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The Environmental Kuznets Curve Hypothesis in Industrialized Countries: A Second Generation Econometric Approach

Lotfi Mekhzoumi[1]*, Nadjoua Harnane[2], Abdellah Ayachi[1], Okba Abdellaoui[1]

[1]University of El-Oued, El-Oued, Algeria, [2]University of Khenchela, Khenchela, Algeria. *Email: lotfimekhzoumi39@gmail.com

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ABSTRACT

This study contributes to the analysis of the Environmental Kuznets hypothesis (EKC) for 31 industrialized countries during 1980–2019 using long-term static and dynamic panel data methods. According to Pesaran's CD tests, the CSD issue is present in all variables. The EKC model had a long-run relationship, according to the results of the second-generation Pesaran CIPS unit roots and Westerlund tests. The estimation results of the static model (MG) and dynamic models (CS-DL and CS-ARDL) reached the same conclusion as the reliability of the EKC hypothesis, implying that environmental pollution and economic growth are linked in an inverted N-letter shape.

Keywords: EKC, MG, CCEMG, AMG, CS-DL, CS-ARDL
JEL Classification: C23, O13, O44, Q50.

1. INTRODUCTION

Economic development creates much-needed wealth for society, but at the expense of the environment. Exports and imports have a significant impact on country growth, with developed countries assisting in expanding economies and increasing trade openness. Concerns about the deterioration of global environmental quality have grown in recent years, as evidenced by the rising trend of carbon dioxide (CO_2) (one of the primary components of the greenhouse effect) in the atmosphere. Numerous studies on total emissions causal factors, such as energy consumption, wealth creation, and rapid urbanization, have been conducted to promote sustainable development strategies. Academics and policymakers are still debating the link between these processes and environmental deterioration. Carbon dioxide emissions are skyrocketing due to increased globalization and financial progress, and increased energy demand for economic activities. As a result, examining the quality of the environment in terms of financial development, globalization, and urbanization necessitates additional attention and research Destek and Sinha (2020).

It has become increasingly important in recent years to understand environmental deterioration and its causes. Given the current debates about global warming as an environmental problem, economic policymakers pay closer attention to the relationship between economic development and the environment. Several empirical studies show that the environment initially exacerbates economic development to a certain threshold level but improves. The environmental Kuznets hypothesis is the scientific term for this (EKC). According to the reviewed studies on energy and the environment, EKC is a viable theory. When studying the relationship between environmental deterioration and economic growth, Grossman and Krueger (1991) discovered parallels with the results of Kuznets (1955), and they coined the term "environmental Kuznets curve hypothesis." Numerous studies were conducted in various settings and for various ecological foreign substances, supporting or refuting this theory Sinha et al. (2018).

The main purpose of this study is to assess the impact of globalisation, energy consumption, and income (GDP per capita, its square, and its cubic) on CO_2 emissions in selected industrialised countries by applying EKC methodology. The EKC hypothesis evaluates the dynamic relationships between energy consumption, income level, quadratic and cubic forms, and CO_2 emissions in industrialised countries.

The rest of this paper is organised as follows: The "Theoretical and empirical framework" section emphasises the EKC hypothesis as well as related studies that serve as the foundation for subsequent analysis; the section "Data and Methodology" describes the variables, estimation strategy, and econometric methodology used in this research; "Results" explain the findings in terms of descriptive statistics, statistical tests, and estimation results; finally, "Conclusion and Discussion" begin with arguments and further information, to reach an essential summary including policy implications derived from the empirical results.

2. THEORETICAL AND EMPIRICAL FRAMEWORK

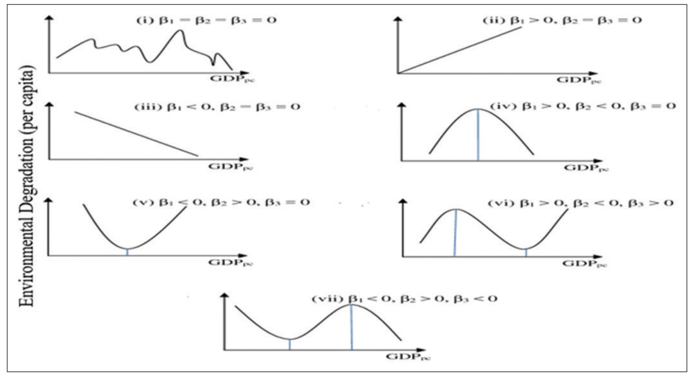
Economic development has long been considered a "synonym" for environmental pollution. Researchers have found that environmental conservation and economic development could be correlated. Sustainability may be defined as a method to improve the relationship between the ecosystem(s) and economic development Almeida et al. (2017). The influence of economic growth on environments has been widely researched, employing statistical tools using a variety of variables and methods. However, the findings remain a complicated black box. Several findings have demonstrated that an economic structure can place the ecosystem(s) beneath stress, as a result, harm its long-term viability Machado et al. (2001).

Researchers are using a variety of metrics to assess the effect of economic expansion on environmental deterioration, while policies are concerned with how to encourage sustainable development that does not harm the environment. Therefore, the EKC is a commonly used hypothesis in environmental economics literature for quantitative analysis of economic growth and environmental deterioration Azam and Khan (2016). Most theorists believe that there is an inverse relationship between pollution problems and economic development, which is generally defined in the following form Grossman and Krueger (1991):

$$EDpc_{i,t} = \beta_0 + \beta_1 GDPpc_{i,t} + \beta_2 GDPpc2_{i,t} + \beta_3 GDPpc3_{i,t} + \beta_4 Z_{i,t} + \varepsilon_{i,t} \quad (1)$$

The idea of EKC is used in economics to examine the link between environmental quality and growth. EDpc stands for per capita environmental pollution, GDPpc, GDPpc2, and GDPpc3 refer to per capita income, square, and cubic, respectively. Z includes other variables that may impact ecological balance. Assuming the income has no effect, β0 calculates the amount of ecological stress, β1 through β4 are the coefficients of the independent variables. EKC will assume various shapes based on the sign of (β1–β3). When per capita income is plotted along the horizontal axis and the per capita environmental degradation index is plotted on the vertical axis for a particular country, we generally get a relationship that takes the forms shown in Figure 1 the following forms Uchiyama (2016).

Figure 1: EKC forms



Source: Uchiyama (2016)

The EKC will take different forms based on the income coefficient sign Álvarez-Herranz and Balsalobre Lorente (2016):

- (i) If β1 = β2 = β3 = 0, there will be either a flat pattern or no relationship between environmental degradation and income.
- (ii) If β1 > 0 and β2 = β3 = 0, there will be a monotonic increasing relationship such that environmental degradation increases along with economic growth.
- (iii) If β1 < 0 and β2 = β3 = 0, there will be a monotonic decreasing relationship between environmental deterioration and income.
- (iv) If β1 > 0 and β2 < 0 and β3 = 0, we will see the classical inverted U-shaped EKC.
- (v) If β1 < 0 and β2 > 0 and β3 = 0, there will be a U-shaped relationship between environmental degradation and income.
- (vi) If β1 > 0 and β2 < 0 and β3 > 0, there will be a cubic polynomial or N-shaped relationship between environmental deterioration and income.
- (vii) If β1 < 0 and β2 > 0 and β3 < 0, there will be an inverted, or opposite, N-shaped relationship between environmental degradation and economic growth.

We have to evaluate the statistical significance of each regression coefficient to verify the EKC hypothesis. First, β2 is the component that dictates the curve's form. β1 is used to calculate the EKC turning point income for a quadratic model by calculating the fraction using β2 as follows:

$$GDPpc_{TP} = e^{-\frac{\beta_1}{2\beta_2}} \quad (2)$$

For a cubic model, the EKC peak and trough turning point incomes are derived as follows:

$$GDPpc_{TP} = e^{\left(\frac{-\beta_2 \pm \sqrt{\beta_2^2 - 3\beta_1\beta_3}}{3\beta_3}\right)} \quad (3)$$

In empirical studies, the curve hypothesis (EKC) is often tested, which gives the most basic foundation for relating energy usage (and its negative consequences) to economic development. Based on the EKC hypothesis, environmental deterioration, pollution, and resource exploitation are related to economic growth. The early phases of economic growth are characterized by increasing pollution, intensive exploitation of natural resources, and increased production and adoption of specific industrial practices. When GDP rises at a high rate, environmental deterioration begins to diminish, potentially owing to increased public knowledge and concern about pollution, other than advancements focusing more on the concept of green economic Maneejuk et al. (2020).

The EKC hypothesis has become an essential issue among researchers and policymakers who study policies related to the environment. Grossman and Krueger (1991) investigated the environmental impact of NAFTA, using nearby quantities of Sulphur Dioxide and Suspended Particulate Matter as indicators of environmental quality. They discovered a U-shaped link between income and pollutants, lending credence to the EKC theory. Following this study, more research was conducted to confirm the EKC hypothesis using different econometric approaches.

There are two types of EKC investigations, the presence and verification of the hypothesis or the absence and disconfirmation of the hypothesis. The inverted U-shaped curve was the starting point for most of these researches. However, some studies have claimed that the EKC relationship is founded on poor findings. A time-series model was used by (Jebli, 2015) to test the EKC in Tunisia, although their experimental results indicated no indication of an EKC relationship. Moreover, (Bolük and Mert, 2014; Zoundi, 2017) employed panel data analysis, and the results revealed no incidence of EKC in 16 European countries and 25 African countries.

Some studies have sought to investigate an N-shaped EKC by including a cubic per capita GDP as an extra variable, as proposed by Grossman and Krueger (1995). In 51 economies, Gangadharan and Valenzuela (2001) proposed an N-shaped correlation between CO_2 emissions and GNP. Through data for 89 countries, Lee et al. (2009) discovered an N-shaped link between CO_2 emissions and income. Many more works have also confirmed the existence of N-shaped EKC curves.

Currently, the EKC hypothesis is analyzed using three distinct experimental requirements Bolük and Mert (2014): Logarithmic linear, square, or cubic. Explanatory variables like time, geographical features, and technological aspects can be used to extend these models.

$$EDpc_{i,t} = \beta_0 + \beta_1 GDPpc_{i,t} + \beta_2 GDPpc2_{i,t} + \beta_3 GDPpc3_{i,t} + \beta_4 Z_{i,t} + \varepsilon_{i,t} \quad (4)$$

CO_2 refers to carbon dioxide emissions, GDP presents the gross domestic product (GDP), and EC presents energy consumption.

3. DATA AND METHODOLOGY

To examine and assess the EKC validity, annual data covering 1980 to 2019 for 31 industrialized countries.

3.1. Data

An econometric model is constructed to analyse the present research. The dependent variable is the per capita CO_2 emissions, while the explanatory variables are the per capita GDP, its square and cube (GDPpc, GDPpc2, GDPpc3), per capita energy consumption, globalisation index (GI), and population density (POPd) (Table 1).

The sources of data used in the present study are the most significant sources of data. They offer data on many different Global Indexes. They are considered the official sources of data worldwide since many are official websites for international and governmental institutions.

3.2. Estimation Strategy

To verify the hypotheses, the following equation was applied:

$$CO_2 pc = f\left(GDPpc, GDPpc2, GDPpc3, ECpc, GI, POPd\right) \quad (5)$$

A natural logarithmic transformation is performed on all the data. Contrary to basic linear modeling, the log-linear provides more efficient and consistent results. The following regression equation presents the log-linear model:

$$LCO_2 pc_{i,t} = \beta_0 + \beta_1 LGDPpc_{i,t} + \beta_2 LGDPpc2_{i,t} + \beta_3 LGDPpc3_{i,t} + \beta_4 LECpc_{i,t} + \beta_5 LGI_{i,t} + \beta_6 LPOPd_{i,t} + \varepsilon_{i,t} \quad (6)$$

The EKC hypothesis is empirically tested in this study using panel data from 31 industrialized countries between 1980 and 2019 (Table 2). The theoretical considerations, dataset structure, and potential econometric difficulties that must be addressed in this study influence the chosen empirical strategy.

Since the 1980s, there has been extensive research into using econometrics to examine or evaluate the relevance of EKC. Throughout the last few decades, econometric literature has presented a wide range of estimating methodologies. A large number of studies have been conducted using a variety of research methodologies. The majority of studies used Panel data to determine whether there was an inverted U-shaped relationship between contamination and economic advancement for various countries. Several researchers used pooled OLS to test the validity of the EKC hypothesis in the 1990s, such as Lau et al. (2019). Later, several EKC investigations applied panel data analysis applied GLS using fixed-effect and random-effects estimates Richmond and Kaufmann (2006).

Table 1: Variables and data source

Variable	Source
Per capita CO_2 emissions	The International Energy Agency
GDP per capita	World Bank, and OECD data files.
Energy consumption per capita (ECpc)	https://ourworldindata.org/energy-production-consumption
Globalization Index	KOF Swiss Economic Institute
Population density	FAO and World Bank population estimates.

Source: Authors' elaboration

Table 2: The descriptive statistics for research variables

	CO2pc	GDPpc	ECpc	GI	POPd
Argentina	3.497	8476.84	18913.17	61.3075	13.35105
Australia	16.00025	43278.83	65270.64	74.4625	2.527369
Austria	7.5245	39835.71	45140.96	82.85	97.70375
Belgium	10.0855	37741.28	64735.91	85.9675	343.1633
Brazil	1.6085	9323.286	12617.75	51.82	20.42023
Canada	15.609	39881.8	109334.8	77.7975	3.372844
China	3.548	2699.266	13195.79	49.3	130.761
Denmark	9.559	52009.01	41675.71	84.12	126.6735
Finland	10.34525	38328.52	63429.93	80.54	16.98244
France	5.74875	36166.13	46541.78	81.12	111.8866
Germany	10.56025	36828.35	49365.38	81.39	231.6469
Hungary	5.71725	11004.89	28682.2	72.515	113.7452
India	0.9215	975.8966	3766.978	46.465	350.7454
Indonesia	1.17725	2435.916	5281.571	53.5425	115.8854
Ireland	8.698	39948.45	37251.32	79.79	57.99745
Italy	6.566	32835.57	32544.93	75.3975	196.7179
Japan	8.55175	40233.97	42712.14	66.4575	342.8914
Korea	8.0135	15417.92	42627.08	63.8475	475.7618
Malaysia	4.66875	7050.639	24363.48	69.3	69.50078
Netherlands	9.86525	42915.73	61521.9	85.4525	467.4196
Norway	7.03	75188.91	104388.4	81.82	12.50722
Portugal	4.2845	19058.89	23553.58	73.515	111.6562
Singapore	8.36475	34242.18	113182	76.9025	5831.088
South Africa	7.139	6567.351	26914.16	54.6525	36.19106
Spain	5.69	26059.61	32100.05	74.8225	84.06226
Sweden	5.7295	44318.02	70336.64	84.5975	21.94124
Switzerland	5.59975	66953.94	46255.29	84.605	184.0507
Thailand	2.32925	3710.648	12267.11	58.175	119.6443
Turkey	2.96825	8913.15	13599.12	60.4175	81.81758
USA	18.27325	42273.86	86684.55	74.705	30.44934
United Kingdom	8.43225	33919.15	41304.4	84.5475	247.7475
Total					
Mean	7.229218	28986.89	44501.89	72.00653	324.2035
Std. Dev	4.303321	20550.14	30482.82	14.57583	1045.197
Min	38	347.1201	1729.04	26	1.912448
Max	20.29	92556.32	174633.5	91.79999	7990.267
Observations	N=1240, n=31, T=40				

Source: Authors' calculation.

In the first phase, we test the stationarity of the data using panel unit root tests. In the EKC literature, the first-generation panel stationarity tests are extensively used. If significant degrees of cross-sectional dependency are ignored, first-generation panel stationarity tests can produce false findings (due to volume distortions). To address this flaw, Pesaran (2007) proposed a second-generation panel unit root test that allows for cross-sectional dependency (Pesaran's CIPS test). The EKC literature prior to 2010 depended on first-generation panel unit root tests based on the assumption of cross-section independence. Cross-sectional dependency is a form of correlation that results from shared shocks that have varied consequences among countries. It also indicates the outcome of regional or national side effects. Some tests are available to detect CSD, as well as a widely used test in the EKC literature is the Pesaran (2004) test; an upgrade to this test is known as Pesaran (2015) test for weak CSD.

Indistinguishable from panel unit root tests, EKC writing before 2010 was established on initial panel co-integration tests that assume cross-sectional dependency. The Pedroni (2004) and Kao (1999) co-integration tests may not be as reliable when the data has a cross-sectional dependency. Westerlund (2007) established an error-corrected co-integration test that is robust even when cross-sectional dependency exists. This is generally known as the second-generation panel co-integration test. The main thought of the test is to check for lack of co-integration by defining whether error correction is present between individual panels or between entire panels.

We estimate the long-run relationship based on three estimators that assume each cross-section has a heterogeneous slope and can account for CSD. The first estimator employed in this work is CCEMG proposed by Pesaran (2006). This estimator adopts a framework of shared factors to take into consideration the CSD in the co-integration. The estimator's primary goal is to produce consistent estimates of coefficients relating to observable variables. CCEMG is robust with both strong and weak elements. A minority of "powerful" factors in addition to limitless 'deficient' factors- Local spillovers can be linked to the latter; however, the first appears systemic shocks Pesaran and Tosetti (2010).

Moreover, as indicated by Kapetanios et al. (2011), these factors may be unstable. The second estimator is the Augmented Mean Group (AMG) created by Eberhardt and Teal (2011) as a proxy for CCEMG, using Monte Carlo simulations for more research and testing by Eberhardt and Bond (2009). Besides CSD, the AMG estimator furthermore allows for the heterogeneous panel slope. The third estimator in this study is the Mean Group estimator (MG), presented by Pesaran and Smith (1995). The MG estimator treats the heterogeneity, which is not considered in the homogeneous panel, models, with fixed and random effects, for example. This approach does not deal with cross-sectional dependence, but we use it to compare with the results of other methods.

The Cross-sectionally augmented distributed lag method (CS-DL), developed by Chudik et al. (2016), is also used to estimate the long-run effects in large heterogeneous dynamic panel data models with cross-sectional dependence errors. This method is known as cross-sectionally augmented autoregressive distributed lag (CS-ARDL). It turns out that, in contrast to the ARDL estimation, the CS-DL is robust to the misspecification of dynamics and the serial correlation of errors. The study also uses the CS-ARDL estimator, developed by Chudik and Pesaran (2015) extending the CCE approach by allowing dynamic panels with heterogeneous coefficients and weakly exogenous regressors. Based on the ARDL specification, the CS-ARDL approach is boosted by cross-section to filter out the effects of common factors that are not observable; this can be used to estimate long-term impacts indirectly. The advantage of CS-ARDL is to consider all essential aspects of the panel (dynamism, heterogeneity, and cross-sectional dependence).

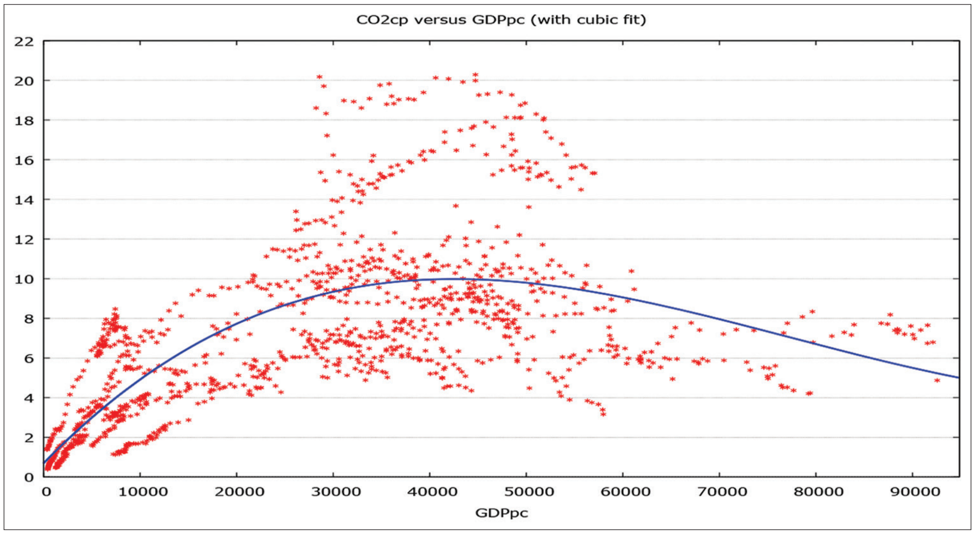
4. RESULTS

4.1. Descriptive Statistics

The following Table 2 describes the variables included in the analysis and summarizes the panel data observations.

The dependent variable mean, CO_2 emissions (CO_2pc), in the 31 countries is equal to 7.229218; it can be observed that this value

Figure 2: CO_2cp versus GDPpc cubic curve



Source: Authors' calculation

ranges between the minimum value (0.38) and the maximum value (20.29) of the CO_2 emissions (CO_2pc) worldwide. Furthermore, the United States pollutes more than other studied countries, while Indonesia pollutes the least.

Figure 2 illustrates a cubic curve fitting for pollution and income in the studied countries.

It can be seen that the cubic curve approaches an inverted U-shaped, although it expands almost horizontally and is not entirely retracted by increasing income.

4.2. Cross-sectional Dependence Tests

Table 3 shows the results of Pesaran M. (2004) and Pesaran M. (2015) CSD tests.

Based on these results, the null hypothesis was rejected, confirming the cross-sectional dependency of all variables.

4.3. Panel Unit Roots and Co-integration Tests

The earlier CSD tests' results require the application of second-generation tests, both unit-roots and co-integration. Table 4 summarizes the results of the second generation of both Pesaran CIPS unit roots and Westerlund co-integration tests.

It can be seen that all variables become stationary after the first difference, except LGI, which is stationary at level, after excluding LPOPd since it is nonstationary neither at the level nor at the first difference. In order to calculate the co-integration, Westerlund (2007) generalized the test procedures by using the bootstrap approach. The results obtained from the Westerlund tests are somewhat uneven. Specifically, the results of Ga, Pa, and Pt indicate the acceptance of the alternative hypothesis at 5%, which confirms that there is co-integration, while the Gt supports co-integration at 10%. Therefore, there is a directory of a long-run relationship between pollution and income, with other explanatory variables across the 31 countries.

Table 3: CSD tests

	Pesaran (2015) test for weak CSD		Pesaran (2004) CSD test	
	CSD	prob-value	CSD	prob-value
LCO2cp	113.743	113.743	22.50	0.000
LGDPpc	136.293	136.293	125.27	0.000
LGDPpc2	136.293	136.293	125.27	0.000
LGDPpc3	136.293	136.293	125.27	0.000
LECpc	136.305	136.305	44.08	0.000
LGI	136.328	136.328	132.72	0.000
LPOPd	136.221	136.221	110.35	0.000

Source: Authors' calculation

4.4. Estimation Results

Since the co-integration results indicate a long-run relationship, we continue to estimate two sets of models**.** The first model includes static long-run models, providing the MG, CCEMG, and AMG estimators, as shown in Table 5.

According to the results in Table 5, only the MG estimator contains statistically significant variables. Both LGDPpc's and LGDPpc3's parameters were significantly negative, while LGDPpc2's parameter was significantly positive. This implies an inverted N relationship between income and pollution. Furthermore, in Monte Carlo simulation, the AMG estimator is efficient and unbiased for various N and T settings. In addition, for robustness, the MG and CCEMG estimators are run concurrently.

The second model refers to dynamic long-run models, including CS-DL, and CS-ARDL estimators, as shown in Table 6.

Table 6 shows that, except for LGI, all variables in both the CS-DL and CS-ARDL models are statistically significant. LGDPpc and LGDPpc3 have a negative impact, whereas LGDPpc2 has a positive and significant impact. These findings suggest that there is an inverted N correlation between pollution and income.

Chudik et al. (2016) have shown that CS-ARDL estimates are robust to endogeneity. They also demonstrated that the CS-DL

Table 4: The second-generation tests Pesaran CIPS and Westerlund

	Pesaran CIPS unit roots tests				Westerlund cointegration tests	
	Level		First difference			
	Constant & trend	Constant	Constant & trend	Constant	Stat.	Robust P value
LCO_2pc	−1.465	−2.545	−5.487***	−5.578***	Gt	0.08
LGDPpc	−1.839	−1.947	−4.059***	−4.195***	Ga	0.045
LGDPpc2	−1.839	−1.947	−4.059***	−4.195***	Pt	0.008
LGDPpc3	−1.839	−1.947	−4.059***	−4.195***	Pa	0.013
LECpc	−1.916	−3.039***	−5.504***	−5.599***		
LGI	−2.639***	−2.685**	−5.524***	−5.676***		
LPOPd	−2.181**	−1.980	−2.134**	−2.321		

Source: Authors' calculation

Table 5: MG, CCEMG, and AMG estimates

	MG	CCEMG	AMG
LGDPpc	−790.7** (279.5)	46.79 (100.1)	63.50 (151.6)
LGDPpc2	74.41** (27.22)	−5.450 (10.76)	−6.548 (14.99)
LGDPpc3	−2.333** (0.889)	0.211 (0.386)	0.229 (0.500)
LECpc	0.927*** (0.0798)	0.783*** (0.0750)	0.652*** (0.0612)
LGI	−0.357** (0.120)	0.143 (0.133)	0.0981 (0.108)

Source: Authors' calculation

Table 6: Estimation results of CS-DL and CS-ARDL

	CS-ARDL		CS-DL		
	Coef.	P>|Z|		Coef.	P>|Z|
Short run			LGDPpc	−923.37	0.027
$L.LCO_2pc$	0.37	0.000	LGDPpc2	85.21	0.03
LGDPpc	−646.02	0.009	LGDPpc3	−2.61	0.034
LGDPpc2	60.12	0.013	LECpc	0.66	0.000
LGDPpc3	−1.87	0.021	LGI	−0.21	0.108
LECpc	0.65	0.000	L.LGDPpc	−0.35	0.000
LGI	−0.02	0.83	$L.LCO_2pc$	0.36	0.000
Long run					
$Lr.LCO_2pc$	−0.63	0.000			
Lr.LGDPpc	1.08	0.000			
Lr.LGDPpc2	−1235.93	0.004			
Lr.LGDPpc3	114.51	0.006			
Lr.LECpc	−3.54	0.009			
Lr.LGI	0.14	0.612			

Source: Authors' calculation

estimators are resistant to residual serial correlation, breaks in error processes, and dynamics misspecification. In terms of bias, both the CS-DL and CS-ARDL estimators perform well. The coefficient signs in the CS-DL and CS-ARDL estimators are identical, confirming the consistency and robustness of the empirical results.

The incomes at the EKC's peak and trough turning points for the cubic model are calculated as follows:

$$GDPpc_{TP} = e^{\left(\frac{-\beta_2 \pm \sqrt{\beta_2^2 - 3\beta_1\beta_3}}{3\beta_3}\right)} = \begin{Bmatrix} GDPpc_{TP-} = 31602.768 \\ GDPpc_{TP+} = 85819.368 \end{Bmatrix} \quad (7)$$

5. CONCLUSION AND DISCUSSION

This study used the cubic shape of the EKC model to examine the effect of per capita income, its squared and cubed, energy consumption, and globalization on the deterioration of the environment expressed in CO_2 across panel data for a sample of 31 industrialized countries from 1980 to 2019. The cubic model was chosen because of its conformity with EKC, demonstrating its appropriateness graphically, statistically, econometrically, and economically. In addition to per capita income, squared and cubed, the study model included energy consumption as an explanatory variable, which plays a significant and influential role in environmental degradation, primarily in industrialized countries. On the other hand, the study used the globalization index, which includes economic, political, and social dimensions, due to its growing importance in explaining global environmental degradation.

The analysis began with CSD tests, which were ignored by most research dealing with the EKC model before and after 2010. The results of Pesaran (2004) and Pesaran (2015) tests showed that the cross-sections were not independent for all variables. This supports the robustness of the econometric approach adopted in this study.

A second-generation panel unit root test (Pesaran CIPS) was used in accordance with the CSD test, which demonstrated the existence of the CSD problem for all variables. After the first difference, the results show that all variables become I(1), except LGI, which is stationary at the level, and the LPOPd, which is nonstationary at both the level and the first difference. This finding is consistent with the findings of numerous empirical studies in this area. Second-generation co-integration tests Westerlund (2007) are also used, with robust error correction despite the presence of CSD. As a result, among the 31 countries, there is a long-run relationship between income and pollution and other explanatory variables. These findings are consistent with previous studies, which applied the EKC approach, such as Khalid et al. (2020).

After pre-tests, from the CSD to Pesaran CIPS, and then the Westerlund (2007) second-generation co-integration, the long-run coefficients were estimated through two stages: The first is by using three long-run static models (MG, CCEMG, and AMG). The results showed that the MG estimator is the best because all the model variables were significant. The second stage is by using two long-run dynamic models (CS-DL and CS-ARDL). The MG estimator indicates an inverted relationship between globalization index and environmental degradation. Although it is difficult to measure how much globalization affects sustainable development, it does. The "global awareness," intercultural shifts, and transnational environmental issues are some examples. According to Tang et al. (2020), some indicators of more globalized countries may conceal the reality of their environmental degradation. People and ecosystems in other world areas have to pay for their pollution or the goods and services they receive (that assist their lives) since they have outsourced their pollutants.

The long-run, static MG and dynamic (CS-DL and CS-ARDL) models indicated a significant positive impact of energy consumption with deterioration of the environment. In this context, Destek and Sinha (2020) showed that countries with high economic growth require high energy consumption to achieve this level of growth. These countries are heavily reliant on fossil fuels; existing renewable energy ideas are insufficiently developed to meet current energy consumption levels. Therefore, increasing emissions of atmospheric CO_2 from the continuous usage of fossil fuels affect the environment.

The income parameter (per capita gross domestic product) was identical in all the long-run models, static MG and dynamic (CS-DL and CS-ARDL). Where the parameter of LGDPpc was significantly negative, the square LGDPpc was significantly positive, and the cube LGDPpc was significantly negative, which demonstrates a correlation between pollutant levels and income in the form of inverted N.

Industrialized nations must use greener and more efficient fossil fuels to reduce pollution and energy consumption, including high-quality coal and natural gas. Increased reliance on renewable energy sources such as hydroelectricity, solar power, and wind power is critical. As a result, air pollution can be controlled and reduced without negatively impacting development and economic growth.

Even though the consensus is that globalization has primarily negative impacts, most notably in underdeveloped nations, perhaps such a conclusion is premature, and globalization may not be an absolute "evil" phenomenon. With our global civilization becoming more complicated, sustainability cannot be handled from a singular viewpoint, a nation, or a scientific subject. The management of sustainability within the framework of globalization is considerably more complicated than most previous challenges, necessitating international policies across nations, particularly industrial ones, and international endeavors to integrate these strategies.

There are significant implications for the studied industrialized countries. Governments must enact policies that encourage businesses and industries to use energy more effectively and efficiently, modernize systems, or accept alternative environmentally sustainable energy sources. Energy infrastructure investment necessitates both energy security and environmental preservation. In terms of capital, authorities should encourage the implementation of energy-saving and environmentally friendly initiatives. Maintaining long-term environmental quality management while globalization (particularly on the economic side), trade, and capital investments expand in these rapidly evolving countries of the world is a critical challenge for authorities. Furthermore, institutional reforms, corruption, the legal framework, and financial stability continue to be critical tasks that require the full attention of government leaders to foster globalization, wealth creation, and energy security, all of which contribute to sustainability.

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