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Dynamic Perspective of the Evolution of the Environmental Kuznets Curve in Ecuador and Mexico

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ABSTRACT

The Environmental Kuznets Curve (EKC) posits that environmental degradation increases during the early stages of economic development and decreases once a certain income level is reached. Ecuador and Mexico illustrate contrasting patterns within this framework: the former relies heavily on natural resources, while the latter has a more diversified economy, albeit with persistent environmental challenges. The aim of this study is to compare the validity of the EKC in both countries over the period 2007–2024 by analyzing the relationship between economic growth and CO₂ emissions using spatial SAR and SEM models. Recent subnational data were transformed into logarithmic form to capture regional variations and facilitate the interpretation of economic and environmental relationships. The results indicate that Ecuador remains in the ascending phase of the EKC, whereas Mexico shows a trajectory trending toward an inverted U-shape, suggesting that the country may have reached its turning point in certain regions. Furthermore, spatial dependence is strong in both countries. The larger Moran's I and Lagrange Multiplier statistics reported for Mexico indicate a stronger spatial association there, while its emissions remain more territorially heterogeneous than in Ecuador.

1. INTRODUCTION

In recent decades, the sustainability of economic growth has become a central topic in economic and environmental research, giving rise to multiple analytical frameworks aimed at explaining the relationship between economic development and environmental degradation. Among these approaches, the Environmental Kuznets Curve (EKC) has gained particular relevance by proposing a nonlinear relationship between per capita income and environmental degradation (Grossman & Krueger 1995). Building on Kuznets' original hypothesis (Kuznets 1955), the EKC suggests that pollutant emissions increase during the early stages of economic development but tend to decline once a certain income threshold is reached. Nevertheless, the empirical applicability of this hypothesis has been widely debated. Empirical evidence provided by studies such as Sarkodie & Strezov (2020) and Dong et al. (2018) indicates that the validity of the EKC depends both on the type of pollutant analyzed and the institutional context in which economic growth occurs.

Al-Mulali et al. (2015) argue that persistent pollutants such as CO₂ do not always conform to the theoretical EKC pattern, while Fang et al. (2021) emphasize that institutional weaknesses may prevent countries from reaching the turning

point required to reverse environmental degradation. In this context, Ecuador and Mexico constitute particularly relevant cases for examining the dynamic validity of the EKC, as both countries exhibit distinct development models while facing similar sustainability challenges. Ecuador maintains a highly resource-dependent economy, particularly reliant on oil extraction, which shapes its productive structure and constrains its transition toward less emission-intensive development paths (Larrea & Warnars 2009, Cevallos-Mina et al. 2024). Mexico, by contrast, displays a more diversified economy, supported by a solid manufacturing base integrated into international value chains (Vázquez-López 2023). Nevertheless, this structural advantage has not necessarily resulted in lower environmental pressure.

Environmental challenges such as air pollution in metropolitan areas, the overexploitation of aquifers, and the degradation of coastal ecosystems indicate that economic growth has not always followed a sustainable path (Blackman et al. 2018, Figueroa et al. 2021). These contrasts provide a valuable basis for examining how factors such as productive structure, institutional quality, and public policies influence the specific form that the EKC adopts in both countries. In this context, the main objective of this study is to compare the validity of the Environmental Kuznets Curve (EKC) in Ecuador and Mexico over the period 2007–2024, incorporating a spatial perspective that enables the identification of regional CO₂ emission patterns and the characterization of structural differences in the relationship between economic growth and environmental degradation.

1.1. The Environmental Kuznets Curve (EKC)

The Environmental Kuznets Curve (EKC) emerges as an environmental extension of Kuznets' original hypothesis (Kuznets 1955), which established a relationship between economic development and income inequality. Grossman & Krueger (1995) later adapted this framework to the environmental context, arguing that during the early stages of economic growth, pollution levels tend to increase, but once a certain per capita income threshold is reached, environmental degradation begins to decline. This hypothesis has been extensively discussed and empirically tested in the literature. Sarkodie & Strezov (2020) emphasize that the EKC does not hold universally, while Fang et al. (2021) argue that institutional factors play a decisive role in determining its validity, particularly in emerging economies. Similarly, Al-Mulali et al. (2015) show that the EKC may fail to emerge even when CO₂ emissions are used as the environmental indicator, whereas Dong et al. (2018) highlight that globalization processes and environmental policies can significantly alter the trajectory of the curve.

Complementarily, Shahbaz et al. (2019) suggest that the transition toward cleaner economic structures is largely driven by development-induced structural transformation and regulatory reforms.

In this framework, the EKC is commonly conceptualized as a three-stage process. The first stage is characterized by environmental deterioration associated with industrialization and rapid economic expansion. The second stage corresponds to income levels at which societies are increasingly able to implement environmental regulations and mitigation policies. Finally, the third stage involves a reduction in environmental degradation driven by technological innovation and growing ecological awareness (Murshed et al. 2021). Tangato (2025) highlights the adoption of clean technologies as a crucial element in this final phase. However, compliance with this theoretical pattern is not guaranteed. Usman et al. (2022) argue that in many developing countries, corruption and weak institutional frameworks hinder the achievement of the EKC turning point. By contrast, Acheampong et al. (2021) contend that technological innovation plays a key role in decoupling economic growth from environmental degradation, although its effective implementation remains uneven across countries.

Several studies have raised conceptual critiques of the Environmental Kuznets Curve. Destek & Sarkodie (2019) question the assumption that economic development alone necessarily leads to environmental improvement. Similarly, Kaika & Zervas (2013) argue that the EKC framework fails to account for the cumulative and long-term impacts of environmental degradation, particularly in the context of climate change. Sinha et al. (2020) further contend that the EKC overlooks the role of international institutions in shaping global environmental governance. In addition, Paramati et al. (2018) warn that certain pollutants, such as plastic waste, do not decline with higher income levels. Dong et al. (2018) emphasize that national and international policy interventions can significantly alter the trajectory implied by the EKC. Finally, Al-Mulali et al. (2015) show that CO₂-based EKC results are context-dependent, reinforcing the need to avoid treating the EKC as universally applicable.

1.2. Studies in Other Countries

Empirical studies on the Environmental Kuznets Curve have employed a wide range of environmental indicators to test its validity. The ecological footprint has been used to measure human pressure on ecosystems, and Charfeddine & Mrabet (2017) demonstrate its relevance in countries with a high dependence on natural resources. Carbon dioxide (CO₂) emissions remain the most commonly used indicator, with Khan et al. (2020) showing that CO₂ emissions tend to increase during the early stages of economic growth but

can be reduced through the implementation of appropriate environmental policies. Goulart et al. (2023) find that, in Latin America, agricultural expansion has sustained critical levels of deforestation, even in economies that have surpassed the medium stage of development. Rakpho & Yamaka (2021) introduce an alternative indicator, water pollution by heavy metals, whose environmental persistence and weak regulatory frameworks prevent it from following the theoretical EKC pattern. Moreover, Jahanger et al. (2022) emphasize that environmental indicators must be adapted to regional contexts to avoid distortions in comparative analyses.

The role of economic development-related variables has also been extensively examined in the EKC literature. Alvarado et al. (2021) note that per capita income is commonly used as a proxy for development levels, although its relationship with pollution differs depending on the type of pollutant considered. Dogan et al. (2020) demonstrate that in countries with a high penetration of renewable energy sources, the declining phase of the EKC tends to be more pronounced. In contrast, Adams & Acheampong (2019) observe that in several African economies, industrialization in the absence of adequate regulatory frameworks leads to increased pollution levels. Li et al. (2023) argue that international trade directly influences environmental outcomes, particularly when countries exporting energy-intensive goods effectively outsource their emissions. Furthermore, Catalán (2021) emphasizes the importance of rigorous monitoring of greenhouse gas emissions to accurately assess climate commitments, while Wackernagel et al. (2017) highlight the ecological footprint as a comprehensive indicator that integrates emissions, resource consumption, and biological regeneration capacity.

In addition, more recent studies reinforce the need to adapt the EKC framework to specific regional realities. Goulart et al. (2023) emphasize that deforestation should be analyzed through the lens of persistent agricultural expansion, while Wang et al. (2023) demonstrate that in Southeast Asian countries, rapid industrialization generates a complex relationship between economic growth and ecological damage, in which the environmental curve may not evolve as theoretically expected. Shahbaz et al. (2019) further reiterate that the trajectory of the EKC is strongly mediated by a country's institutional capacity to design and enforce effective environmental regulations. Finally, Stern (2004) stresses that historical analyses of emissions and sustainability provide a more accurate assessment of national environmental trajectories and potential turning points, highlighting the need to strengthen policy frameworks based on observed environmental outcomes.

1.3. Relevance of Spatial Modeling

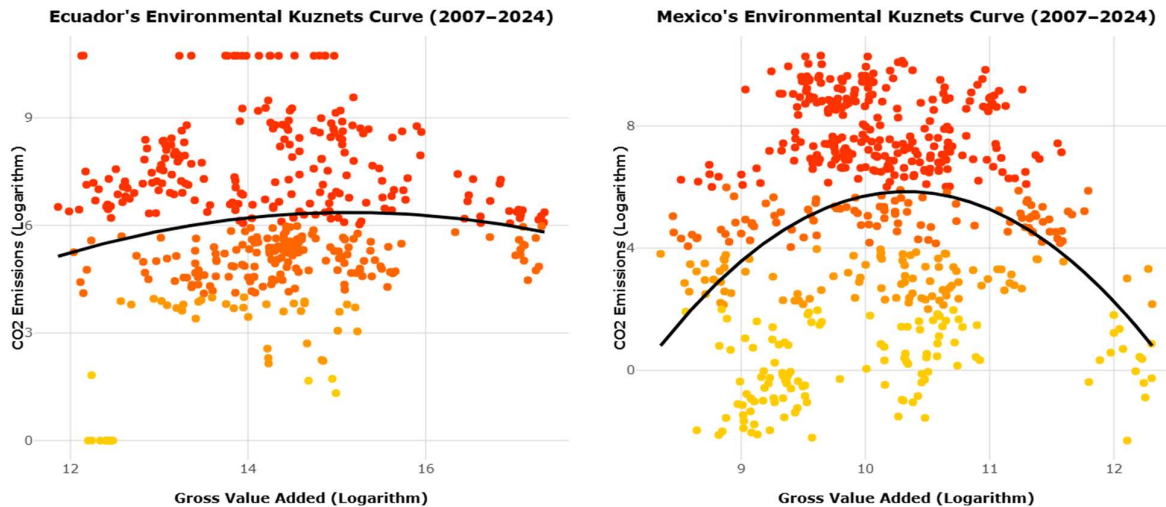
Recent advances in economic–environmental analysis have allowed the EKC to be examined from a dynamic perspective, thereby overcoming the limitations inherent in traditional static models. Unlike approaches that focus exclusively on contemporaneous relationships between variables, dynamic models incorporate temporal evolution and the cumulative effects of economic growth on environmental outcomes (Okullo 2020, Pei et al. 2021). This framework makes it possible to identify feedback mechanisms, such as the impact of environmental degradation on future growth potential (Herrera et al. 2024). In addition, dynamic models facilitate the analysis of the roles of technological innovation and institutional quality in shaping a country's long-term environmental trajectory (Meckling & Nahm 2019, Medina-Rivas et al. 2022).

Thus, the EKC has evolved into an analytical framework that no longer seeks to validate a single curve shape, but rather to identify the conditions under which environmentally sustainable development can be achieved. A particularly important aspect of this comparative analysis is the selection of appropriate indicators to capture the relationship between economic growth and environmental degradation. Variables such as GDP per capita, CO₂ emissions, deforestation, and energy consumption are among the most frequently used measures in the EKC literature (Khan et al. 2020, Alvarado et al. 2021). In the case of Ecuador, energy-related emissions and the loss of Amazonian forests constitute critical indicators (Chen et al. 2022), whereas in Mexico, factors such as urban pollution and the degradation of agricultural and water ecosystems are especially relevant (Renner 2018, Percastre et al. 2024).

The validity and comparability of these indicators, according to Stern (2004) and Wackernagel et al. (2017), depend on both their statistical quality and their contextual relevance. Consequently, the selection of indicators reflects not only methodological considerations but also policy-related criteria, reinforcing their relevance in dynamic and comparative analyses.

1.4. Graphical Representation of the Environmental Kuznets Curve

In Ecuador, the distribution of provinces in the development–emissions space (Fig. 1) shows a clear concentration in the ascending phase of the Environmental Kuznets Curve (EKC), with no evidence of a transition toward its declining phase at the aggregate level. This pattern is closely linked to the country's strong dependence on oil and its primary-export economic model, in which growth continues to rely on emission-intensive activities (Cevallos-Mina et al. 2024).



Source: Prepared by the authors in the Observatory of Economic and Financial Sustainability (OSEF 2025).

Fig. 1: Environmental Kuznets curve in Ecuador and Mexico (2007–2024).

In addition, institutional weaknesses and the budgetary constraints of the Ministry of Environment have significantly limited the country's capacity to design and implement effective environmental policies, a situation also observed in comparable developing-country contexts (Sinha et al. 2020, Usman et al. 2022).

According to EKC theory, in its initial stage, economic growth typically generates higher levels of pollution as production expands before stronger environmental regulation and cleaner technologies are adopted (Grossman & Krueger 1995, Kaika & Zervas 2013). Consistent with this framework, the evidence indicates that Ecuador remains in the ascending phase of the EKC, reflecting a persistent dependence on extractive activities and a limited capacity for environmental management (Cevallos-Mina et al. 2024). In resource-based economies with weak institutional structures, economic growth tends to intensify pollution levels (Almeida et al. 2024). Similarly, in contexts of low institutional development, environmental pressures increase as a result of the absence of effective and sustainable governance mechanisms (Jeetoo 2023). Overall, Ecuador's trajectory supports the premise that, without productive diversification and effective environmental policies, the EKC continues along its upward path, driven by an economic model based on the intensive exploitation of natural resources.

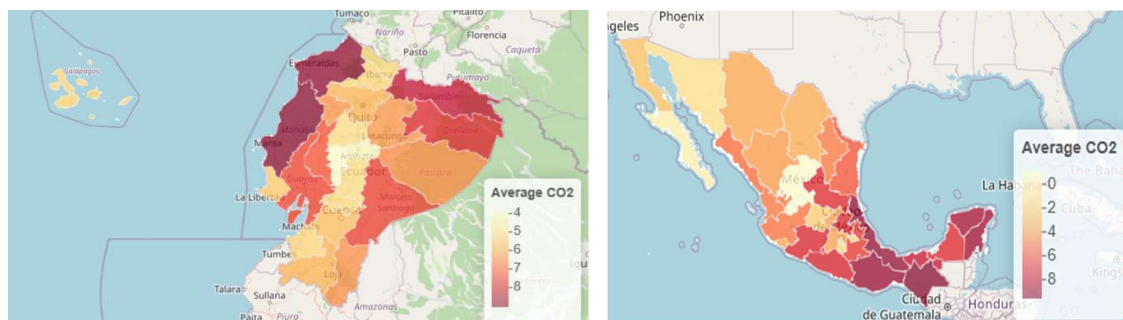
In contrast, in Mexico, the regional distribution of the EKC graph suggests a trajectory that tends toward an inverted U-shape, indicating that the country may have reached its turning point in certain regions. This pattern is associated with a more diversified economic structure and a stronger institutional capacity to implement environmental

policies, particularly reflected in the promotion of renewable energy during the 2013–2018 period (Percastre et al. 2024). This behavior is consistent with previous findings showing that in countries with solid regulatory frameworks, technological progress, and widespread use of clean energy, the Environmental Kuznets Curve tends to display a more pronounced declining phase (Dogan et al. 2020, Acheampong et al. 2021).

In this context, the empirical results confirm that Mexico displays an EKC with signs of partial decoupling between economic growth and environmental degradation, explained by institutional consolidation, productive diversification, and progress in energy efficiency. Mahmoodi & Dahmardeh (2022) argue that countries with greater regulatory capacity tend to generate more sustainable environmental trajectories, while Almeida et al. (2024) emphasize that middle-income economies with mixed productive structures can reduce ecological pressure without halting growth. Thus, the Mexican case demonstrates a gradual transition toward a sustainable development model, consistent with the theoretical predictions of the Environmental Kuznets Curve.

In countries such as Ecuador and Mexico, where industrial zones coexist with active volcanic regions, understanding these dynamics through spatial analyses and graphical representations is essential for assessing environmental impacts and informing control and mitigation policies. The spatial distribution of CO₂ emissions in Ecuador and Mexico is shown in Fig. 2.

Both Ecuador and Mexico exhibit spatial CO₂ emission patterns that remain consistent with substantial environmental pressure. Over the 2007–2024 period (Fig. 2), the distribution



Note: Areas with greater color intensity correspond to higher CO₂ levels.

Source: Observatorio Social, Económico y Financiero (OSEF 2025).

Fig. 2: Spatial distribution of average CO₂ emissions in Ecuador and Mexico (2007–2024).

of average emissions in Ecuador shows comparatively high levels in the Amazonian provinces (Pastaza, Orellana, Sucumbíos, Morona Santiago) and in coastal provinces such as Guayas and Manabí, while some areas in the Sierra display relatively lower values. This pattern may indicate an incipient transition toward the declining phase of the Environmental Kuznets Curve in certain territories. The creation of the Ministry of Environment, Water, and Ecological Transition points to a process of institutionalizing sustainability. However, recent studies indicate that the services sector, despite its low direct emissions, accounts for up to 35.5% of national emissions due to indirect effects, thereby limiting deeper structural transformation (Buenaño et al. 2023). Overall, the evidence suggests that although progress has been made in formalizing environmental policy, the extractivist economic model continues to strongly shape environmental trajectories, consistent with Larrea & Warnars (2009) and Sinha et al. (2020), who highlight the structural limitations of the EKC in resource-dependent economies.

In Mexico, the spatial distribution of average emissions is concentrated in the southeast (Chiapas, Tabasco, Campeche, Quintana Roo, Yucatán, Veracruz) and in the central industrial zones (Mexico City, State of Mexico, Puebla, Hidalgo). This spatial pattern can be explained by the suspension of clean energy auctions and the promotion of large-scale polluting projects, such as the Dos Bocas Refinery, which, according to Renner (2018) and Fujii et al. (2024), have weakened environmental governance under the current administration. Despite some localized advances, such as the emission reduction program in Jalisco, the 75% cut in the environmental budget has constrained any structural attempt at ecological transition. The persistence of these environmental pressures is consistent with the critique by Kaika & Zervas (2013) of the fallacy that economic growth automatically leads to environmental improvements and reinforces the argument of Medina-Rivas et al. (2022) that strong institutions and coherent policies are essential for sustainable development.

2. MATERIALS AND METHODS

This study adopts a quantitative and comparative research design to examine the relationship between economic development and carbon dioxide (CO₂) emissions in Ecuador and Mexico, grounded in the theoretical framework of the Environmental Kuznets Curve (EKC). The methodological sequence comprises: (i) description of the dataset; (ii) operationalization of variables; (iii) variable construction and specification of the spatial weights matrix (*W*) to ensure cross-country comparability; and (iv) econometric specification and estimation of spatial panel models (SAR and SEM).

2.1. Data Description and Panel Structure

The empirical analysis relies on secondary data compiled from official national and international statistical sources, consisting of annual subnational observations for Ecuador and Mexico. In Ecuador, the unit of analysis is the province, whereas in Mexico it is the federal state. The study period spans 2007–2024, corresponding to the most recent years for which statistically comparable subnational information is simultaneously available for both economies, thereby ensuring methodological consistency and temporal homogeneity in the construction of the panel.

The resulting dataset is structured as an annual panel with territorial units observed over time. This panel structure increases the number of observations and improves the statistical efficiency and robustness of the econometric estimates. The subnational level of disaggregation is a core component of the empirical design, as it enables the identification of regional heterogeneity in total CO₂ emissions, emissions intensity, value-added dynamics, and access to basic infrastructure. Compared with nationally aggregated studies, the subnational approach reduces aggregation bias and allows the detection of differentiated spatial patterns within each country.

Table 1: Description of variables.

Variable Type	Variable	Description	Unit of measure	Source, Ecuador	Source, Mexico	Expected sign
Endogenous	CO ₂ emissions	Total CO ₂ emissions generated in territorial unit <i>i</i> at time <i>t</i> .	Metric tons (t CO ₂)	Global Forest Watch (GFW)	Global Forest Watch (GFW)	N/A
Exogenous	CO ₂ intensity	Emissions intensity: CO ₂ emissions per unit of economic output.	t CO ₂ USD million ¹	Calculated from GFW and BCE	Calculated from GFW and INEGI	(+)
	GVA	Total Gross Value Added (constant USD millions).	Constant USD million	Central Bank of Ecuador (BCE)	National Institute of Statistics and Geography (INEGI)	(+)
	GVA ²	Quadratic term of GVA to capture nonlinearities.	(USD million) ²	Central Bank of Ecuador (BCE)	National Institute of Statistics and Geography (INEGI)	(-)
	H ₂ Ored	Households with piped water access through the public network.	Percentage (%)	Ministry of Economic and Social Inclusion (MIES)	National Institute of Statistics and Geography (INEGI)	(-)

Source: Prepared by the authors.

Note: The sources are presented separately according to their national origin, which facilitates the comparison between Ecuador and Mexico and ensures the traceability of the data used.

Cross-country comparability between Ecuador and Mexico is ensured through the conceptual harmonization of variables and the application of equivalent statistical definitions across jurisdictions. Detailed information on data sources, units of measurement, and expected coefficient signs is reported in Table 1, ensuring traceability, methodological transparency, and reproducibility of the empirical analysis.

2.2. Definition and Measurement of Variables

2.2.1. Dependent Variable: CO₂ Emissions

The dependent variable is territorial carbon dioxide emissions, denoted as CO_{2_{it}}, measured in metric tons (t CO₂) at the subnational level. This variable captures the environmental pressure associated with economic activity in territorial unit *i* at time *t*. For econometric estimation, the natural logarithm of total emissions is employed to improve numerical stability and mitigate potential heteroskedasticity:

$$\ln(\text{CO}_{2it})$$

The choice between level and logarithmic specifications was guided by econometric criteria derived from goodness-of-fit tests and spatial dependence diagnostics, ensuring consistency with the statistical properties of the data and the theoretical structure of the model.

2.2.2. Independent Variables

CO₂ Intensity: CO₂ intensity measures the amount of carbon emissions generated per unit of economic output and serves as an indicator of the environmental efficiency of production at the subnational level. Higher values indicate that a territory produces the same level of value added with a greater

emissions burden, whereas lower values are consistent with cleaner or more efficient production structures.

For each territorial unit *i* and year *t*, CO₂ intensity is constructed as:

$$\text{CO}_2 \text{ Intensity}_{it} = \frac{\text{CO}_2 \text{ Emissions}_{it}}{\text{GVA}_{it}}$$

Where CO_{2_{it}} denotes total CO₂ emissions (metric tons) and GVA_{it} represents Gross Value Added measured in constant USD millions.

Gross Value Added (GVA): Gross Value Added (GVA) is used as the proxy for territorial economic activity at the subnational level and is expressed in constant U.S. dollars (USD millions) to ensure temporal comparability across the study period. The variable is initially obtained in levels (GVA_{it}) from official sources and then used to construct a nonlinear term in levels:

$$\text{GVA}_{it}^2 = (\text{GVA}_{it})^2$$

This quadratic transformation is introduced to allow for nonlinearities in the relationship between economic activity and emissions within the econometric specification. For estimation purposes, GVA is also incorporated in logarithmic form, $\ln(\text{GVA}_{it})$ to reduce scale effects across territories and improve numerical stability. Thus, the empirical models combine the log-transformed activity indicator with a nonlinear output term in levels.

2.2.3. Control Variable: H₂Ored

The percentage of households with access to piped water from the public network, denoted as H₂Ored_{it} is included

as a control variable at the subnational level (provinces in Ecuador and federal states in Mexico). This indicator captures differences in basic infrastructure and territorial development that may be correlated with production patterns and, indirectly, with emission dynamics.

In the econometric specification, $H2ORed_{it}$ enters in levels (percentage points) to control for structural heterogeneity in access to public services and to reduce omitted-variable bias when estimating the relationship between economic activity and CO_2 emissions.

2.3. Data Processing, Variable Construction, and Spatial Weights (W)

Before estimation, the series were checked to ensure temporal consistency, homogeneity of measurement units, and methodological compatibility across statistical sources, thereby supporting cross-country comparability. Geographic coordinates (longitude and latitude) were compiled and validated for each subnational unit, as they are required to construct the spatial weights matrix used in spatial diagnostics and spatial econometric estimation.

2.3.1. Variable Construction and Transformations

Two derived variables were constructed for the econometric analysis. First, the quadratic output term was generated as:

$$GVA_{it}^2 = (GVA_{it})^2$$

Second, CO_2 intensity was computed as the ratio between total emissions and economic activity:

$$CO2\ Intensity_{it} = \frac{CO2_Emissions_{it}}{GVA_{it}}$$

Logarithmic transformations were then applied to selected variables used in the econometric specification to stabilize variance and facilitate interpretation in elasticity terms. Specifically, the analysis uses $\ln(CO2_Emissions)_{it}$, $\ln(GVA_{it})$ and $\ln(CO2_Intensity)_{it}$. The quadratic term GVA_{it}^2 and the infrastructure control $H2ORed_{it}$ enter the specification in levels.

2.3.2. Data Completeness and Spatial Referencing

Data completeness was verified for all variables included in the econometric specification. Observations with missing geographic coordinates were excluded prior to spatial modeling to ensure that all units included in the estimation could be spatially referenced and consistently connected through the spatial weights matrix. The final estimation samples correspond to the sets of subnational units and years with complete information required for panel estimation and spatial diagnostics.

2.3.3. Spatial Weights Matrix (W)

Spatial dependence was modeled using a distance-based inverse-distance spatial weights matrix, constructed from the longitude and latitude coordinates of subnational units. The baseline matrix assigns weights according to the inverse of inter-territorial distance within a fixed distance band:

$$W_{ij} = 1/d_{ij} \text{ for } 0 < d_{ij} \leq 100 \text{ and } i \neq j; W_{ij} = 0 \text{ otherwise; } W_{ii} = 0.$$

The matrix was row-standardized so that each row sums to one. Inter-territorial distances d_{ij} were computed as Euclidean distances between the longitude–latitude coordinate pairs of the subnational units, expressed in decimal degrees. Spatial links were defined for pairs satisfying $0 < d_{ij} \leq 100$, and inverse-distance weights were assigned within this threshold. Accordingly, the cutoff of 100 is expressed in decimal-degree coordinate units. The resulting W matrix was used for spatial-dependence diagnostics and for estimation of the spatial autoregressive (SAR) and spatial error (SEM) models.

2.4. Econometric Specification and Spatial Panel Models (SAR/SEM)

This section presents the spatial econometric specifications used to estimate CO_2 emissions at the subnational level in Ecuador (provinces) and Mexico (federal states). Models are estimated separately for each country to account for potential structural differences in spatial interaction mechanisms.

2.4.1. General Spatial Specifications

To capture territorial interdependence in CO_2 emissions, two alternative spatial specifications were estimated using the previously defined spatial weights matrix W : a Spatial Autoregressive Model (SAR), in which spatial dependence enters through the lagged dependent variable, and a Spatial Error Model (SEM), in which spatial dependence operates through the disturbance process.

The general SAR specification is expressed as:

$$Y_{it} = \rho \sum_{j=1}^N w_{ij} Y_{jt} + X_{it}\beta + \alpha_i + \tau_t + \varepsilon_{it}$$

Where Y_{it} denotes the logarithm of CO_2 emissions in territorial unit i at time t ; $\sum_{j=1}^N w_{ij} Y_{jt}$ represents the spatial lag of the dependent variable; ρ is the spatial autoregressive coefficient; X_{it} contains the explanatory variables; β is the corresponding parameter vector; α_i and τ_t capture territorial and common time effects, respectively; and ε_{it} is the idiosyncratic disturbance.

The SEM model is defined as:

$$Y_{it} = X_{it}\beta + \alpha_i + \tau_t + u_{it}, \quad u_{it} = \lambda \sum_{j=1}^N w_{ij} u_{jt} + \varepsilon_{it}$$

where l is the spatial error coefficient and u_{it} is the spatially correlated disturbance. Both SAR and SEM specifications were estimated by maximum likelihood, and model comparison was based on information criteria and the statistical significance of the spatial parameters.

2.4.2. Spatial Autoregressive Model (SAR)

The Spatial Autoregressive Model (SAR) incorporates the spatial lag of CO₂ emissions to capture interdependence among neighboring territorial units. The empirical specification retains CO₂ intensity, Gross Value Added (GVA), its quadratic term, and access to piped water as explanatory variables and is expressed as:

$$\ln(\text{CO}_2 \text{ Emissions}_{it}) = \alpha_i + \rho \sum_{j=1}^N w_{ij} \ln(\text{CO}_2 \text{ Emissions}_{it}) + \beta_1 \ln(\text{CO}_2 \text{ Intensity}_{it}) + \beta_2 \ln(\text{GVA}_{it}) + \beta_3 (\text{GVA}_{it})^2 + \beta_4 \text{H2ORed}_{it} + \tau_i + \varepsilon_{it}.$$

The SAR specification models spatial dependence through the lagged dependent variable. The parameter ρ measures the strength and direction of dependence between CO₂ emissions in territorial unit and the spatially weighted emissions of neighboring units. The terms a_i and t_i represent territorial and common time effects, respectively, and e_{it} is the idiosyncratic error term. The admissible range of ρ is determined by the eigenvalues of the spatial *weights matrix* w .

2.4.3. Spatial Error Model (SEM)

The Spatial Error Model (SEM) captures spatial dependence through the disturbance term while retaining the same explanatory variables used in the SAR specification. The empirical model is expressed as:

$$\ln \text{CO}_2 \text{ Emissions}_{it} = \alpha_i + \beta_1 (\ln \text{GVA})_{it} + \beta_2 (\text{GVA})_{it}^2 + \beta_3 (\text{H2ORed})_{it} + u_{it} + \lambda_{it} + \varepsilon_{it}$$

with the error structure defined as:

$$u_{it} = \lambda \sum_{j=1}^N w_{ij} u_{jt} + \varepsilon_{it}$$

Where l measures spatial autocorrelation in the disturbance term and ε_{it} is a white-noise error. As with ρ in the SAR model, the admissible range of λ is determined by the eigenvalues of w .

3. RESULTS AND DISCUSSION

This section reports the empirical results for Ecuador and Mexico and discusses their economic and spatial interpretation within the Environmental Kuznets Curve (EKC) framework. It compares the SAR and SEM specifications and evaluates

whether the estimated relationship exhibits a turning (inflection) point in CO₂ emissions.

3.1. Validation of Spatial Dependence Tests

Table 2 presents the results of the spatial dependency tests applied to CO₂ emissions in Ecuador and Mexico. For both countries, the values of Moran's I and the Lagrange Multiplier tests, for the spatial error model and the spatial lag model, are statistically significant ($p < 0.01$), confirming the presence of spatial autocorrelation in the distribution of emissions.

In the case of Ecuador, although the test statistics are high, their values are slightly lower than those observed for Mexico. This indicates a strong, albeit less intense, spatial dependence, meaning that emissions in one province are influenced by emissions in neighboring provinces. This pattern is consistent with the concentration of emissions in extractive zones such as the Amazon region and the Coast. Such dependence reflects how the extractivist development model tends to spatially cluster environmental impacts and aligns with the findings of Larrea and Warnars (2009) and Cevallos-Mina et al. (2024), who identify a territorial degradation pattern associated with oil-based development.

In Mexico, the values are even higher, indicating a very strong degree of spatial dependence. This suggests that CO₂ emissions exhibit greater continuity and concentration across regions, possibly driven by the presence of industrial corridors (e.g., Monterrey–Toluca) and the structural weight of the manufacturing sector in specific areas (Elizondo et al. 2025). These results are consistent with the findings of Blackman et al. (2018) and Vázquez-López (2023), who

Table 2: Spatial dependence in Ecuador and Mexico.

Country	Test	Statistic	p-value
Ecuador	Spatial error:		
	Moran's I	14.363***	0.000
	Lagrange multiplier	40.057***	0.000
	Robust Lagrange multiplier	9.861***	0.002
	Spatial lag:		
	Lagrange multiplier	137.344***	0.000
Mexico	Robust Lagrange multiplier	107.148***	0.000
	Spatial error:		
	Moran's I	39.551***	0.000
	Lagrange multiplier	408.348***	0.000
	Robust Lagrange multiplier	193.306***	0.000
	Spatial lag:		
	Lagrange multiplier	271.186***	0.000
	Robust Lagrange multiplier	56.143***	0.000

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

emphasize that intensive industrialization has generated regional pollution hotspots affecting contiguous territories. At a theoretical level, this spatial dependence reinforces the arguments of Herrera et al. (2024) regarding the need to incorporate dynamic and regionalized approaches into EKC analysis, as the environmental effects of economic growth are neither homogeneous nor spatially independent.

3.2. Spatial Autoregressive Model (SAR)

Table 3 presents the results of the Spatial Autoregressive Model (SAR), in which spatial dependence is represented by the spatial lag of CO₂ emissions and summarized by the coefficient ρ . The estimated ρ coefficients are positive and statistically significant for both Ecuador and Mexico, indicating strong positive spatial dependence in CO₂ emissions. The nonlinear relationship between economic activity and CO₂ emissions is assessed through the coefficients of the economic activity variable and its squared term, consistent with the EKC specification.

In Ecuador, the positive and statistically significant coefficient of $\ln GVA$, combined with the negative and significant coefficient of the squared term (GVA^2), confirms the presence of a nonlinear relationship between economic growth and carbon emissions. The estimated signs are consistent with the inverted U hypothesis of the Environmental Kuznets Curve (EKC), implying that economic expansion initially intensifies environmental degradation but eventually leads to a decoupling process as income levels rise. From an economic standpoint, the negative quadratic term indicates diminishing marginal environmental pressure as productive structure and technology evolve.

Table 3: Spatial Autoregressive Model (SAR) results for Ecuador and Mexico.

Country	Variable	Coefficient	Standard error	z-value	p-value	95% confidence interval	
Ecuador	$\ln CO_2_Intensity$	1.0239***	0.0150136	68.20	0.000	0.9945124	1.053365
	$\ln GVA$	0.4138***	0.0236224	17.52	0.000	0.3675195	0.4601175
	GVA^2	-5.55e-16	1.51e-16	-3.69	0.000	-8.50e-16	-2.60e-16
	H_2ORed	0.4155***	0.1389119	2.99	0.003	0.1432845	0.6878092
	_Cons	-10.0849***	0.366126	-27.55	0.000	-10.80257	-9.367383
	ρ	0.97918***	0.0206487	47.42	0.000	0.9387154	1.019657
Mexico	$CO_2_Intensity$	8.91e-07***	9.26e-08	9.63	0.000	7.10e-07	1.07e-06
	$\ln GVA$	1.3148***	0.1679059	7.83	0.000	0.9857409	1.64392
	GVA^2	-1.65e-10***	2.09e-11	-7.90	0.000	-2.06e-10	-1.24e-10
	H_2ORed	-1.7994***	0.277874	-6.48	0.000	-2.344056	-1.25481
	_Cons	-12.1318***	1.702017	-7.13	0.000	-15.46774	-8.795961
	ρ	0.96714***	0.0321469	30.09	0.000	0.9041368	1.03015

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. The ρ point estimates for both countries lie within the admissible ranges implied by W. The reported 95% confidence intervals are asymptotic Wald intervals calculated from the standard errors and are not truncated at the parameter-space boundaries. Therefore, confidence limits exceeding the admissible boundary do not imply that the estimated spatial parameter lies outside the admissible parameter space; rather, they reflect the properties of the asymptotic Wald approximation near the boundary.

However, the curvature implied by the model suggests that the turning point lies at relatively high-income levels, meaning that Ecuador remains on the ascending segment of the EKC. This finding supports the argument that structural dependence on resource-intensive activities delays the environmental transition, as highlighted by Acheampong et al. (2021) and Schneider and Mellon-Bedi (2025).

To complement the sign-based EKC interpretation, we compute the implied turning point (i.e., the level of economic activity at which the effect of further growth on emissions changes from increasing to decreasing). Given the estimated EKC terms $\ln(GVA)$ and GVA^2 , the turning point is obtained as:

$$GVA^* = \sqrt{\frac{\beta_{\ln(GVA)}}{-2\beta_{(GVA)^2}}}$$

Using the SAR coefficients in Table 3, the implied turning point equals 19,308,274 for Ecuador and 63,122 for Mexico (in the same units used for GVA in the dataset). These values provide a direct quantitative benchmark to evaluate whether each country is still on the rising segment of the EKC or has moved beyond the turning phase.

The coefficient associated with access to drinking water (H_2ORed) is positive and statistically significant, suggesting that improvements in service coverage are linked to higher carbon emissions. Rather than capturing a direct environmental effect, this variable reflects processes of urbanization and structural transformation that increase energy demand, infrastructure expansion, and productive activity, thereby intensifying environmental pressure in

the absence of cleaner technologies. Furthermore, the spatial autoregressive parameter ρ is positive, statistically significant, and close to the upper admissible boundary, indicating strong spatial dependence across provinces. This result reveals the existence of substantive spillover effects, whereby emissions in one territory are systematically influenced by those of neighboring regions. The presence of these spatial interactions supports the use of the SAR specification not only on statistical grounds but also from a theoretical perspective, as environmental externalities and productive structures tend to diffuse across contiguous areas.

In the case of Mexico, the positive and statistically significant coefficient of $\ln GVA$, together with the negative and highly significant coefficient of the squared term (GVA^2), confirms a nonlinear relationship consistent with the inverted U hypothesis of the Environmental Kuznets Curve. Compared to Ecuador, the estimated curvature suggests a more pronounced adjustment process, indicating that Mexico is positioned closer to, or already within, the declining segment of the EKC. From an economic perspective, this implies that further increases in income are associated with reductions in carbon emissions, reflecting structural transformation, technological upgrading, and greater regulatory capacity in more industrialized regions. These findings align with Gómez and Rodríguez (2020) and Escamilla-García et al. (2024), who highlight the role of technological change and climate policy in accelerating the downward phase of the EKC.

An additional relevant finding is the negative and statistically significant coefficient of H_2ORed , indicating that, unlike in Ecuador, greater access to basic infrastructure in Mexico is associated with lower carbon emissions. This

result suggests that infrastructure expansion operates under higher efficiency standards, likely reflecting technological upgrading, improved urban planning, and stronger regulatory frameworks that mitigate environmental externalities. From an economic perspective, the negative association may capture the role of more advanced urban systems in reducing energy intensity and promoting cleaner production processes (Castro-Rosales & Esqueda-Walle 2020). Furthermore, the spatial autoregressive parameter ρ is positive, statistically significant, and close to the upper admissible boundary, confirming strong spatial dependence in CO_2 emissions. This implies that environmental outcomes in one state are systematically influenced by those of neighboring regions, reinforcing the existence of regional spillovers and the importance of coordinated environmental policies.

3.3. Spatial Error Model (SEM)

Table 4 presents the results of the Spatial Error Model (SEM), which captures spatial effects through the error term. In this model, the spatial error coefficient (λ) measures the spatial autocorrelation of the unobserved error. The results confirm a strong spatial dependence in both countries, which reinforces the need to incorporate regional structures in environmental analysis.

In Ecuador, the positive coefficient of $\ln GVA$ together with the negative and statistically significant coefficient of GVA^2 reveals a concave relationship consistent with the initial stage of an Environmental Kuznets Curve. Rather than describing background conditions, the model results indicate that economic activity is still associated with increasing environmental pressure, although the negative quadratic component suggests the emergence of a moderating effect

Table 4: Spatial Error Model (SEM) results for Ecuador and Mexico.

Country	Variable	Coefficient	Standard error	z-value	p-value	95% confidence interval	
Ecuador	$\ln CO_2_Intensity$	0.9782***	0.0168036	58.22	0.000	0.9453332	1.011202
	$\ln GVA$	0.3566***	0.025516	13.98	0.000	0.3066046	0.4066254
	GVA^2	-4.19e-16***	1.61e-16	-2.60	0.009	-7.36e-16	-1.03e-16
	H_2ORed	0.4953***	0.1601639	3.09	0.002	0.1814752	0.8093061
	_Cons	-3.2443***	0.6617473	-4.90	0.000	-4.541388	-1.947386
	λ	0.9157***	0.0841231	10.89	0.000	0.7508432	1.0806
Mexico	$CO_2_Intensity$	8.54e-07***	9.49e-08	9.00	0.000	6.68e-07	1.04e-06
	$\ln GVA$	1.3432***	0.1639544	8.19	0.000	1.021883	1.664573
	GVA^2	-1.70e-10***	2.10e-11	-8.10	0.000	-2.11e-10	-1.29e-10
	H_2ORed	-1.6753***	0.2790382	-6.00	0.000	-2.222255	-1.128446
	Cons	-8.6013**	4.232454	-2.03	0.042	-16.89681	-0.3058964
	λ	0.9718***	0.0279994	34.71	0.000	0.9170163	1.026772

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. The λ point estimates for both countries lie within the admissible ranges implied by W. The reported 95% confidence intervals are asymptotic Wald intervals calculated from the standard errors and are not truncated at the parameter-space boundaries.

at higher income levels. From a spatial perspective, this pattern implies that the structural transformation required for environmental improvement has not yet materialized uniformly across regions. Consequently, the EKC should be interpreted as incipient and not yet validated in its mature phase. This interpretation aligns with Zafar et al. (2019) and Usman et al. (2022), who argue that in fossil-fuel-dependent economies with limited environmental governance, the upward segment of the EKC tends to persist for longer periods.

Applying the same turning-point calculation to the SEM estimates confirms the nonlinear EKC implications. Based on the coefficients in Table 4 and the expression:

$$GVA^* = \frac{\beta_{\ln(GVA)}}{\sqrt{-2\beta_{(GVA)^2}}}$$

the implied turning point equals 20,628,982 for Ecuador and 62,854 for Mexico (in the same units used for GVA in the dataset). Overall, the turning-point values are very similar across SAR and SEM, which strengthens the robustness of the estimated nonlinear relationship.

The positive and statistically significant coefficient of H_2O_{red} indicates that the expansion of basic infrastructure is associated with higher environmental pressure, suggesting that improvements in service coverage are occurring alongside increases in energy use and emissions. This result points to a scale effect that continues to dominate over potential efficiency gains, particularly in regions where infrastructure growth is not yet accompanied by cleaner technologies. Moreover, the positive and statistically significant λ estimate lies close to the upper admissible boundary and indicates strong spatial dependence in the error term, implying that unobserved territorial factors influence environmental outcomes. This pattern highlights the presence of spatial spillovers and suggests that the model captures only part of the regional dynamics, reinforcing the need to interpret the EKC within a spatially interconnected context.

In Mexico, the estimated signs reinforce the presence of a more advanced stage of the Environmental Kuznets Curve. The positive effect of $\ln GVA$ combined with the negative and highly significant quadratic term indicates a steeper concave pattern, suggesting that the economy is moving closer to the turning phase of the EKC. Rather than reflecting background conditions, the results point to a context in which structural change and environmental management may be beginning to offset the scale effect of growth. This interpretation is consistent with Dogan et al. (2020), who emphasize that active environmental policies and more diversified productive structures can

accelerate the transition toward the declining segment of the EKC.

Additionally, the negative coefficient of H_2O_{red} suggests that the expansion of basic services is associated with efficiency gains or stricter environmental standards that help mitigate environmental pressure. This pattern contrasts with less efficient infrastructure expansions and is in line with Medina-Rivas et al. (2022). Finally, the positive and statistically significant λ estimate lies close to the upper admissible boundary, confirming persistent spatial dependence in the disturbance process and indicating that unobserved territorial factors continue to shape environmental outcomes beyond the variables included in the model.

3.4. Comparative Analysis of SAR and SEM Spatial Models

The comparison between the SAR and SEM spatial models for Ecuador and Mexico (Table 5) reveals notable differences in the spatial distribution of pollution, reflecting the structural heterogeneity of both economies in relation to the Environmental Kuznets Curve (EKC). Although the information criteria favor the SAR specification in both cases, the model selection is not based solely on goodness-of-fit measures. In Ecuador, the spatial autoregressive coefficient is positive and highly significant, indicating the presence of substantive spatial dependence whereby pollution levels in one province directly influence neighboring areas. This finding points to the existence of spillover effects rather than merely spatially correlated disturbances, thereby supporting the preference for the SAR model over the SEM specification. The lower residual dispersion and more favorable information criteria further reinforce the robustness of the SAR model. This pattern confirms that Ecuador's EKC remains in its ascending phase, where oil-related activities continue to generate persistent environmental pressures without reaching the turning point (Larrea & Warnars 2009, Zafar et al. 2019).

The choice between the SAR and SEM specifications is supported by both statistical evidence and the underlying economic interpretation of spatial interaction. Statistically, Table 5 indicates that SAR provides better overall fit in both countries (higher R^2 and lower AIC/BIC), and the spatial parameters are highly significant, confirming that spatial dependence is a core feature of the data. In addition, the spatial dependence diagnostics reported in Table 2 justify the inclusion of a spatial structure. From a theoretical standpoint, SAR is appropriate when environmental outcomes propagate through direct inter-territorial spillovers, meaning that emissions in one province/state can influence neighboring territories through geographic and economic

Table 5: Comparison of SAR and SEM models for Ecuador and Mexico.

Country	Model:	SAR (Spatial Autoregressive Model)	SEM (Spatial Error Model)
Ecuador	Log likelihood	-265.26353	-313.62024
	Sigma (σ)	0.44	0.50
	R ² (squared correlation)	0.945	0.927
	λ (λ)	-	0.9157 (-3.626 < λ < 1.000)
	ρ (ρ)	.9791 (-3.626 < ρ < 1.000)	-
	Wald test (spatial effect)	2248.772 (0.000)	118.494 (0.000)
	Likelihood ratio test	113.613 (0.000)	16.899 (0.000)
	Lagrange multiplier test	137.344 (0.000)	40.057 (0.000)
	AIC (Akaike Information Criterion)	542.5271	619.9926
	BIC (Bayesian Information Criterion)	566.9376	644.0602
Mexico	Log likelihood	-1337.0007	-1346.6644
	Sigma (σ)	2.45	2.49
	R ² (squared correlation)	0.441	0.334
	λ (λ)	-	0.9718 (-3.385 < λ < 1.000)
	ρ (ρ)	0.9671 (-3.385 < ρ < 1.000)	-
	Wald test (spatial effect)	905.114 (0.000)	1204.871 (0.000)
	Likelihood ratio test	85.847 (0.000)	66.520 (0.000)
	Lagrange multiplier test	271.186 (0.000)	408.348 (0.000)
	AIC (Akaike Information Criterion)	2686.001	2705.329
	BIC (Bayesian Information Criterion)	2712.138	2731.465

Note: Prepared by the authors.

linkages. By contrast, SEM is more consistent with spatial dependence driven by spatially correlated unobserved shocks captured in the error term. Therefore, SAR is retained as the baseline specification for comparative interpretation of spillover effects, while SEM is reported as a complementary robustness specification.

From a methodological perspective, the results indicate that the SAR model provides a more robust specification than the SEM for both countries, although with differences in the intensity of spatial effects. In Ecuador, the spatial autoregressive coefficient is large and statistically significant, revealing strong regional interdependence whereby pollution spreads from major extractive hubs to neighboring areas. This pattern is consistent with the presence of substantive spatial spillovers rather than merely spatially correlated errors, which supports the appropriateness of the SAR specification. Such dynamics tend to prolong the ascending phase of the EKC by transmitting environmental pressures across adjacent territories. This evidence aligns with Jeetoo (2023), who highlights that economies characterized by concentrated productive structures and limited territorial planning often exhibit pollution processes that diffuse spatially. Under these conditions, spatial lag models such as SAR are better suited to capture distributed environmental externalities.

In Mexico, the SAR model also shows superior performance relative to the SEM in terms of overall fit and information criteria, although residual variability remains comparatively higher. The statistical significance of both spatial parameters confirms the presence of regional interdependence; however, the magnitude and interpretation of the spatial lag coefficient suggest that spatial dependence operates mainly through interregional spillovers rather than through omitted spatial shocks. This indicates a more heterogeneous and less spatially uniform pattern of emissions compared to Ecuador. Such complexity reflects Mexico's broader territorial diversity and uneven industrial and urban development, consistent with the observations of Blackman et al. (2015) regarding the heterogeneous nature of environmental pressures in large and diverse national contexts.

The spatial distribution of pollution in Mexico is characterized by fragmentation across regions with differing levels of development and urbanization, revealing a spatial structure shaped by economic inequalities and differentiated urbanization processes (Chen et al. 2022). Similarly, Karahasan & Pinar (2022) demonstrate that regional productive heterogeneity generates complex environmental dispersion patterns, as also observed in the Mexican case. In

this sense, the superior explanatory performance of the SAR model in both Mexico and Ecuador supports its usefulness as an analytical tool for examining environmental trajectories in developing economies (Herrera et al. 2024).

From a comparative standpoint, the findings indicate that the SAR model provides a more solid explanatory framework for both countries. In Ecuador, pollution is transmitted in a more direct and geographically dependent manner, reflecting a rigid EKC that remains in its ascending phase (Buenaño et al. 2023). In contrast, Mexico, due to its territorial scale and structural diversity, exhibits more dispersed and complex spatial patterns, with emissions fragmented across regions with varying degrees of industrialization and urban development (Medina-Rivas et al. 2022). This diversity complicates the representation of environmental dynamics through a single spatial specification, in line with the arguments of Percastre et al. (2024) regarding the role of economic and urban heterogeneity in shaping environmental pressures.

4. CONCLUSIONS

The environmental trajectories of Ecuador and Mexico reveal distinct paths within the framework of the Environmental Kuznets Curve (EKC), shaped by differences in productive structures and institutional capacities. While Ecuador remains in the ascending phase of the EKC, largely due to its dependence on extractive activities and the limited consolidation of environmental institutions, Mexico exhibits clearer evidence of having reached, or even surpassed, the turning point in certain regions. This divergence highlights how the nature of economic growth, whether resource-based or more industrialized and diversified, conditions the potential for transitioning toward environmentally sustainable development pathways. The Mexican case illustrates that policies aimed at energy diversification and institutional strengthening can generate positive effects on emission reduction, although these efforts remain insufficient to achieve a homogeneous transition at the national scale.

The results further confirm that CO₂ emissions do not follow random patterns but are driven by significant spatial and territorial dynamics. In both countries, the spatial autocorrelation detected across all estimated models indicates that pollution processes are governed by shared regional logics. In Ecuador, emissions are concentrated in the Amazon and coastal regions, closely associated with oil extraction activities, whereas in Mexico, a more fragmented network of interconnected industrial hubs is observed. These findings validate the use of spatial econometric models as essential tools for capturing environmental externalities across contiguous territories and for designing differentiated mitigation policies tailored to regional characteristics.

The comparison between the SAR (Spatial Autoregressive Model) and SEM (Spatial Error Model) indicates that direct spatial interaction among regions, as captured by the SAR specification, exerts a stronger influence on emission patterns than unobserved residual spatial effects modeled by the SEM. This result highlights the importance of geographical contagion in shaping CO₂ emission processes. In Ecuador, the superior performance of the SAR model suggests that pollution in one province is closely linked to pollution in neighboring provinces, reflecting development patterns concentrated in extractive hubs. In Mexico, although the SAR model also performs better, the lower value of the spatial autoregressive parameter (ρ) and the higher residual variance reveal a more heterogeneous structure that is less dependent on immediate geographical proximity. Consequently, mitigation strategies should be adapted not only to the type of economy but also to the territorial configuration of each country: Ecuador requires targeted interventions in extractive clusters, whereas Mexico demands multi-level policies capable of addressing dispersed and diverse sources of pollution.

Access to basic services, such as piped water, exhibits contrasting effects across the two countries, indicating that its environmental impact depends critically on institutional context and the technological efficiency of infrastructure. In Ecuador, the expansion of public water networks is associated with higher emission levels, likely linked to rapid urban growth and increased energy demand in low-efficiency environments. By contrast, in Mexico, this variable exerts a negative effect on emissions, suggesting that efficient urban infrastructure and higher technological standards can contribute to reducing environmental pressures. This contrast underscores the importance of complementing the expansion of basic service coverage with policies aimed at improving energy efficiency, promoting sustainable urban planning, and strengthening environmental regulation.

Finally, the dynamics of CO₂ emissions in both countries demonstrate that the Environmental Kuznets Curve hypothesis is neither automatic nor uniform. The transition toward sustainability requires more than economic growth alone; it depends on political commitment, sustained public investment, and strong institutions. Ecuador, despite recent advances, remains constrained by an extractivist model that perpetuates environmental degradation, while Mexico, although more advanced in relative terms, faces setbacks derived from policy decisions that weaken environmental governance and slow the expansion of clean energy. Consequently, EKC phases should be interpreted not as inevitable stages of development but as outcomes shaped by structural conditions and policy choices. This analysis highlights the urgency of rethinking growth strategies through an ecological and territorial lens, in which the State

plays an active role in correcting externalities and leading a transition toward a genuinely sustainable development model.

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