consumption and production of renewable and clean energy and increase environmental tax rates to reduce carbon dioxide emissions in line with global goals. Furthermore, it is imperative to boost economic complexity through policies that encourage the development of technology and human capital, generating cleaner technologies and the knowledge necessary to improve environmental standards. One of the limitations of this study is the availability of data for a more extended period in all Latin American and Caribbean countries. In future research, other variables can be analyzed, such as the effect of poverty and income inequality on environmental sustainability.

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