Autonomous City of Buenos Aires, January 31, 2025

Dear researcher,

Through this letter, we certify the acceptance of the scientific article entitled *"**Estimation of GHG emissions and costs in Sinaloa: Towards sustainable economic and environmental policies**"*, authored by *Abril Yuriko Herrera Ríos, Pamela Herrera Ríos, Reyna Christian Sánchez Parra*, following the peer review process in the journal **Data and Metadata**.

The article has been published on the journal's website with the persistent identifier: https://doi.org/10.56294/dm2024.682.

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Without further ado, on behalf of the editors of the journal, we cordially greet you and congratulate you on this academic achievement.

Sincerely,

William Castillo-González

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ORIGINAL

Estimation of GHG emissions and costs in Sinaloa: Towards sustainable economic and environmental policies

Estimación de emisiones de Gases de Efecto Invernadero y costos en Sinaloa: Hacia políticas económicas y ambientales sostenibles

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ABSTRACT

Introduction: climate change and its impacts have created the need for policies that balance economic growth with environmental sustainability. This study focuses on the relationship between economic growth and greenhouse gas (GHG) emissions in the state of Sinaloa, located in northwestern Mexico, during the period 2003-2021.
Method: using historical energy consumption data and the State Quarterly Economic Activity Indicator, GHG emissions were estimated through an official national tool for emissions calculation. An economic cost was assigned using rates proposed by a center specialized in environmental and economic analysis in Mexico.
Results: the findings reveal a strong positive correlation (R=0,893) between the State Quarterly Economic Activity Indicator and emissions, highlighting that Sinaloa's economic growth heavily depends on energy-intensive activities. Over the period analyzed, emissions increased by 83,8 %.
Conclusions: this study underscores the importance of designing public policies that reduce emissions without hindering economic development, promoting sustainable strategies that contribute to Mexico's commitments under the Paris Agreement.

Keywords: Greenhouse Gas Emissions; Economic Growth; Energy Consumption; Environmental Sustainability.

RESUMEN

Introducción: el cambio climático y sus impactos han generado la necesidad de políticas que equilibren el crecimiento económico con la sostenibilidad ambiental. Este estudio analiza la relación entre el crecimiento económico y las emisiones de gases de efecto invernadero (GEI) en el estado de Sinaloa, ubicado en el noroeste de México, durante el periodo 2003-2021.
Método: con un enfoque basado en datos históricos del consumo energético y el Indicador Trimestral de Actividad Económica Estatal, se estimaron las emisiones de GEI mediante una herramienta oficial nacional para el cálculo de emisiones. Se les asignó un costo económico utilizando tarifas propuestas por un centro especializado en análisis ambiental y económico en México.
Resultados: los hallazgos muestran una correlación positiva fuerte (R=0,893) entre el Indicador Trimestral de Actividad Económica Estatal y las emisiones, evidenciando que el crecimiento económico en Sinaloa depende significativamente de actividades intensivas en energía. Durante el periodo analizado, las emisiones aumentaron un 83,8 %.
Conclusiones: este estudio resalta la importancia de diseñar políticas públicas que reduzcan las emisiones sin comprometer el desarrollo económico, promoviendo estrategias sostenibles que contribuyan a cumplir

con los compromisos de México en el Acuerdo de París.

Palabras clave: Emisiones de Gases de Efecto Invernadero; Crecimiento Económico; Consumo Energético; Sostenibilidad Ambiental.

INTRODUCTION

Climate change represents one of the most pressing global challenges, with significant implications for the economy, the environment, and society. In response to this issue, Mexico has made international commitments, most notably its ratification of the Paris Agreement in 2016.(1) This agreement establishes ambitious goals to limit global temperature increases and reduce greenhouse gas (GHG) emissions.

As part of its Nationally Determined Contributions (NDC), Mexico committed to an unconditional reduction of 22 % in its GHG emissions and 51 % in black carbon emissions by 2030.(2) In its position paper for COP28, Mexico reaffirmed its commitment to the Paris Agreement, incorporating recommendations from the Sixth Assessment Report of the IPCC, which calls for a 43 % reduction in global GHG emissions by 2030 or 60 % by 2035. Recent events, such as Hurricane Otis in Guerrero, underscore the urgency of implementing robust strategies to mitigate climate change and achieve these international objectives.(3)

Nationally, Mexico's gross GHG emissions in 2021 reached 714 million tons of CO_2 equivalent, representing 1,4 % of the global total, positioning Mexico as the second-largest emitter in Latin America after Brazil.(4) In this context, the energy transition poses both a critical challenge and an opportunity for the country, given its rich renewable resources and historical reliance on fossil fuels.(5)

At the subnational level, states like Sinaloa play a fundamental role in implementing environmental policies and contributing to national emission reduction goals. Sinaloa is particularly relevant as a case study due to its unique combination of economic activities, such as agriculture, fishing, and tourism, which create a distinct emissions profile compared to other regions in Mexico. Additionally, its vulnerability to climate change, evidenced by recurring droughts and extreme weather events, highlights the need to understand and address its GHG emissions. Although there is no formal GHG inventory specific to the state, this study uses estimates based on official data to identify the main sources and economic costs associated with emissions in the region.

From an environmental economics perspective, it is essential to analyze the relationship between economic growth and GHG emissions, particularly in emerging economies like Mexico. Such analyses help identify strategies that promote sustainable development by balancing economic progress with environmental protection. Recent studies have explored this relationship, emphasizing the importance of public policies that foster energy efficiency and the adoption of clean technologies.(6,7,8,9,10)

This article aims to analyze the relationship between economic growth and GHG emissions in Sinaloa through a correlation analysis based on historical energy consumption data. By assigning a price to emissions, this study highlights the associated economic costs. This approach seeks to provide empirical evidence to better understand the local dynamics of emissions and economic growth, contributing to the design of public policies aimed at fulfilling Mexico's commitments under the Paris Agreement and promoting more sustainable and environmentally responsible economic development.

METHOD

Data Sources

The analysis was based on data from the state of Sinaloa collected for the period 2003–2021. Various official sources were used to ensure the quality and reliability of the data:

- Energy consumption: Data were obtained from the Ministry of Energy (*Secretaría de Energía*, SENER), broken down by fuel type and economic sector.(11)
- Emission estimation: The RENE calculator, developed by the Ministry of Environment and Natural Resources (*Secretaría de Medio Ambiente y Recursos Naturales*, SEMARNAT), was used to calculate greenhouse gas (GHG) emissions derived from energy consumption.(12)
- Economic activity: The State Quarterly Economic Activity Indicator (*Indicador Trimestral de la Actividad Económica Estatal*, ITAEE), provided by INEGI, was used as a proxy for economic growth.(10)
- Economic costs: These were calculated using the CO_2e tariff per ton proposed by a specialized environmental and economic analysis center in Mexico, adjusted to the average annual exchange rate.(7)

Emission Estimation

To estimate GHG emissions, a top-down approach was applied. This method considers the total energy consumption by fuel type and economic sector, multiplied by the specific emission factors provided by the RENE calculator, version 8.0 (March 2022), which aligns with the IPCC's Scope 1 guidelines. The following equation was used:

$$Emission = \sum_t [Electricity\ Consumption_{\ t} \cdot EF\ ] \qquad \text{(Eq. 1)}$$

Where:

- Emission: CO_2 emissions.
- Electricity Consumption: Electricity consumption reported by the Ministry of Energy for year t.
- EF: Emission factor for Mexico per electricity consumption in MWh for the corresponding year.

Calculation of Economic Costs

The economic costs associated with GHG emissions were calculated by multiplying the total annual emissions by the estimated cost per ton of CO_2e. This cost was adjusted to the average annual exchange rate to express the results in Mexican pesos, as shown in the following equation:

$$Emission\ Cost = \sum_t [\ CO\ Emissions_2 \cdot Estimated\ Cost\ per\ tCO_2] \quad \text{(Eq. 2)}$$

Where:

- Emission Cost: The total economic cost for the year.
- CO_2 Emissions: The total estimated emissions for the year.
- Estimated Cost per tCO_2: The average price per ton of CO_2e.

Data Analysis

A correlation analysis was conducted to compare how CO_2e emissions related to energy consumption have evolved alongside the State Quarterly Economic Activity Indicator (ITAEE). This approach allows for determining the strength and direction of the relationship between these two variables.

The correlation analysis revealed a strong positive relationship between the ITAEE and CO_2e emissions in Sinaloa, with a correlation coefficient of R=0,893. This indicates that economic growth in the state is highly associated with an increase in GHG emissions. The coefficient of determination (R2) of 0,798 suggests that 79,8 % of the variability in GHG emissions can be explained by changes in the ITAEE.

Figure 1 illustrates the relationship between the State Quarterly Economic Activity Indicator (ITAEE) and energy consumption in Sinaloa. The observed linear trend reinforces the positive relationship identified in the analysis, indicating that economic growth is closely linked to higher energy consumption.

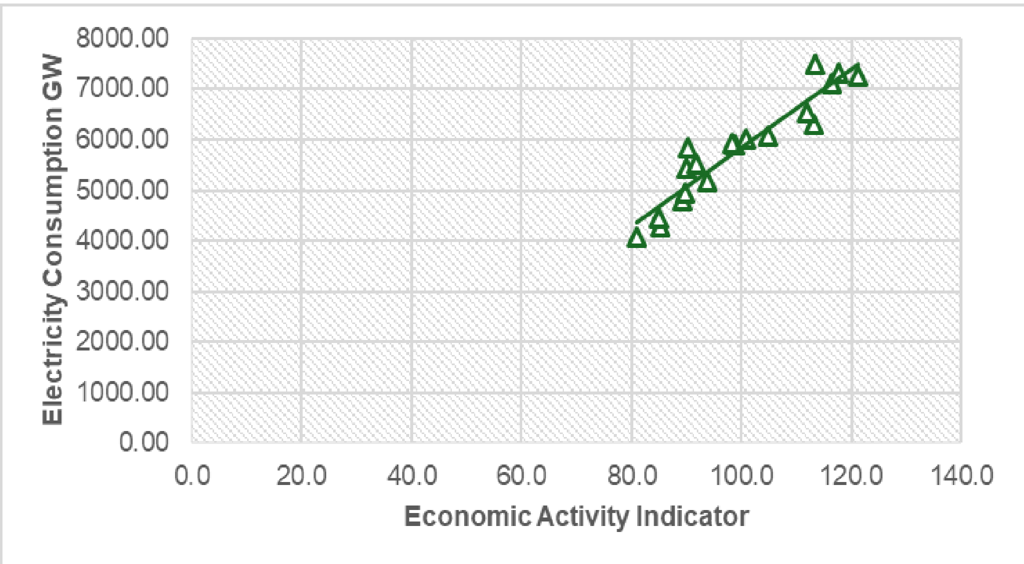

Figure 1. Correlation analysis of economic activity and emissions in Sinaloa
Source: Author’s elaboration with data from INEGI and SENER.

RESULTS

Emission Estimation and Trends

During the analysis period from 2003 to 2021, greenhouse gas (GHG) emissions from energy consumption in Sinaloa increased by 80 %, reaching a total of 3,17 million tons of CO_2 equivalent (tCO_2e) in 2021. This growth aligns with national trends, where total CO_2e emissions grew by 27 % between 2003 and 2022, with an average annual growth rate (AAGR) of 1,4 %. At the state level, Sinaloa's AAGR is higher, highlighting a faster-growing dependence on energy consumption as an economic driver.(5) This increase underscores the state's reliance on energy-intensive economic activities, particularly in the agricultural and fishing sectors.

Table 1 presents the evolution of the State Quarterly Economic Activity Indicator (ITAEE), greenhouse gas (GHG) emissions, and the associated economic costs during the study period (2003–2021). These data reflect a consistent increase in emissions and costs, aligned with the economic growth observed in Sinaloa.

Table 1. Comparison of economic activity, emissions, and their cost

Year	Economic activity	Emissions (tCO_2e)	Emissions Cost (MXN)
2003	80,93	1 725 799	$ 191 232 285,29
2004	85,12	1 808 942	$ 200 445 262,53
2005	84,99	1 877 173	$ 208 005 775,04
2006	89,14	2 031 160	$ 225 068 791,80
2007	89,71	2 094 611	$ 232 099 606,27
2008	93,86	2 194 708	$ 243 191 242,58
2009	90,10	2 304 210	$ 255 324 897,25
2010	91,84	2 330 329	$ 258 219 088,36
2011	90,22	2 469 223	$ 273 609 683,31
2012	98,83	2 497 006	$ 276 688 215,05
2013	100,85	2 538 579	$ 281 294 907,56
2014	98,29	2 503 109	$ 277 364 515,83
2015	104,80	2 574 574	$ 285 283 376,72
2016	113,24	2 667 454	$ 295 575 287,12
2017	111,93	2 767 989	$ 306 715 285,63
2018	116,50	3 015 077	$ 334 094 634,71
2019	121,12	3 069 342	$ 340 107 615,22
2020	117,74	3 090 820	$ 342 487 635,61
2021	113,44	3 172 899	$ 351 582 640,74

Source: Author's elaboration with data from INEGI and SENER.

Associated Economic Costs

The cumulative economic cost of emissions in Sinaloa during the study period amounts to 5,178 million Mexican pesos, with an average annual cost of 351 million pesos in 2021, calculated using a reference price of $5,7 USD per ton of CO_2e. Nationally, the estimated costs for the same period reached 9 622,5 million pesos in 2022, reflecting a 27 % increase since 2003, as shown in table 2.(6)

Table 2. Comparison of Sinaloa with the National Context

Year	Emissions in Sinaloa (tCO_2e)	Economic Cost in Sinaloa (MXN)	National Cost (MXN)
2003	1 725 799	$191 232 285	$7 576 billion
2021	3 172 899	$351 582 641	$9 622,5 billion

Source: Author's elaboration with data from RENE and national projections.(7)

Regional Comparison

At the national level, the Mexico City Metropolitan Area is the region with the highest emissions; however, states like Nuevo León and Jalisco have surpassed Mexico City in recent years.(5) In comparison, Sinaloa has lower total emissions but stands out in terms of per capita emission intensity due to its reliance on agricultural and fishing sectors.

Sectoral Analysis

In Sinaloa, the energy and agricultural sectors are responsible for over 70 % of GHG emissions, whereas at the national level, the industrial and transport sectors dominate with 80 % of total emissions. This contrast highlights the need for differentiated regional strategies to meet the objectives of the Paris Agreement.

DISCUSSION

The findings of this study align with recent environmental economics literature, which suggests a direct relationship between economic growth and GHG emissions in emerging economies.[13] Additional studies emphasize that while developing countries face significant challenges in implementing clean technologies, these are essential to decouple economic growth from carbon emissions.[14,15]

For instance, research highlights the importance of tailoring climate policies to local conditions to maximize their effectiveness.[16,17] In Sinaloa, the agricultural and fishing sectors account for 70 % of emissions, suggesting that adopting sustainable agricultural practices and electrifying production chains could be key strategies.

At the national level, studies have shown that a lack of coordination among government levels limits the impact of mitigation policies.[9] This underscores the need to integrate subnational data into national emissions inventories, as demonstrated by this study.

Finally, the comparison between per capita emissions in Sinaloa and other states with different economic profiles confirms that mitigation strategies should consider not only the magnitude of emissions but also their relative intensity. This perspective allows for the design of more equitable and effective public policies.[18,19]

The findings of this study suggest a direct relationship between economic growth and GHG emissions in emerging economies.[20] Studies have pointed out that, in developing countries, investment in clean technologies remains insufficient to decouple economic growth from environmental impact.[14]

The continuous increase in emissions observed in Sinaloa, even with moderate economic growth, supports the conclusions of authors who argue that local environmental policies must be complemented by financial incentives to promote the energy transition.[14] In Sinaloa, the emphasis on agricultural and fishing sectors underscores the need for specific strategies, such as adopting sustainable agricultural practices and increasing electrification in production chains.

Additionally, the regional analysis shows that current national mitigation strategies do not sufficiently account for the specific characteristics of each state.[20,21] Greater coordination between government levels can significantly improve the effectiveness of public policies.[9]

These findings highlight the importance of continuing to explore how economic, social, and environmental characteristics influence the relationship between economic growth and emissions. The incorporation of more dynamic economic models and the availability of more disaggregated data could provide a clearer view of local opportunities and challenges.

CONCLUSIONS

This study highlights the importance of analyzing greenhouse gas (GHG) emissions in local contexts, such as Sinaloa, identifying their main sources and estimating the associated economic costs. Among the primary limitations is the availability of updated and disaggregated data, which restricts the precision of analyses and comparisons across regions. Additionally, the lack of integration of variables related to the energy transition and the use of renewable energies limits the evaluation of current public policies.

The contribution of this work lies in the construction and analysis of a database that includes GHG emissions, economic activity, and associated costs, enabling the exploration of key relationships for designing sustainable strategies. The methodology used can be replicated in other states or regions, contributing to a more comprehensive framework for environmental and economic analysis.

The creation of databases like the one used in this study has a significant impact, as it facilitates evidence-based decision-making and promotes transparency in environmental management. Moreover, linking economic costs to emissions provides a stronger argument for implementing policies aimed at reducing emissions without compromising economic growth.

For future research, it would be valuable to incorporate sensitivity analyses to evaluate the impact of different carbon prices and explore the interaction between local and national policies. This will help identify best practices and adjust mitigation strategies to meet the specific needs of each region.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORSHIP CONTRIBUTION

Conceptualization: Abril Yuriko Herrera Ríos.
Data curation: Abril Yuriko Herrera Ríos.
Research: Abril Yuriko Herrera Ríos.
Methodology: Abril Yuriko Herrera Ríos.
Validation: Reyna Christian Sánchez Parra.
Drafting: Reyna Christian Sánchez Parra and Pamela Herrera Ríos.
Writing: Abril Yuriko Herrera Ríos, Reyna Christian Sánchez Parra and Pamela Herrera Ríos.

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