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Incidence of Energy Consumption, Mining Sector and Economic Growth on CO_2 Emission Levels: Evidence from Peru

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ABSTRACT

Environmental pollution and its harmful effects have become a growing topic of study in recent years because the exploitation of resources, rationalized by the prevailing desire for economic growth, is going to directly affect the sustainability of our existing ecosystem in the coming decades. This is considering that there are productive sectors that have a larger environmental footprint, such as the mining industry. This study focuses on establishing the relationship between the variables of energy consumption, gross domestic product per capita, and mineral rents and their impact on the level of pollution by CO_2 emissions in the period 1971–2019, using the Environmental Kuznets Curve theory. To this end, we used statistical and econometric tools based on the autoregressive distributed lag dynamic model through a time series analysis starting from historical data. We concluded that the variables CEpc, PBIpc, and RM have deleterious effects as a 1% increase in these variables increases the level of environmental pollution by CO_2 emissions by 0.724%, 0.136%, and 0.061%, respectively.

Keywords: Environmental Kuznets Curve, Gross Domestic Product, Dynamic Model, Autoregressive Distributed Lag
JEL Classification: Q43

1. INTRODUCTION

Environmental degradation, global warming, and greenhouse gases (GHGs) are pressing issues that cannot be ignored. All of these have become a growing concern over the years because, if not addressed in time, they will directly affect (deplete and deteriorate) the limited resources of our planet. Is this environmental degradation the result of economic growth or of a particular sector? Are these variables related in any way?

Currently, there are a large number of studies dealing with the impact of economic growth on the environment. Among these, various variables reflect income level, such as gross domestic product (GDP) per capita, Gini coefficient, exports, or waste emissions. Accordingly, several researchers have used a well-understood method to show the short- and long-term relationship between economic growth and environmental degradation, namely the environmental Kuznets curve (EKC). The theory suggests an inverted U-shaped relationship between economic growth and environmental degradation, as environmental degradation behaves the same way as economic growth. However, there is a turning point where this direct relationship changes and environmental degradation begins to decrease as the economy continues to grow.

The research is organized as follows: The introductory part explains the formulation of the problem, which includes the general question and the specific problem to be solved within the paper and its justification, which supports the motivation of the research. The next section develops a frame of reference that provides information about the national and international context while developing a theoretical framework, followed by an econometric analysis to derive key findings for the final discussion, and then to present conclusions and policy recommendations.

2. LITERATURE REVIEW

2.1. Environmental Economics and Economic Growth

Throughout all these years, the EKC has probably been one of the most analyzed topics by several authors in environmental economics. They have aimed to determine the relationship that exists between economic growth and environmental degradation since this topic is very controversial globally (Ahmed and Long, 2012; Iglesias et al., 2013; Zilio, 2012).

The relationship between the environment and economic growth is controversial, where destructive relationships or mutual harmony can coexist. Destruction may occur due to increasing production, and thus consumption, when policies are not adjusted to control resource extraction and polluting emissions. Whereas mutual harmony is when the debate for environmental protection is linked to economic expansion because as economies grow and develop, they are concerned about the state of the environment and its subsequent impact (Gómez et al., 2011).

2.2. The Mining Sector and CO_2 Pollution

Akpalu and Normanyo (2017), who modeled the incidence of mining pollution on the health of the population, translated the health costs into a moral hazard problem and calculated a hedonic price function for an individual represented by the following equation:

$$M = f(h_0, B, z; A) \tag{1}$$

Where
M: Health expenditure of an individual
h_0: The initial state of health of the individual
B: The budget that the individual has for their expenses
z: Externalities caused by mining (pollution)
A: Physical and social characteristics of the individual.

Jyotsna and Tandon (2017) propose a mathematical model to show the impact of pollution caused by mining on forests and wildlife. The optimization model proposed is the following:

$$\frac{dP}{dt} = Q + \lambda M - \alpha_1 FP + \pi_2 \beta_2 WP - \delta_0 P \tag{2}$$

Where
P: Amount of environmental pollution concentration.
Q: Autonomous growth rate of pollution.
M: Volume of mining activities.
F: Amount of forest resources.
W: Population density of wildlife.
λ: Pollution rate caused by mining.
α_1: Depletion rate on forest resources.
π_2 β_2: Interaction coefficient measuring the depletion rate of wildlife and the pollution this causes.
δ_0: Depletion rate of pollutants.

Therefore, equation (2) shows that the increase in pollution is partly due to pollution from mining activities if the impacts on wildlife and forest are not changed, and in the steady state, the magnitude of pollution (P) is expressed based on the following relationship:

$$P = \frac{Q + \lambda \frac{M_0}{\theta_0}}{\alpha_1 F + \delta_0 - \pi_2 \beta_2 W} \tag{3}$$

According to equation (2), in the steady state, the size of pollution is still affected by the aforementioned coefficients. Meanwhile, equation (3) shows that in the steady state equilibrium mining activity is regulated by the government through the control rate θ_0, which reduces the rate of mining extraction (M_0). Therefore, this equation corroborates the main impact of pollution to be due to mining.

2.3. EKC

The EKC suggests that indicators of environmental degradation first increase and then decrease as per capita income increases (Stern, 2004). Over the past two decades, the relationship between environmental pollution and real income has been extensively studied in the literature (Sun et al., 2019). The Kuznets inverted U-shaped pattern develops the relationship shown between environmental degradation and economic growth. As GDP per capita increases, pollution also increases and starts to decrease up to a certain level of income (Figure 1). Therefore, economic growth is an important factor in improving environmental quality. This relationship is based on the deterministic concept of income. An increase in income automatically improves environmental quality in the long run.

Similarly, Kuznets (1955) argues that the model that best represents the relationship between environmental deterioration and economic growth is the following:

$$Da = f(PIBp) \tag{4}$$

where *Da* refers to environmental deterioration and *PIBp* refers to per capita income.

$$\begin{aligned} lnE_t &= a_0 + a_1 lnY + a_2 (lnY)^2 + a_3 (lnY)^3 \\ &+ a_4 lnEN_t + a_5 lnX_t + a_6 lnP_t + \varepsilon_t \end{aligned} \tag{5}$$

After developing the relationship between carbon emissions, economic activities such as growth, energy consumption, and mineral rents, we have concluded that there is a relationship between these determinants and emissions. These various studies have been conducted in various countries, with mixed results due to differences in each country's economic and political characteristics.

Thus, according to the model of Ahmed and Long (2012), based on the EKC hypothesis, which formed a linear quadratic function that creates a relationship between carbon dioxide emissions, energy consumption, economic growth, and other variables; this research is supported by this econometric specification model:

where E represents the CO_2 emission per capita, Y is the real income per capita, EN is the energy consumption per capita (metric tons), and Et is a standard error term.

After defining the proposed model, we will estimate the optimal model for the research using the autoregressive distributed lag (ARDL) Model.

2.4. Empirical Studies

There are currently many studies aimed at assessing the impact of economic growth on the environment. These include various variables that indicate income level (GDP per capita, Gini coefficient, exports, energy consumption, or waste emissions). For example, Mosikari and Eita (2020) studied the non-linear impact of urban population, energy consumption, and economic growth on carbon emissions in African economies. They concluded that if energy consumption increases by 1%, carbon emissions increase by 0.213%. The opposite is true for the urban population as, if it increases by 1%, carbon emissions decrease by 0.484%, demonstrating the existence of the EKC. In another recent study, Mourad et al. (2021) empirically evaluated the impact of mining, energy consumption, and economic growth on sustainable development in Saudi Arabia. Their findings highlight the mining sector's importance in improving economic and social sustainability in both the short and long terms. However, there is no evidence of negative environmental impacts from mining. In the same year, Zmami et al. (2021) demonstrated the impact of mining on environmental sustainability in Saudi Arabia. They concluded that mineral rents, GDP per capita, and energy consumption per capita worsen the environment in the long run as a 1% increase in these variables increases CO_2 emissions by 0.71%, 0.289%, and 0.497%, respectively.

In Peru, researchers such as Vergara et al. (2018) demonstrated whether the hypothesis of the EKC with the U-inverted shape exists in the countries that make up the "Pacific Alliance." They found that out of the four countries, Mexico showed greater compliance with the hypothesis of the EKC according to the data analyzed in the period studied. Mougenot et al. (2022) analyzed the Peruvian commitment to climate change through the impact of per capita income on environmental pollution. They concluded that the inverted U-shaped pattern of the EKC is not shown because Peru, being a developing country, still has high levels of inequality in income distribution. Thus, this delays reaching the turning point that would lead to lower pollution levels as the level of per capita income increases, found in the initial part of the EKC (monotonically increasing shape).

3. MATERIALS AND METHODS

3.1. Materials

This study considered time series data, which expose a quantitative and continuous perspective, applying an annual frequency. All the data were extracted from secondary sources of the World Bank and consisted of an annual sample of 49 observations, considering the period from 1971 to 2019. The four variables used in this study are the following pollution levels measured by CO_2 emissions (LCO_2) (metric tons per capita), GDP per capita (LPBI_pc) (current US$), electricity consumption per capita (LCE) (kWh per capita), and mineral rents (LRM) (% of GDP). All tests and analyses were conducted using E-Views software, version 12.

3.2. Empirical Analysis

The research work is based on a multiple linear regression (MLR) model, which indicates a relationship between the exogenous variables and the endogenous variable. We analyzed the dispersion and carried out the descriptive statistical analysis of the central tendencies given for each series and individually. Then we proceeded with the assumptions of the optimal model and its subsequent compliance. Following Gujarati (2010), to estimate the multiple regression model and the Jarque-Bera test for normality, we performed an analysis to observe the distribution of the series and whether they followed a normal distribution. Because of the theoretical model used, and to reduce the variance, they were transformed into natural logarithms.

We then applied the augmented Dickey and Fuller (ADF) test (1979) and the Phillips and Perron test (1988) to assess stationarity and the Granger test (1969) to estimate causality. For these tests, the 5% significance level was considered.

We then estimated the model based on the proposal of Pesaran and Shin (1995) and Pesaran et al. (2001). This time series method allows us to determine the elasticity or variation of the variables in both the short and long terms. Furthermore, this is a suitable model to treat the exogenous regressor variables; whether they are integrated of order one (I [1]), of order zero (I [0]), or if they are mutually integrated.

Then, the ARDL model is defined as

$$Y_t = \alpha_0 + \sum_{ij=1}^{p} \lambda_j Y_{t-j} + \sum_{j=0}^{q} \beta_i X_{t-i} + \varepsilon_t \qquad (6)$$

Thus, this research work is based on the following model, which indicates a relationship between the exogenous variables and the endogenous variable.

$$LCO2_t = \beta_0 + \beta_1 LPIBpc_t + \beta_2 LCEpc_t + \beta_3 LRM_t \ \varepsilon_t \qquad (7)$$

The estimated ARDL model must satisfy the assumptions of the MLR model (Larios-Meoño et al., 2016). Subsequently, we will apply the Glejser test for heteroscedasticity and the Breusch-Pagan-Godfrey test for heteroscedasticity to determine whether the errors are heteroscedastic or homoscedastic. We also perform the ARCH test to check if the series have conditional volatility or autoregressive conditional heteroskedasticity, the Breusch-Godfrey test to check whether the errors are autocorrelated, and the Jarque-Bera test for normality to check if the random variables (errors) follow a normal distribution or not. Furthermore, the Ramsey RESET test was applied to estimate whether the model is linear in parameters, i.e., whether it is correctly specified. Finally, the CUSUM and CUSUM Q tests were conducted to confirm the stability of the parameters, i.e., whether the study series presents structural changes at any given time during the analysis period.

4. RESULTS

In this section, we interpret and describe the results of the tests. We analyzed the stationarity of the series using the Enders notation and applying the ADF test and the Phillips-Perron

Table 1: Unit root tests, augmented Dickey-Fuller test, and Phillips-Perron test

Variable	Test: Unit root	Augmented Dickey-Fuller test			Philipps-Perron test		
		Intercept	Trend and intercept	None	Intercept	Trend and intercept	None
LCO2	Level	0.9228	0.9286	0.7847	0.8931	0.9036	0.7361
	1st difference	0	0.0002	0	0	0.0002	0
LCE	Level	0.9997	0.9933	0.9999	0.9992	0.9814	1
	1st difference	0	0	0	0	0	0
LPBI_pc	Level	0.9029	0.5838	0.9971	0.9024	0.5501	0.9971
	1st difference	0	0	0.0008	0	0	0
LRM	Level	0.0902	0.208	0.1212	0.0762	0.1918	0.1712
	1st difference	0	0	0	0	0	0

Source: Compiled by the authors

test to detect the unit root of the series based on the proposed model. For this purpose, we used intercept only, intercept and trend, or no trend or intercept. To obtain the degree and order of integration of the series, we eliminated the existence of a unit root of the variables. In addition, we test the assumptions of the estimated errors to verify the validity of the parameters evaluated, namely normality, absence of autocorrelation, and homoskedasticity of the errors.

4.1. Unit Root Test

To check whether the series has a unit root or not, we concluded that the four variables mentioned above (LCO2, LCE, LPBI_PC, and LRM) are non-stationary in the Dickey-Fuller Test, since in the tests with intercept, trend and intercept, and without any of them, their P-values were >5% significance level, as shown in Table 1. Therefore, we analyzed the stationarity of the series using the first differences for each case. This way, the P-value was lower than the 5% significance level; i.e., the null hypothesis indicating the presence of a unit root was rejected. Thus, the series is stationary in the first difference, obtaining the variables DLCO2, DLCE, DLPBI_PC, and DLRM, both for the Dickey-Fuller and Phillips-Perron tests.

4.2. Granger Causality Test

Next, we performed the Granger causality test, analyzing only up to lag eleven. Table 2 shows that DLCO2t Granger-causes DLRMt at lag ten since the P-value at this lag is 0.014, which is <5% significance level. Therefore, the null hypothesis of no causality is rejected. The P-values, up to lag eleven, in the other relationships are not <5% significance level. Therefore, the null hypothesis of no Granger causality is accepted. However, in the case of DLCO2t and DLCE, there is causality at the 10% significance level because the P-value of the test is 0.069, which is <10% significance level. Therefore, the null hypothesis of no Granger causality between the above variables is not accepted.

4.3. Estimation of the ARDL Dynamic Model

After analyzing the study variables, we estimated the ARDL Model (Table 3). We incorporated the dummy variable, according to the residual trend of the model, used to stabilize the structural breaks observed in 1980, 1982, 1997, and 2001.

4.4. Final Tests to Contrast the Assumptions of the ARDL Model

Table 4 shows the results of the tests used to contrast model assumptions. The Breusch-Godfrey test for autocorrelation, used to evaluate the correlation, indicates no serial correlation in the model since the P-value for the first and second lag is 0.7720 and 0.8909, respectively, which is >5%. Furthermore, homoskedasticity of the model residuals is indicated since the P-values of the ARCH test with the first and second lag, the Breusch-Pagan-Godfrey test, and the Glejser test are >5% significance. Moreover, the residuals have a normal probability distribution at 5%, as shown by the Jarque-Bera test for normality.

Table 2: Granger Causality Test

Causality	Criterion	Lag	P-value
$\Delta DLCE \rightarrow \Delta DLCO2$	AIC	1	0.7731
$\Delta DLCO2 \rightarrow \Delta DLCE$	HIC	1	0.0697
$\Delta DLRM \rightarrow \Delta DLCO2$	AIC	1	0.3554
$\Delta DLCO2 \rightarrow \Delta DLRM$	HIC	10	0.0144
$\Delta DLPBIPC \rightarrow \Delta DLCO2$	AIC	1	0.8735
$\Delta DLCO2 \rightarrow \Delta DLPBI\_PC$	AIC	1	0.2542

Source: Compiled by the authors

Table 3: ARDL dynamic model

Dependent variable: DLCO2	
Variable	Coefficient
DLCO2 (−1)	−0.090584
DLCO2 (−2)	−0.458017
DLCO2 (−3)	−0.244822
DLCO2 (−4)	−0.249196
DLCE	0.723862
DLCE (−1)	0.462065
DLCE (−2)	0.474953
DLCE (−3)	−0.948106
DLCE (−4)	−0.390256
DLPBI_PC	0.136281
DLPBI_PC (−1)	0.621441
DLPBI_PC (−2)	0.063268
DLPBI_PC (−3)	0.138745
DLPBI_PC (−4)	−0.577699
DLRM	0.061330
DLRM (−1)	−0.046432
DLRM (−2)	0.046858
DLRM (−3)	−0.059946
DLRM (−4)	0.037781
DUMMY_1980	0.106645
DUMMY_1982	−0.049497
DUMMY_1997	0.133867
DUMMY_2001	−0.094897
C	−0.040065
Adjusted R^2	0.706799
Probability (F-statistic)	0.029962

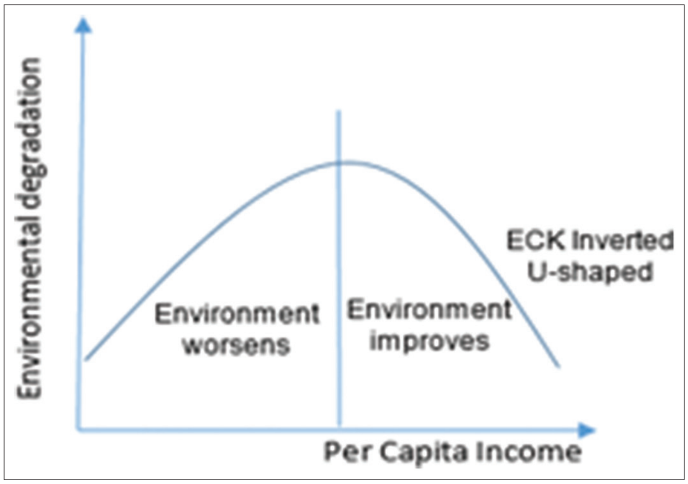
Source: Compiled by the authors, with E-Views 12 software. ARDL: Autoregressive Distributed Lag Model

Table 4: Test to contrast the assumptions

Test	Statistic	P
Heteroskedasticity (ARCH 1)	Chi-square test	0.6719
Heteroskedasticity (ARCH 2)	Chi-square test	0.4659
Heteroskedasticity (Breusch-Pagan-Godfrey Test)	Chi-square test	0.4300
Heteroskedasticity (Glejser)	Chi-square test	0.3305
Breusch-Godfrey Test for Serial Correlation LM (1)	Chi-square test	0.7720
Breusch-Godfrey Test for Serial Correlation LM (2)	Chi-square test	0.8909
Normality	Jarque-Bera Test	0.9871
Linearity (Ramsey)	T-statistic	0.8675

Source: Compiled by the authors

Figure 1: Kuznets curve



Source: Compiled by the authors based on Roca and Padilla. (2003)

Finally, we found that the model is linear in parameters, i.e., the model is correctly specified since the P-value is 0.8675, which is >5% significance.

5. DISCUSSION AND CONCLUSION

This study analyzes the impact of energy consumption, mineral rents, and economic growth on environmental pollution levels in Peru for the period 1971-2019, given that environmental degradation, global warming, and GHGs are pressing, critical problems, and this increases the concern for environmental welfare at the national level.

The results show that economic growth in terms of GDP per capita, electricity consumption, and mineral rents hurt the level of environmental pollution for the period 1971-2019. However, the results also indicate that the inverted U-shaped pattern of the EKC for Peru has not been demonstrated.

In conclusion, this research summarizes the main arguments in favor of the environmental impact determinants (Georgescu-Roegen, 1971) because economic growth drives the reduction of environmental quality, and the increase in growth and pollution emissions tends to have an increasingly monotonic relationship. Thus, increasing resource extraction, waste hoarding, and pollutant concentration will reduce the capacity of the blogosphere and thus degrade environmental quality. Similarly, Beckerman (1992) argues that as economic activity increases, environmental quality increases, and pollutant emissions and growth have a monotonically decreasing relationship.

Moreover, regarding the energy consumption variable, the aforementioned authors argue that energy consumption in Latin America and the Caribbean has shown constant growth. This, together with the constant fluctuations in energy prices, bears out that these variables are directly related to macroeconomic indicators, such as GHG emissions, and specifically CO_2, where this part of the region contributes 10% of the global percentage.

In respect of mining pollution, we detailed the theoretical model of Akpalu and Normanyo (2017), which simulates the impact of mining pollution on population health, considering the transformation of health costs into a moral hazard problem and hedonic price. In addition, Martinez-Alier (2004) argues that mining causes an imbalance in environmental justice because mining communities are affected by the negative externalities that result from their mineral extraction activities. Thus, depending on the valuation of their environment, they will demand compensation for these negative effects, which becomes an input for future social conflicts. Therefore, further ecological and political economy studies are needed.

Finally, given that Peru has focused significantly in recent years on improving environmental quality and mitigating the negative externalities caused by sectors such as mining and hydrocarbons, policies and regulations for efficient energy use should be promoted while forcing economic agents to switch to renewable and eco-efficient energy use. In addition, with regard to energy consumption, progressive targets should be set for the contribution of non-conventional renewable energies toward the augmentation of energy supply from the primary energy sources used to generate electricity to promote the consumption of cleaner energy and thus to mitigate environmental impacts.

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