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Relationship between renewable energy consumption and its impact on CO2 emissions in Peru, 1990-2020

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C H R O N I C L E

Article history:
Received: April 5, 2024
Received in the revised format: July 29, 2024
Accepted: September 10, 2024
Available online: September 10, 2024

Keywords:
Renewable energy
Consumption
Impact
Emissions
CO2

A B S T R A C T

In his research, he has established an analysis of the consumption of renewable energy and its impact on CO2 emissions in Peru, 1990-2020. The research employs a quantitative approach and longitudinal non-experimental design, with a multiple linear regression model. It uses time series drawn from the World Bank on renewable energy consumption and energy consumption. A progressive increase was reflected mainly driven by industrial growth, fossil fuel consumption and changes in consumption and production patterns.

1. Introduction

Globally, renewable energy consumption has seen significant growth in recent decades, accounting for an increasing proportion of total energy supply (Saidi & Omri, 2020). According to data from the International Energy Agency (IEA), in 2020, renewable sources provided approximately 29% of global electricity generation, an increase of 10% compared to 2010 (Shahbaz et al., 2020). This increase has been largely driven by the declining costs of technologies such as solar and wind, as well as supportive policies and clean energy targets set by many countries (Ali et al., 2022). Despite this progress, global CO2 emissions remain worryingly high, with a 62% increase since 1990, according to the Intergovernmental Panel on Climate Change (IPCC) (Shen et al., 2020). Although economic growth and industrial development have been key factors, CO2 emissions are also closely linked to the use of fossil fuels for power generation, transport and industry (Lin & Xu, 2020). In fact, in 2020, fossil fuels still accounted for around 80% of global primary energy consumption, according to the IEA, highlighting the persistent reliance on these non-renewable sources (Fareed & Pata, 2022). Meinshausen et al. (2022) indicate that in response to the urgent need to reduce greenhouse gas emissions, many countries have intensified their efforts to increase the penetration of renewable energy in their energy matrices. Ambitious targets have been set, such as the Paris Agreement, which seeks to limit global warming to less than 2°C, with additional efforts to reach 1.5°C. However, achieving these goals will require a significant increase in investment in renewable infrastructure, as well as the implementation of policies and regulations that encourage the decarbonization of the economy globally (Huang & Zhai, 2021). In Argentina, a country with an economy highly dependent on fossil fuels, CO2 emissions have been significant. According to World Bank data, in 2018, Argentina emitted around 4.8 metric tons per capita of CO2, one of the highest figures in Latin America (Murshed et al., 2022). This high emission is closely related to power generation, where 60% comes from the use of fossil fuels. If adequate measures are not taken to reduce this dependence, Argentina faces serious environmental risks, such as the exacerbation of extreme weather events and the degradation of key ecosystems such as the Patagonia region (Cubillos & Estenssoro, 2021).

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doi: 10.5267/dsl.2024.9.002

In Brazil, deforestation of the Amazon and historical dependence on hydropower have contributed to its CO_2 emissions. According to Brazil's System of Environmental and Economic Accounting (SEEG), in 2019, the country emitted approximately 2.2 metric tons per capita of CO_2 (Jazeera, 2020). Although Brazil has made progress in the adoption of renewable energies, such as biomass and wind energy, the pressure to expand agriculture and livestock, as well as the need to meet growing energy demand, pose challenges for reducing emissions (Arias et al., 2020). Without effective measures to curb deforestation and diversify its energy matrix, Brazil faces risks of biodiversity loss and climate imbalances at the regional and global levels (Bertassoli et al., 2021). In Mexico, CO_2 emissions have increased significantly in recent decades due to rapid industrial and urban growth, as well as dependence on oil and coal for power generation (Hernández, 2021). According to the Ministry of Environment and Natural Resources (SEMARNAT), in 2019, Mexico emitted around 3.8 metric tons per capita of CO_2 (Juárez, 2023). These emissions have contributed to local environmental problems, such as air pollution, as well as global challenges, such as climate change. If Mexico fails to diversify its energy mix towards cleaner sources and adopt stricter mitigation policies, it will face risks of serious environmental and economic impacts, including loss of agricultural productivity, desertification, and increased extreme weather events (Vallarta et al., 2023).

Peru's energy situation is aggravated by its diverse geography and unique socio-economic characteristics. Although the country has great potential for renewable energy generation, with abundant hydroelectric and solar resources, limited infrastructure and lack of investment have hindered its full utilization. In addition, the unequal distribution of wealth and accessibility to energy in rural and remote areas pose additional challenges for the implementation of sustainable and equitable solutions. In this context, there is a need to critically examine the country's energy and environmental policies and seek innovative strategies that address both development needs and sustainability imperatives (Arredondo et al., 2020). The transition to renewable energy sources has become an urgent global concern in response to climate change and the need to reduce greenhouse gas emissions. However, in the specific context of Peru, this change presents significant and complex challenges. Over the past few decades, the country has faced an increasing demand for energy due to economic development and population expansion, which has put additional pressures on its energy resources. Despite efforts to increase the use of renewable sources, such as hydropower and solar power, Peru is still heavily dependent on fossil fuels, raising questions about its ability to mitigate CO_2 emissions and meet international carbon reduction commitments (Lizarraga, 2022). The challenge of balancing economic growth with environmental protection and climate change mitigation is a crucial issue in the Peruvian and global context. The transition to a more sustainable and resilient energy model requires not only significant investment in infrastructure and technology, but also a cultural and political transformation that promotes the adoption of more responsible practices and habits (Lozano, 2022). In this sense, this study aims to address the complex problem of renewable energy consumption and its implications for CO_2 emissions in Peru, in order to offer valuable insights that can inform future policies and actions towards a more sustainable and prosperous future for the country.

2. Methodology

The research employs a quantitative approach and longitudinal non-experimental design, with a multiple linear regression model. It uses time series drawn from the World Bank on renewable energy consumption and energy consumption. A control variable is also added to avoid errors due to specification bias. The selection of the control variable is subject to literature review and the availability of statistical data.

Table 1
Study variables

Variable	Abbreviation	Description	Scale
Dependent			
CO2 emissions	LnCO2	CO2 emissions (metric tons per capita)	Logarithm
Independent			
Renewable energy consumption	CER	Renewable energy consumption (% of total final energy consumption)	Percentage change
Control			
Production growth	CPBI	Gross Domestic Product Growth (% per year)	Percentage change

Note. Own elaboration.

The multiple linear regression model will be specified as follows:

$$LnCO2 = \beta_0 + \beta_1 CER + \beta_2 CPBI + e$$

where β_0 is the intercept coefficient, β_1 is the coefficient of the independent variable CER, β_2 is the coefficient of the control variable CPBI, and is the error term. The dependent variable is transformed into logarithms because it shows a right-leaning distribution (see Appendix 1).

Before estimating the model, when working with time series, stationarity is reviewed through Dickey-Fuller and Phillips-Perron unit root tests, the results of which will determine the need to differentiate the series. The model is then estimated using the ordinary least squares (OLS) method. Finally, tests are carried out to verify compliance with the assumptions in the systematic part of the model: multicollinearity; and in the residual part: normality, homoscedasticity and autocorrelation.

3. Results

Fig. 1 shows the evolution of CO2 emissions per capita in Peru during the period between 1990 and 2020, where a general upward trend in CO2 emissions per capita is observed. The lowest level occurred at the beginning of the period analyzed, which increased due to the increase in industrial activity, the consumption of fossil fuels and changes in consumption and production patterns. The greatest decrease occurred in 2020, related to the impact of the COVID-19 pandemic and the containment measures implemented to mitigate its spread.

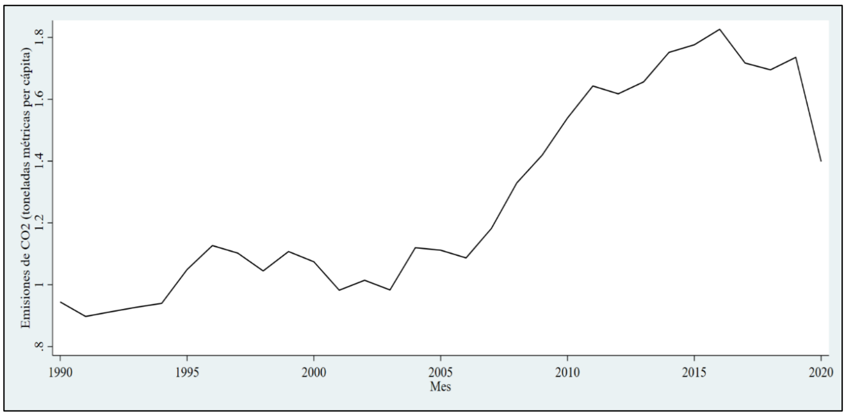


Fig. 1. Evolution of CO2 emissions (metric tons per capita)
Note. Own elaboration

Fig. 2 shows the evolution of renewable energy consumption as a percentage of total final energy consumption. It can be seen that, in 1990, renewable energy consumption represented about 40% of total final energy consumption in Peru, however, over time, this consumption has gradually decreased its participation in the energy matrix, with a recovery to before the 2000s and subsequent fall. The first decrease responds to the recovery of economic growth, the increase in energy demand and the dependence on fossil fuels to meet the country's energy needs. The increase in consumption before the beginning of the 2000s persisted until before 2004, and subsequently, the economic boom brought with it industrialization and the increase in the consumption of fossil fuels that contributed to the relative decrease in renewable energy consumption compared to total energy consumption.

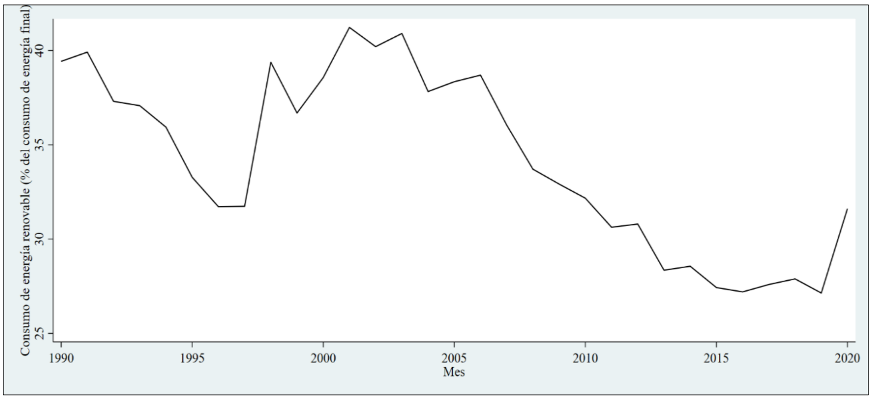


Fig. 2. Evolution of renewable energy consumption (% of total final energy consumption)
Note. Own elaboration

Table 2 presents the descriptive statistics of the variables of the econometric model. The LnCO2 variable (logarithm of CO2 emissions per capita) has an average of 0.219, a standard deviation of 0.243, which indicates a moderate variability in CO2 emissions per capita over time, with a minimum value of -0.108 and the maximum of 0.602. The positive skewness shows a slightly rightward skewed distribution and the kurtosis of 1.531 indicates a platycurrtic distribution, i.e., more flattened compared to a normal distribution. In relation to the CER variable (renewable energy consumption as a percentage of total final energy consumption) an average of 34.205% is observed, that is, on average, approximately one third of the total energy consumption came from renewable sources during the period studied. On the other hand, there are moderate fluctuations over time, reflected in a standard deviation of 4.698%, as well as a minimum value of 27.140% and a maximum of 41.230%, that is, there is no evidence of homogeneous consumption. Negative skewness of -0.120 indicates a skew towards higher values, and kurtosis of 1.619 shows a more pointed distribution than a normal distribution. Regarding the control variable (CPBI), there is an average of 3.761%, that is, an average economic growth of 3.761%. This variable presents greater fluctuations than the previous ones, with a standard deviation of 4.354%, having a minimum value of -10.870% and a maximum value of 12.308%. On the other hand, the negative asymmetry of -1.172 indicates a skewed distribution towards lower values, and kurtosis denotes a leptocurtic distribution, which is characterized by having a higher concentration of values around the mean and heavier tails than a normal distribution.

Table 2

Descriptive statistics

Statistical	LnCO2	CER	CPBI
Media	0.219	34.205	3.761
Standard deviation	0.243	4.698	4.354
Variance	0.059	22.069	18.961
Minimal	-0.108	27.140	-10.870
Maximum	0.602	41.230	12.308
Asymmetry	0.299	-0.120	-1.172
Kurtosis	1.531	1.619	5.767
Remarks	31	31	31

Note. Own elaboration.

Subsequently, as it is a time series analysis, unit root tests are performed and their results are presented in Table 3. The analysis of the variables in levels through the Dickey-Fuller and Phillips-Perron tests shows that only the CPBI variable with p-values of 0.029 and 0.021 for the Dickey-Fuller and Phillips-Perron tests, is significant, since the values are lower than the conventional level of significance, allowing to reject the null hypothesis of the presence of a unit root. Since the LnCO2 and CER variables are not stationary in levels, it is necessary to differentiate them to achieve stationarity. Thus, when applying the unit root tests in first differences, the p-values for both variables are lower than the level of significance in both tests, that is, when differentiating the series, the null hypothesis that postulates the presence of a unit root is rejected, maintaining that the series in first differences are stationary.

Table 3

Unit root testing at levels and in first differences

Variables	Levels		First differences	
	Dickey-Fuller	Phillips-Perron	Dickey-Fuller	Phillips-Perron
LnCO2	0.707	0.684	0.004	0.002
SKY	0.536	0.512	0.000	0.000
CPBI	0.029	0.021	0.000	0.000

Note. Own elaboration.

After the verification of stationarity, the multiple linear regression model (See annex) is estimated, where renewable energy consumption has a negative (-0.018) and significant coefficient indicating that an increase of one percentage point in renewable energy consumption as a percentage of total final energy consumption, is associated with an average decrease of 0.018 units in the first in CO2 emissions per capita. In addition, the BUPC has a positive and significant relationship, i.e. an increase in economic growth is related to an increase in CO2 emissions per capita. However, the estimated model is subjected to the evaluation of the underlying assumptions, where multicollinearity is evaluated through the variance inflation factor (VIF), whose value is 1,400 for both independent variables, i.e., it is lower than the commonly accepted threshold of 5 or 10, therefore, there is no evidence of severe multicollinearity in the model. The Jarque-Bera normality test presents a statistic of 1.394 with a p-value of 0.498, therefore, the null hypothesis of normality in the model residuals is not rejected. However, in the verification of heteroskedasticity, the Breusch-Pagan/Cook-Weisberg heteroskedasticity test presents a statistic of 7.200 with a p-value of 0.007, indicating the presence of heteroskedasticity in the model residuals, i.e., the variance of errors is not constant throughout the observations (non-homoscedasticity). Finally, the Breusch-Godfrey and Durbin Watson autocorrelation tests indicate the absence of autocorrelation in the model residuals.

Table 4

Evaluating Model Assumptions

Assumptions of the model	Test	Statistical	P-value
Multicollinearity	Variance Inflation Factor (VIF)	1.400	-
Normality	Jarque-Bera	1.394	0.498
Heteroskedasticity	Breusch-Pagan/Cook-Weisberg	7.200	0.007
Autocorrelation	Breusch-Godfrey	0.333	0.564
	Durbin Watson	2.094	-

Note. Own elaboration.

In this sense, the previously estimated model must be corrected, an action that is carried out through the application of the robust standard error method, whose results indicate that there is a negative and statistically significant relationship between renewable energy consumption (Dif_CER) and CO2 emissions per capita (Dif_LnCO2), that is, a one percentage point increase in renewable energy consumption as a percentage of total final energy consumption is related to an average decrease of 0.018 units in per capita CO2 emissions. On the other hand, unlike the first model, GDP growth is not a significant variable at 5% significance, but its relationship is positive, in line with expectations. However, the model as a whole is statistically significant, as shown by the F statistic of 9.600 and its corresponding p-value (Prob > F) of 0.001. Likewise, the model corrected for heteroskedasticity presents a good fit, with an R-squared of 0.6588, therefore, the independent variables explain approximately 65.88% of the variability of CO emissions$_2$ per capita, denoting that Peru has a challenge to reconcile economic growth with environmental sustainability.

Table 5
Results of the econometric model

Dif_LnCO2	Coefficient
Dif_CER	-0.018** (0.007)
CPBI	0.005 (0.003)
Constant	-0.014 (0.013)
R-square	0.659
F(2,27)	9.600
Prob>F	0.001
Number of observations	30

Note. Own elaboration. ** denotes significance at 5%. Standard errors are presented in parentheses.

4. Discussion

The upward evolution of CO2 emissions per capita in Peru, as shown in Figure 1, reflects a progressive increase driven mainly by industrial growth, fossil fuel consumption, and changes in consumption and production patterns. However, the most significant decline recorded in 2020 is directly related to the measures to contain the COVID-19 pandemic and its impacts on economic activity. Fig. 2 reveals a gradual decline in renewable energy consumption as a percentage of total final energy consumption in Peru over time, attributed in part to economic growth and increased reliance on fossil fuels to meet energy demand. This pattern suggests a challenge to move towards a more sustainable energy matrix in the country. The descriptive statistics presented in Table 2 offer a detailed view of the variables of the econometric model. The moderate variability in CO2 emissions per capita and the consumption of renewable energy is highlighted, as well as the influence of economic growth in both aspects, evidencing the complexity of the factors involved in the environmental and economic dynamics of the country. The unit root tests in Table 3 indicate the need to differentiate the series to achieve stationarity, which highlights the importance of considering temporality in the analysis of these variables. This finding underscores the dynamic nature of the data and the relevance of appropriate methodologies for data analysis. Table 4 evaluates the assumptions of the econometric model. It is observed that there is no severe multicollinearity between the independent variables, which guarantees the reliability of the estimates. Although the residuals appear to be distributed in a normal manner, the presence of heteroskedasticity suggests the need to address non-constant variability in errors to improve model accuracy. Fortunately, no autocorrelation is detected in the residuals, which ensures consistency of the estimates of the model parameters. The results of the econometric model presented in Table 5 suggest that an increase in renewable energy consumption is associated with a significant decrease in CO2 emissions per capita, although economic growth does not turn out to be a significant variable at conventional levels of significance. These findings underscore the need for policies that promote the transition to cleaner and more efficient energy sources, while seeking a balance between economic growth and environmental sustainability in Peru.

5. Conclusion

The upward trend in CO2 emissions per capita in Peru underscores the influence of industrial growth and changes in consumption patterns on the increase in emissions, although the decline in 2020 due to the pandemic highlights the importance of policies for environmental mitigation. The gradual decrease in renewable energy consumption, as a percentage of total final energy consumption, reveals a challenge to move towards a more sustainable energy matrix in the country, highlighting the need to promote policies that promote the use of renewable energy sources. The descriptive statistics presented provide a detailed understanding of the variables of the econometric model, highlighting the variability in CO2 emissions per capita and renewable energy consumption, as well as their relationship with economic growth in the country. Unit root tests indicate the importance of differentiating the series to achieve stationarity, which underscores the need to consider temporality in the analysis of environmental and economic variables. Evaluation of the econometric model assumptions reveals that while the model meets several key assumptions, such as the absence of multicollinearity and autocorrelation, the presence of heteroskedasticity suggests the need to apply robust methods to improve the accuracy of the model and ensure its validity. Overall, the analysis of renewable energy consumption and its impact on CO2 emissions in Peru during the period 1990-2020 suggests a significant inverse relationship between both factors. Although a gradual decrease in renewable energy consumption as a percentage of total final energy consumption is observed, this study highlights the importance of promoting policies that promote the use of renewable energy sources as an effective strategy to mitigate CO2 emissions in the country.

References

Ali, U., Guo, Q., Kartal, M. T., Nurgazina, Z., Khan, Z. A., & Sharif, A. (2022). The impact of renewable and non-renewable energy consumption on carbon emission intensity in China: Fresh evidence from novel dynamic ARDL simulations. *Journal of Environmental Management*, *320*, 115782. https://doi.org/10.1016/j.jenvman.2022.115782

Arias, M. E., Farinosi, F., Lee, E., Livino, A., Briscoe, J., & Moorcroft, P. R. (2020). Impacts of climate change and deforestation on hydropower planning in the Brazilian Amazon. *Nature Sustainability*, *3*(6), 430-436. https://doi.org/10.1038/s41893-020-0492-y

Arredondo, J., Ramos, M., Arredondo, J., & Ramos, M. (2020). Auctions in photovoltaic solar power plants and grid parity in Peru. *Tecnia*, *30*(2), 27-32. https://doi.org/10.21754/tecnia.v30i2.567

Bertassoli, D. J., Sawakuchi, H. O., De araújo, K. R., & De camargo, M. G. (2021). *How green can the Amazon's hydropower be? Net carbon emission from the largest hydroelectric plant in the Amazon*. *7*(26). https://www.science.org/doi/full/10.1126/sciadv.abe1470

Cubillos, A., & Estenssoro, F. (Eds.). (2021). *Energy and the environment: A difficult equation for Latin America; the challenges of growth and development in the context of climate change* (1st ed.). Inst. Equality Study Center.

Fareed, Z., & Pata, U. K. (2022). Renewable, non-renewable energy consumption and income in top ten renewable energy-consuming countries: Advanced Fourier based panel data approaches. *Renewable Energy*, *194*, 805-821. https://doi.org/10.1016/j.renene.2022.05.156

Hernández, J. (2021). Effect of renewable energy consumption on greenhouse gas emissions in low- and high-income countries. *Acta universitaria*, *31*. https://doi.org/10.15174/au.2021.3030

Huang, M.-T., & Zhai, P.-M. (2021). Achieving Paris Agreement temperature goals requires carbon neutrality by middle century with far-reaching transitions in the whole society. *Advances in Climate Change Research*, *12*(2), 281-286. https://doi.org/10.1016/j.accre.2021.03.004

Jazeera, A. (2020). *Brazil's Carbon Emissions Increased in 2019 with Amazon Deforestation | News about the climate crisis*. https://www.aljazeera.com/news/2020/11/7/brazils-carbon-emissions-rose-in-2019-with-amazon-deforestation

Juárez, G. (2023). *Climate Change and Livestock Production | International Journal of Life Science and Agriculture Research*. https://ijlsar.org/index.php/ijlsar/article/view/167

Lin, B., & Xu, B. (2020). How does the abundance of fossil energy affect China's economic growth and CO2 emissions? *Science of The Total Environment*, *719*, 137503. https://doi.org/10.1016/j.scitotenv.2020.137503

Lizárraga, D. (2022). *PERUVIAN JOURNAL OF ENERGY. 10*(1), 27.

Lozano, V. (2022). *Renewable energies: Necessary change with a vision of the future to ensure sustainability*. El Peruano. https://elperuano.pe/noticia/198353-energias-renovables-cambio-necesario-con-vision-de-futuro-para-asegurar-sostenibilidad

Meinshausen, M., Lewis, J., McGlade, C., Gütschow, J., Nicholls, Z., Burdon, R., Cozzi, L., & Hackmann, B. (2022). Realization of Paris Agreement pledges may limit warming just below 2 °C. *Nature*, *604*(7905), 304-309. https://doi.org/10.1038/s41586-022-04553-z

Murshed, M., Rashid, S., Ulucak, R., Dagar, V., Rehman, A., Alvarado, R., & Nathaniel, S. P. (2022). Mitigating energy production-based carbon dioxide emissions in Argentina: The roles of renewable energy and economic globalization. *Environmental Science and Pollution Research*, *29*(12), 16939-16958. https://doi.org/10.1007/s11356-021-16867-y

Saidi, K., & Omri, A. (2020). The impact of renewable energy on carbon emissions and economic growth in 15 major renewable energy-consuming countries. *Environmental Research*, *186*, 109567. https://doi.org/10.1016/j.envres.2020.109567

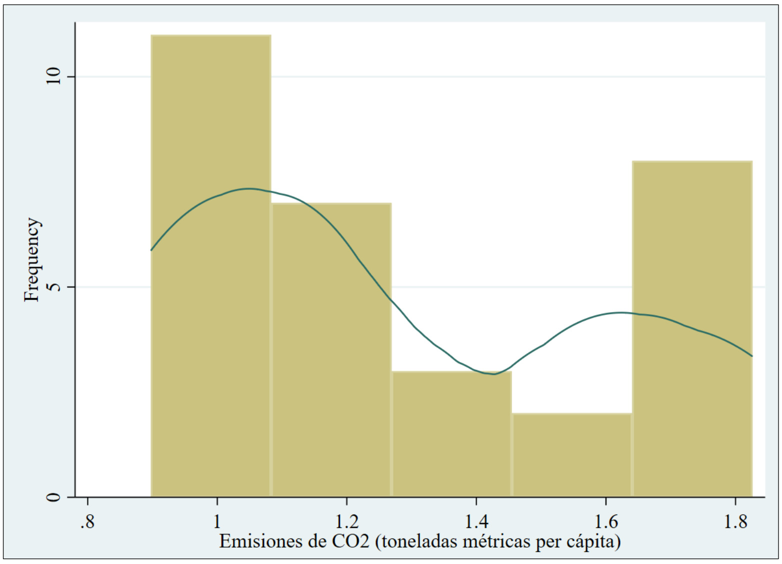
Shahbaz, M., Raghutla, C., Chittedi, K. R., Jiao, Z., & Vo, X. V. (2020). The effect of renewable energy consumption on economic growth: Evidence from the renewable energy country attractive index. *Energy*, *207*, 118162. https://doi.org/10.1016/j.energy.2020.118162

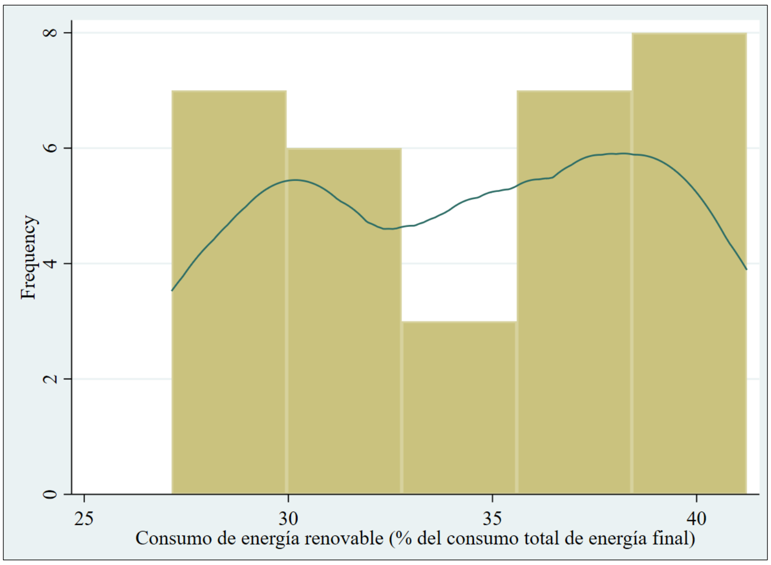
Shen, M., Huang, W., Chen, M., Song, B., Zeng, G., & Zhang, Y. (2020). (Micro)plastic crisis: Un-ignorable contribution to global greenhouse gas emissions and climate change. *Journal of Cleaner Production*, *254*, 120138. https://doi.org/10.1016/j.jclepro.2020.120138

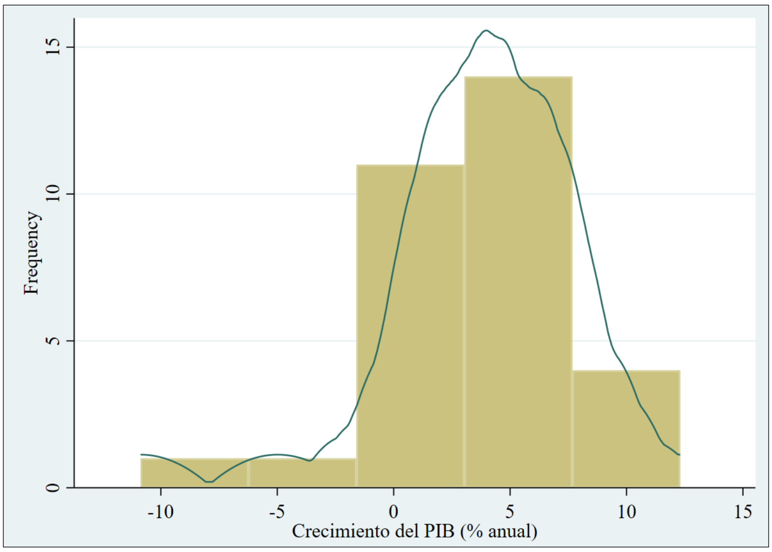
Vallarta, S. I., Galindo, A. B., Cespi, R., & Bustamante, R. (2023). Analysis of GHG Emission from Cargo Vehicles in Megacities: The Case of the Metropolitan Zone of the Valley of Mexico. *Energies*, *16*(13), Article 13. https://doi.org/10.3390/en16134992

Appendix

Appendix 1. Distribution of study variables







Appendix 2. First Estimated Model

Dif_LnCO2	Coefficient
Dif_CER	-0.018** (0.004)
CPBI	0.005** (0.002)
Constant	-0.014 (0.012)
R-square	0.659
R-squared adjusted	0.634
F(2,27)	26.070
Prob>F	0.000
Number of observations	30

Note. Own elaboration. ** denotes significance at 5%. Standard errors are presented in parentheses.