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Economy and pollution by CO2 emissions; Kuznets environmental curve in Asia Pacific economies

Economía y contaminación por emisiones de CO2; curva ambiental de Kuznets en las economías de Asia Pacífico

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Abstract

The economies of the Asia Pacific (APEC) region are among the most dynamic in the world with the highest levels of trade activity and environmental degradation. One way to study trends in the relationship between the economy and pollution is the Environmental Kuznets Curve (EKC). This perspective assumes that, in the long run, higher wealth levels would achieve lower pollution levels. The objective was to analyze whether the behavior of EKC occurs for APEC economies. The method used was an econometric model for carbon dioxide (CO2) emissions and GDP. The results showed a stationary unit root in the first differences, suggesting that the presence of EKC behavior was explained by a high probability that the GDP coefficient reached an inflection point to become negative and significant. However, when tests were carried out to find the differences between two groups of economies (developed and developing), it was found that the turning point for developing economies had not yet been reached, unlike developing economies.

JEL Code: F13, Q53, Q56, C23, C31
Keywords: economy; economic growth; CO2 emissions; Kuznets curve; Asia-Pacific economic forum; FMOLS and DOLS

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Resumen

Las economías de la región de Asia Pacífico (APEC) se encuentran entre las más dinámicas del mundo con los niveles más altos de actividad comercial y degradación ambiental. Una forma de estudiar las tendencias en la relación entre la economía y la contaminación es la Curva Ambiental de Kuznets (EKC). Esta perspectiva asumió que a largo plazo, mayores niveles de riqueza lograrían menores niveles de contaminación. El objetivo fue analizar si el comportamiento de la EKC ocurre para las economías de APEC. El método utilizado fue un modelo econométrico para las emisiones de dióxido de carbono (CO2) y el PIB. Los resultados mostraron una raíz unitaria estacionaria en las primeras diferencias, lo que sugiere que la presencia del comportamiento de la EKC se explicó con un alto nivel de probabilidad de que el coeficiente del PIB alcanzara un punto de inflexión para volverse negativo y significativo. Sin embargo, cuando se realizaron pruebas para conocer las diferencias entre dos grupos de economías (desarrolladas y en desarrollo), se encontró que el punto de inflexión para la economías en desarrollo aún no se alcanza, a diferencia de las economías en desarrollo.

Código JEL: F13, Q53, Q56, C23, C31
Palabras clave: economía; crecimiento económico; emisiones de CO2; curva de Kuznets; foro económico Asia-Pacífico; FMOLS y DOLS

Introduction

The Asia Pacific region is better understood if one considers the economies of the 21 countries that make up the Asia Pacific Cooperation Forum[2] (APEC) are found in it which cover 47% of international trade represent 39% of the world's population, and contributes around 60% of GDP, (APEC, 2019). This explains why this region's economies have sustained economic growth for more than 20 years (World Bank, 2019).

Economic growth has come at the expense of primary goods consumption, natural resources, and the deterioration of the environment. The region is one of those that generate the largest ecological footprint on the planet, consumption of resources over the bio-capacity to re-generate them, in Wakernagel and Ress, (1998) concept. The ecological footprint of the countries located in the Pacific Basin predominantly exceeds their bio-capacity, that is, they have ecological debt, (Footprintnetwork, 2021; Wackernagel & Rees, 1998).

This situation has led to concern about environmental deterioration, considering several sections on ecological, environmental, and energy aspects as challenges that humanity will face in the coming years, in the Millennium Development Goals (Motala, et al., 2015). In such a way that one of the great

[2] Countries in APEC: Australia, Brunei Darussalam, Canada, Korea, Chile, China, United States, Philippines, Hong Kong, Indonesia, Japan, Malaysia, Mexico, New Zealand, Papua New Guinea, Peru, Russia, Singapore, Taiwan, Thailand and Vietnam.

planetary challenges; is sustainable development; Recognized at the Rio Summit (Cumbre de Rio) in 1992, almost five decades after its completion, it still maintains as one of the pending subjects of humanity, the reduction of environmental deterioration.

In this way, a boost in environmental protection policies is to be expected, even in commercial and economic aspects. However, the economic integration policies of APEC have focused on aspects such as cooperation, tariff reduction, education, science and technology, and new communication technologies development, among other items. The integration has been in economic, commercial, and investment terms, remaining a perspective of domination of large economies such as China in Asia and North America (Hernández, 2013).

Then, environmental policy was still a secondary issue in the APEC integration agenda, however, the last years of the twentieth century, were included declarations against environmental deterioration, as an example some APEC economies have suggested lists and classifications for environmental goods in the non-agricultural market access negotiation group, identifying more than 109 products to be considered in the trade liberalization agreement, emphasizing in environmental goods according to their end use (Martínez, 2006).

The main concern of APEC's economic integration was economic growth from a neoclassical paradigm, which relies on technological innovation to reduce long-term negative environmental impacts and maintain growth rates (Guilló & Magalhaes, 2018). But: ¿what have been the environmental pollution consequences? ¿How have long-term economic growth and environmental impact behaved in APEC countries? This research considers GDP and CO2 emissions (per inhabitant) as an approximation to these variables and takes as a reference the Environmental Kuznets Curve (EKC).

There is an implicit idea in the EKC model that economic development is a process that progresses in phases to consolidate itself. An initial stage of development and environmental degradation are incipient. The second phase of development is accompanied by high rates of environmental degradation. In the third stage, as economic processes incorporate technological improvements, materials substitution, and greater social demands, they will promote changes in the laws and environmental management, with which the environmental impact would tend to decrease with increases in incomes and development.

Present aims to verify the trend in the behavior and interaction between the variables GDP and carbon dioxide (CO2), per inhabitant in APEC economies. To achieve this aim, the article is organized into five sections. The first describes the relationship between economy, development, and environmental quality, discussing the theoretical positions, and relevant background work for the study in the countries of the Pacific Basin. The third part describes the econometric techniques, the fourth part describes the results, discusses them, and finally, the conclusions are presented.

Theoretical aspects of EKC

The relationship between the economy and the environment has been emphasized since the 1970s. After the Club of Rome declared that the greatest challenges for humanity in the last quarter of a century would be: 1) degradation of natural resources in quality and quantity; 2) increased demand for energy, supplies, and food; and 3) an increase in income inequality, (Meadows, et al. 1972 y Mesarovic and Pestel 1975).

This assumes that greater economic growth leads to greater development which in turn modifies the economic structure. The EKC implies that a low-income economy (incipient agricultural and industrial sectors) has low impacts on environmental quality. In the second phase, more developed agriculture and industry generate a higher level of wealth and cause further deterioration in environmental quality. Then, in the third stage, policies are implemented to improve environmental quality and economic structure changes, to be based on more efficient and less polluting technologies and increase the relative participation of the services sector in GDP (Selden 1994; Dasgupta, Laplante, Wang & Wheeler 2002; Deacon & Norman 2004; Cantos, et al. 2011; Catalán, 2014 & Balsalobre et al 2016).

Other evidence shows that innovations also generate new sources of pollution, replicating the behavior of the EKC, with different growth rates starting a new initial stage, which can show an inverted N form between income level and environmental quality, due to energy regulation delays technological obsolescence. Some studies have obtained evidence of the pattern described by the relationship between air pollution and production levels, in which, despite finding the relationship described, per inhabitant, the global emission of pollutants will continue to increase. (Selden, 1994; Dasgupta, Laplante, Wang, y Wheeler, 2002; Balsalobre, et al 2017).

A decisive factor in the analysis of the EKC is the income elasticity of CO2 emissions, which implies that reaching the determined level of income would produce changes in the preferences of consumers who would be willing to spend a greater proportion of their income. income in environmental quality, as if it were a luxury good (Baldwin, 1995; Selden & Song, 1994).

Some less optimistic working papers highlighted that empirical repercussions could approach theoretical aspects of EKC, without significant repercussions on economic policy, Stern (2004), Selden & Song (1994), and Wagner (2008). It is argued that the behavior of the EKC, despite finding the expected ratio per inhabitant, indicates that the global emission of pollutants will continue to increase (Selden & Song, 1994).

There is skepticism of both theoretical and empirical works, for the proposition of a simple and predictable relationship between pollution and per capita income. However, there may be an inverted U shape about urban environmental concentrations of some pollutants and income, although this should be more rigorously tested in time series or panel data methods (Stern 2004). On the other hand, other authors comment that the studies referring to EKC are wide and varied, at the same time that they have had applications in several economies of the world, despite being such a widespread analysis with econometric tools, they might not be adequate, since they can lead to contradictory conclusions (Wagner, 2008). Alternatively, some studies propose the use of non-parametric techniques such as polynomial splines, which are presented as an alternative method when decomposing the time series and examining the EKC using confidence bands and simulations (Wang, 2011).

A study for 182 countries, applying panel data and cross-section, found EKC hypothesis is acceptable in both approaches, although inflection points in the cross-sections are not entirely reliable. It also highlights the importance of adequately addressing problems such as heterogeneity, structural changes, and spatial interaction, and the issue of causality was not reviewed (Atwi, et al., 2018).

Particularly for some economies in APEC, studies can be seen that demonstrate the EKC with different methodological approaches, which are shown in Table 1. Although it is a highly studied hypothesis for different countries and regions of the world, the techniques and variables used give an important diversity to the analysis.

Table 1
EKC some studies in APEC economies

Authors and year	Countries	Variables	Methodological approach	EKC is tested	Considerations
Navarro-Chávez et al 2023	APEC	CO2, GDP, Trade openness and energy intensity.	DOLS	YES	Tourism and economic growth have had a positive influence on the rise of environmental pollution in both groups of economies during the specified period.
Ravinthirakumaran & Ravinthirakumaran 2022	APEC	CO2, Trade openness, energy consumption,	Panel data, Westerlund Cointegration	YES	Tourism and trade openness have significant positive effects on CO2 emissions while economic growth and energy consumption adversely affect CO2 emissions in the long-run.
Jiang, et al., 2022	APEC	Ecological footprint and diversifications of exports and imports, renewable	FMOLD and DOLS	YES	The analysis suggests a cointegrating relation between the key variables.

		energy and globalization index.			
Fong, et al. 2020	Southeast Asian	Nox, SO2, PM2.5, Urbanization, Renewable Energy Consumption, Energy intensity, Foreign Direct Investment and Services Sector	Spatial Econometrics	YES	The EKC is tested for three contaminants. There is a significant difference in the inflection point for low-income and high-income countries.
Dong, et al. 2018	14 APEC Countries	Natural Gas Consumption and CO2 Emissions	Panel Data, Cointegration, Dependence Analysis of Cross Section, AMG y FMOLS.	YES	Test EKC, in 13 of the 14 countries independently of GDP per capita. Furthermore, the EKC hypothesis is presented independently of income levels.
Wen-Cheng Lu 2017	16 Asian Countries	Energy consumption, CO2, GDP y GDP^2	Panel Data, Granger Causality, Cointegration, Dependence Cross Section	Partially	There is regional heterogeneity in the EKC hypothesis. Energy use is an important determinant of GHG emissions. The results, (except for Southeast Asia), indicate that the environment degrades as income increases, until the threshold is reached.
Al-Mulai, et al. 2015	Vietnam	Electricity consumption (renewable and fossil sources), GDP, CO2, Labor Force, Exports, Imports and Capital.	Autoregressive with Distributed Lags, Granger Causality and Unit Root	NOT	The consumption of renewable energy has not been significant in reducing pollution. The short-term relationship between pollution and GDP is positive.
Brajer, et al 2011	China	SO2, TSP, NO2, Income, Pupulation Density, North Location, Coast Location	Nemerrow Methodology	YES	Individual analysis of pollutants with an inverted U EKC behavior. However, when the indices are analyzed as a whole, an N shape appears to

					occur, which raises a worrying picture of an increase in health costs derived from pollution.
Jalil & Mahmud 2009	China	GDP, GDP^2, CO2 y Energy Consumption	Autoregressive with Distributed Lags, Granger Causality and Unit Root.	YES	Energy consumption is significant in explaining CO2 emissions. GDP squared and CO2 has negative sign.

Source: Own elaboration.

The studies presented in Table 1 are just some studies for the region in the last decade, it can be seen that the use of macroeconomic variables such as the emission of Greenhouse Gases (GHG), (mainly CO2), the GDP, GDP^2, and Renewable Energy Consumption. It is emphasized that the work of Al-Mulai, Saboori, and Ozturk (2015) CAK is not demonstrated, whereas it is only partially demonstrated for 16 Asian countries (Wen-Cheng, 2017) because that non-fossil energy consumption was decisive, an aspect related to energy supply policies.

According to the above, there are different arguments for and against the validation of the EKC hypothesis, so it is important to continue generating empirical evidence that contributes to the generation of knowledge that provides elements on the relationship between economic activity and environmental quality.

From a reflective perspective, EKC approaches contain arguments that serve as theoretical support for the hypothesis, but that are not largely operative in the economic, social, and institutional circumstances in developing countries. In particular, inequality in income distribution and the fragility of the institutional framework in environmental matters weaken the main foundations that support this hypothesis, making it less important to wait and grow to achieve improvements in environmental quality (Zilio, 2012).

Although conclusive results are not presented, however, most studies show similar trends. It is worth noting that the variants and the assumptions of the models have differences, which influence the results obtained. The EKC continues to be a reference for interpreting the relationship and behavior between environmental quality, economic growth, and development styles. With analysis, EKC could show phenomena such as technology advances, structural composition of GDP, environmental regulations, and social preferences. But is necessary to know the context and other issues about the countries to study.

Theoretical model and method to estimate EKC

It is possible to define a parametric form of the EKC hypothesis defined as the relationship between CO2 pollutant emissions and income per inhabitant, it can be described in a model as follows:

$$E_{it} = A_{Ei} + \alpha_1 Y_{it} + \alpha_2 Y_{it}^2 + \mu_i (1)$$
(i=1, 2, …n; t=1, 2, …, tn)

(1)

For E_{it} observations corresponding to each APEC economies, i and t indicate year, A_{Ei} are fixed effects or unobserved heterogeneity, and μ is the error term. E is pollutant emissions, per capita in metric tons, Y is the logarithm of income per inhabitant, and Y^2 squares this variable. In both cases α represents the degree of response of E_{it}, income elasticity; μ the stochastic error decomposes into:

$$\mu_{it} = \mu_i + \delta_t + \varepsilon_{it}.$$

(2)

In which μ_i are the unobservable effects, δ_t are the non-quantifiable effects that change over time, although not between countries, and finally, ε_{it} denote randomness.

A disadvantage of this model is that it is not clear what kind of interpretation to give to the estimated coefficients. However, seven different behaviors of the relationship between E_{it} y GDP per capita (Balsalobre, et al., 2016).

Empirical model

Starting from equation [1], the effect of the income level on CO2 has been estimated using an autoregressive panel data cointegration model, with distributed lags. The expression takes the following form:

$$E_{it} = \alpha_{Ei} + \beta_1 Y_{it} + \beta_1 Y_{i,t}^2 + \delta_1 E_{i,t-1} + \delta_1 Y_{i,t-1} + \delta_2 Y_{i,t-1}^2 + \varepsilon_{it}$$
(i=1, 2, …, N; t=1, 2, …, T)

(3)

E is pollutant emissions, per capita in metric tons, Y is the logarithm of income per inhabitant, and Y^2 squares this variable. In both cases α represents the degree of response of E_{it}; μ is the error term, which in turn decomposes into: $\mu_{it} = \mu_i + \delta_t + \varepsilon_{it}$. (2). Which μ_i are the unobservable effects, δ_t there were the non-quantifiable effects that change over time, with a lag for the variable Y, although not so between countries, and finally, ε_{it}, the random error term.

For this model, the influence of per capita income on environmental pressure (increase in CO2) would be explicit in the estimate—however, seven different behaviors of the relationship between E_{it} and GDP. Where α_{Ei} are the fixed effects or unobserved heterogeneity and ε is the error term, GDP is a non-stationary variable. Fundamental statistical tests have been used to determine the order of integration of the variables.

If the variables are cointegrated they tend to move together maintaining a long-term equilibrium, that is, a stationary relationship between variables, the cointegration between variables implies, according to the Granger representation theorem, (Granger 1998) that the system admits a representation in the form of error correction mechanism (Engle & Granger, 1987). For this reason, instead of estimating the equation [3], its parametric transformation has been used:

$$\Delta Ex_{it} = \alpha_{Ei}\, \beta_1 \Delta Y_{it} + \beta_2 \Delta Y^2{}_{it} + (\delta_0 - 1)\left[E_{i,t-1} \frac{\delta_1 + \beta_1}{\delta_0 + \beta_0} Y_{i,t-1} + \frac{\delta_2 + \beta_2}{\delta_0 - 1} Y^2{}_{i,t-1}\right] + \epsilon_{it} \tag{4}$$

A model is established with an error correction mechanism, all the variables are expressed in differences and there is a term that collects the adjustment of the deviations of the dependent variable concerning its long-term equilibrium value. The existence of an error correction mechanism representation is not subject to the most common problems of a regression, (given the cointegration) since all the variables that enter the equation are stationary.

The test of the cointegration between emissions, income, and income squared can be performed using the two-stage method of Engle and Granger. First, we must perform the regression in levels by ordinary least squares (OLS) and collect the residuals of the estimate. Second, we estimate the equation [4], OLS, where the error correction mechanism includes the residuals of the previously estimated equation instead of the terms in levels of the variables that enter it.

If the parameter associated with the error correction mechanism, using the residuals of the cointegration equation, is statistically significant "t" it can be stated, according to the Granger representation theorem, that the series are cointegrated (Granger, 1998). The evidence in favor of the EKC requires that the coefficient β_1 is positive and the coefficient β_2 is negative, since in this way a quadratic relationship in the shape of an inverted U is obtained.). The evidence in favor of the EKC requires that the coefficient β_1 is positive and the coefficient β_2 is negative, since in this way a quadratic relationship in the shape of an inverted U is obtained. Another test is the cross-sectional independence has as its null hypothesis that residuals are normally distributed and independent [5]. The test was proposed following cross-section dependence (Pesaran, 2004):

$$CD = \sqrt{\frac{2T}{N(N-1)}\left(\sum_{i=1}^{N-1} \sum_{i=1}^{N-1} \hat{\rho}ij\right)} \sim N(0,1) \tag{5}$$

Data was obtained in World Bank Open Data, available at: https://data.worldbank.org/ and the information used includes 20 of 21 APEC countries, which is missing Taiwan. The principal variables used were GDP in dollars and CO2 in tons, both were standardized per inhabitant. The econometric model and Z test the information used covers a data period from 1990 to 2019. Both methodologies are complemented in analyses and interpretations of study phenomena, giving robust results.

On the other hand, the classification made by the United Nations Conference on Trade and Development (UNTAD, 2020) was taken, for industrialized or developed economies and developing economies. Being classified in the first: Australia, Canada, Hong Kong (China), Japan, New Zealand, Republic of Korea, People's Republic of China, and Singapore. Developing economies include Brunei Darussalam, Chile, Indonesia, Malaysia, Mexico, Papua New Guinea, Peru, Russian Federation, Thailand, Taiwan and Vietnam

EKC applied in APEC economies.

The behavior of the variables GDP and CO2, per inhabitant, maintains several performances, when there are classified in developed and developing economies. If it’s related to GDP/CO2, per habitant is an indicator that emissions by wealth unit generated; in other words, efficiency is observed, as appreciated in Figure 1. That suggests a constant reduction of CO2 and consistent growth of GDP per capita by developed economies, this situation is as would be expected for the EKC. However, this was not the case in developing economies. To illustrate the behavior of developed and developing countries over 30 years, Figure 2 has been provided. While developed countries conform very well to the EKC, the same is not true for developing countries.

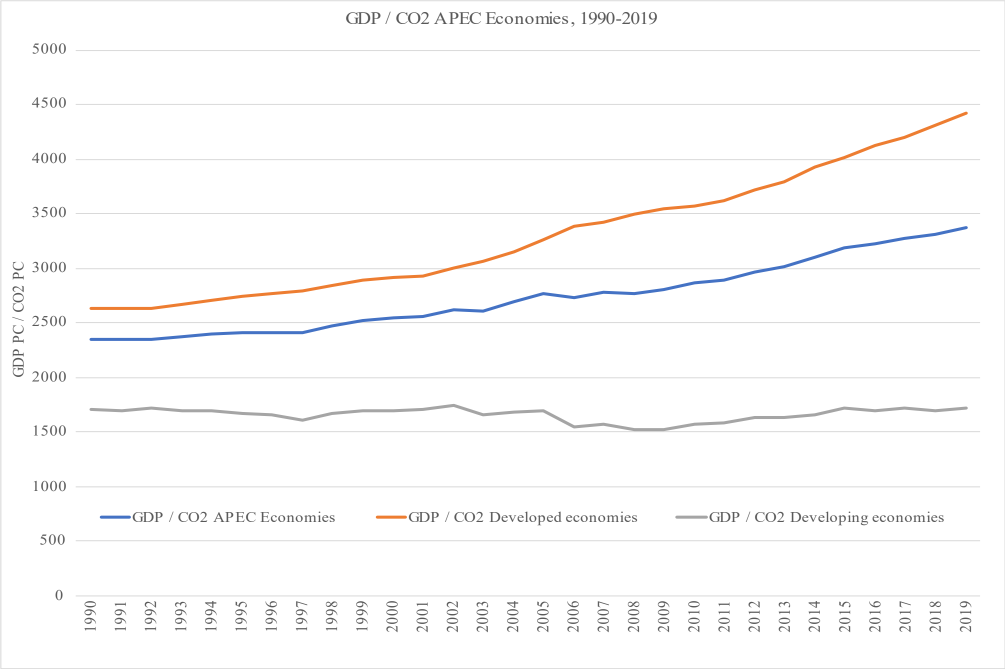

Figure 1. Performance of GDP and CO2 (both per capita) in APEC economies, 1990-2019
Source: data from World Bank, 2023. (Is not available data for Taiwan)

Regarding the relationship between GDP and CO2 per inhabitant for the countries of the Asia Pacific region, it is observed that the behavior of the relationship between the variables adjusts to a quadratic form between 2000 and 2006. Pollutant emissions per unit of However, as of 2007, the rising trend of emissions begins as GDP grows (both per inhabitant). Concerning the behavior, among economies of APEC, the relationship between per capita GDP and CO2 emissions is heterogeneous, as can be seen in Figures 1 and 2.

Hong Kong was located below the average pollutant emissions, but above the average per capita GDP, with greater efficiency in terms of polluting units per unit of GDP / capita. Malaysia and China emit slightly more pollutants with a GDP / inhabitant below the average, unlike Russia whose emissions are above the average. Finally, the economies that have emissions and GDP / inhabitants below the average are Papua New Guinea, the Philippines, Indonesia, Peru, Vietnam, Mexico, Chile, and Thailand. In this sense, the question is, ¿what is the general trend when incorporating all APEC economies? Or ¿what happens when they are separated into two study groups: developing economies and developed economies?

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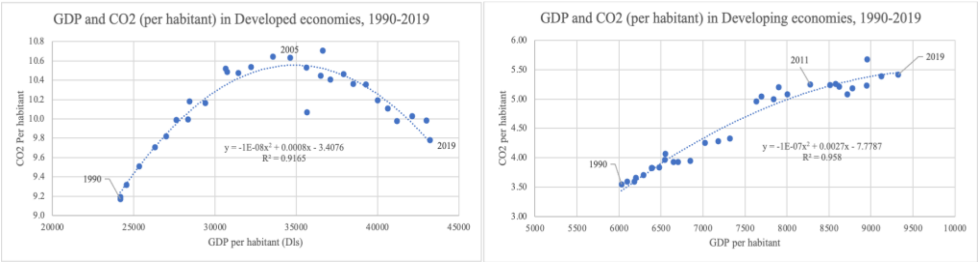

Figure 2. GDP and CO2 (both per capita) in APEC economies 1990-2019).
Source: data from World Bank, 2023

Econometrical analysis of CO2 and PIB (per capita) ($E_{it} = A_{Ei} + \alpha_1 Y_{it} + \alpha_2 Y_{it}^2 + \mu_i$)

In analyzing time series variables, it is important to know the order of integration and verify if there is cointegration between the variables, to avoid obtaining spurious results. The econometric literature suggests that unit root tests on panel data have greater power than time series unit root tests. According to Baltagi (1995), when combining the time series with the cross-sectional data, there is a greater number of observations, more degrees of freedom, more variability, less collinearity, and greater efficiency. However, it is important to first apply some cross-section dependency tests before unit root tests with panel data (Pesaran, 2007).

Table 2
Pesaran cross-section dependency test, 2004

Variable	CO2	GDP	GDP ^2
CD statistic	55.417***	83.432***	83.493***
P value	0.000	0.000	0.000

Source: World Bank, 2023
Note: *** denotes rejection of the null hypothesis at 1% significance.
Source: data from World Bank, 2021

Table 2 shows the results of the cross-section dependency CD test. For all variables, the null hypothesis of non-dependence of the cross-section is rejected at 1% of significance. Therefore, there is cross-sectional dependence for all variables, that is, the GDP (per inhabitant) and CO2 (per inhabitant) of each country are correlated with each other.

According to these results, traditional or first-generation tests such as the Levin, Lin & Chu (2002, LLC), Im, Pesaran, and Shin (2003, IPS) tests, Fisher's test using ADF (ADF-Fisher) and PP (PP-Fisher) (Maddala & Wu (1999) & Choi (2001) would not be adequate. It is very important to apply unit root tests that generate consistent results in the absence of independence and heterogeneity in all panel countries (Riti, Song, Shu & Kamah, 2017), for this, two tests were applied (Pesaran, 2007).

Table 3
Unit Root Test

Variables	Parameters	CADF	CIPS
CO2	CT	-0.496	-1.863
GDP	CT	-0.252	-2.009
GDP^2	CT	1.112	-1.930
First difference			
ΔCO2	C	-16.070***	-5.449***
ΔPIB	C	-13.710***	-5.867***
ΔPIB cuadrado	C	-13.326***	-5.354**

Source: World Bank, 2023
Note 1: The tests used were: Augmented Dickey Fuller Cross Section (CADF) and Im, Pesaran & Shin (2003) and Cross Section (CIPS) Pesaran (2007)
Note 2: *** denotes the rejection of the null hypothesis at the 1% level of significance, **5% level of significance. C denotes constant and CT denotes constant and trend.

Table 3, shows the results of the new unit root tests with panel data that are consistent in the presence of dependency on the cross sections. The evidence indicates that the variables present unit roots in levels, but are stationary when taking the first difference at a significance level of 1%. To test the presence of an equilibrium or long-term relationship between the integrated variables of the same order, in this research, two cointegration tests with panel data are used: the Pedroni (2004) and Fisher tests proposed by Maddala and Wu (1999).

Table 4
Results of the Pedroni cointegration test

Test	Statistical	Prob. Value
Panel v	3.043***	0.001
Panel rho	-4.293***	0.000
Panel PP	-5.086***	0.000
Panel ADF	-3.647**	0.000
Group rho	-0.807	0.209
Group PP	-3.387***	0.000
Group ADF	-2.464***	0.006

Note: *** and ** denote rejection of the null hypothesis of no cointegration at 1%, and 5% significance, respectively

In the results of the Pedroni test shown in Table 4, the null hypothesis of no cointegration is rejected for most of the statistics with a significance level of 1%. This is confirmed by the results of the Kao and Fisher tests (Tables 5 and 6). In the case of Fisher's test, it is indicated that at least two cointegration relationships exist between the analyzed variables, that is, there is a long-term equilibrium relationship between the three variables: CO2, GDP, and GDP2 (Table 4).

Table 5
Kao cointegration test

Test	t-Statistic
ADF	-4.678***
P-value	(0.000)

Note: *** The null hypothesis is rejected at 1%.

Table 6
Fisher cointegration test

Hypothesis	Fisher statistics*		Fisher statistics *	
CE(s) number	(Trace test)	Prob.	(Maximum eigenvalue test)	Prob.
Ninguno	173.20	0.000	144.50	0.0000
Al menos 1	66.55	0.002	55.03	0.036
Al menos 2	57.58	0.021	57.58	0.021

Source: World Bank, 2023
Note: * denotes rejection of the null hypothesis of no cointegration at 1% significance

The most common Tables OLS, technique to estimate the coefficients of panel data models turns out to be biased and produces inconsistent estimates when the variables are cointegrated. Recently, new methods have been developed to estimate cointegration relationships using panel data such as Fully Modified OLS (FMOLS) and Dynamic OLS (DOLS) estimators (Phillips & Moon 1999; Pedroni 2001a; Kao & Chiang 2001).

These approximations produce coefficient estimators that are asymptotically unbiased and normally distributed (Pedroni 2001b; Kao & Chiang, 2001). Pedroni (2001b) argues that the FMOLS estimator behaves relatively well and, even in small samples, generates consistent estimates and allows controlling the endogeneity of its regressors and the serial correlation. Due to the above, in this research, both FMOLS and DOLS estimators will be used for heterogeneous cointegrated panels (Pedroni, 2001b: 117 and 118).

Table 7
Long-term estimation with DOLS and FMOLS

Variable	DOLS Coefficients	FMOLS Coefficients
GDP	1.367***	1.541***
GDP^2	-0.061***	-0.073***

Source: World Bank, 2023.
Note: ***, **, and * denote rejection of the null hypothesis of no cointegration at 1, 5, and 10% significance, respectively.

According to Table 7, with the FMOLS and DOLS estimators all the variables are statistically significant. The long-term elasticity of per capita GDP is positive, which implies that as economic activity increases, carbon dioxide emissions also increase. Furthermore, the hypothesis of the

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environmental Kuznets curve is supported by the results for these countries, since the coefficient of GDP is positive and that of GDP squared is negative, both statistically significant at 1%.

Table 8
Short-term and long-term causality results

Variables	ΔCO2	ΔGDP	Short term	long term
			ΔGDP^2	ECT-1
ΔCO2	---	0.491***	-0.024***	-0.035***
ΔPIB	0.037	---	-0.012	0.014
ΔPIB ^2	0.150	0.879	---	0.212

Source: World Bank, 2023
Note: ***, **, and * denote statistical significance at the 1, 5, and 10% levels, respectively

In Tables 7 and 8, the results show that the causal relationship goes from economic activity to emissions in the long term at a significance level of 1%. These results are also confirmed in the short term, there is a unidirectional causal relationship that goes from economic activity to polluting emissions. The above can be interpreted as that economic activity contains important information that helps to better predict the behavior of emissions.

However, on the one hand, developed economies in comparison with developing economies with a hypothesis testing analysis to know the behavior of the difference in means in the trends for the study period, the differences can be seen, following results. The normality test indicates that it is most likely that there is a normal distribution of residuals in the behavior of CO2 emissions. Therefore, a comparison can be made between the differences between these; to which the Z test indicates that there is a significant difference in emissions for the two types of economies in APEC; a situation that was expected.

Table 9
Normality test and Z test for two independent samples in CO2 emissions

Shapiro-Wilk Test	Developed economies	Developing economies	Two-sided Z test	
W	0.91189	0.86701	Difference	-5.5601713
valor-p (bilateral)	0.01446	0.00119	z (Valor observado)	-36.858117
alfa	0.05000	0.05000	|z| (Valor crítico)	1.95996398
			valor-p (bilateral)	0
			alfa	0.05

Source: World Bank, 2023

In the case of GDP in APEC economies, there is also an important difference between developing economies and developed economies, as seen in Figure 1. The growth of GDP per inhabitant has been greater in developed economies and the reduction of CO2 emissions as well, however, per capita emissions remain higher in developed economies. In Table 19, it is most likely that there is no normal distribution of the information, which is why a test was run that estimates the differences for information with these characteristics (Mann-Whitney) to know if there are significant differences. The result indicates that for the study period, the growth of GDP per inhabitant has significant differences between both types of economies.

Table 10
Normality test, Z test, and Mann-Whitney test in GDP of APEC economies, 1990-2019

Test Shapiro-Wilk	Developed economies	Developing economies	Two-sided Z test		Mann-Whitney. Bilateral test	
W	0.944	0.911	Diferencia	26854.295	U	1089
valor-p (bilateral)	0.092	0.010	z (Observed value)	23.379	U (estandarizado)	0.000
alfa	0.05	0.05	$\lvert z \rvert$ (Critical value)	1.960	Valore esperado	544.500
			valor-p (bilateral)	<0.0001	Varianza (U)	6080.250
			alfa	0.05	valor-p (bilateral)	<0.0001
					alfa	0.05

Source: World Bank, Data Bank, 2023

Discussion

The econometric tests were implemented to check if the CAK shows a quadratic trend for the variables GDP and CO2. In other words, the hypothesis of the relationship between economic growth and environmental quality, measured from carbon dioxide emissions, (both variables relativized per inhabitant) per unit of product is confirmed. Therefore, it can be affirmed that, in the long term, pollutant emissions per unit of production maintain a tendency to grow to a lesser extent than the growth of the economy. This situation would suggest that productivity is moving towards a trend of less negative environmental impact, about CO2 pollution. The implications this has would be a function of the degree of technological development and the prevailing economic structure in APEC.

Although they have reduced emissions per unit produced, it must be considered that pollution as a whole is greater, since the wealth generated or GDP is also greater, although more efficient, in absolute terms, it continues to grow, going from 44 in 1960 to 154 in 1990 and 283 in 2020 of CO2 kilotons emissions, for the main countries of the Asia Pacific region, during the period 1960-2019. On average per inhabitant, it went from 2.4 to 7.6 tons per inhabitant. Meanwhile, the GDP / inhabitant has grown from 574 dollars to 23.7 thousand dollars. In both cases, the standard deviation is important: 5.5

tons for the first and 21 thousand for the second; This reflects the differences in the levels of economic development in the Asia-Pacific region.

The difference in the increases between the two variables suggests that the Asia Pacific countries are improving aspects such as regulatory frameworks and technologies, although there is still a heterogeneous rate. CO_2 emissions per unit of GDP / per hab, are increasingly efficient, which can be attributed to technological innovation, as well as increasingly rigid regulations, it is also appreciated that this relationship is relatively slow, so It would be necessary for innovations to be more frequent, of greater scope for their diffusion and above all of greater impact. The analysis of Figure 2, it shows the trend in a comparison between developed and developing economies with a different trend between both.

The productive structure of the economies analyzed has a close and determining relationship in terms of the behavior of the relationship between the variables analyzed. That may be why Hong Kong has very low emissions and high income levels, given that its productive structure is predominantly tertiary, focused on activities mainly of an administrative and financial nature.

The revised EKC under the statistical tests applied to the available information, reaches results similar to those found by Vergara, Maza, and Quezada, (2018) for Latin America, confirming the relationship for seven countries, including Mexico, Brazil, and Chile (2018: 5). At the same time, there was also a coincidence with the studies by Brajer, Mead & Xiao, 2011; Dong, Sun, Li & Liao, 2018; Jalil &Mahmud, 2009; Fong, Salvo &Taylor, 2020 and Al-Mulai & Navarrete, et al. 2009. Whose variables analyzed have slight variations with the present study. However, the long-term trend would be confirmed by different methods and for different analysis periods.

As could be seen in the long term, cointegration of both types of economies is suggested when carrying out the analysis for both types of countries, which indicates that a reduction in CO_2 emissions could be achieved at the same time as an improvement in income levels for APEC members. However, it can be seen that the limitations are important in the sense that when the economies are analyzed separately there are significant differences in terms of adjustment to the EKC. While developed economies show a tendency to adjust to the third stage of the EKC, developing economies have not yet shown that they have passed phase 2; growth of GDP per inhabitant with relative reduction of CO_2 emissions.

Conclusions

The formulation of the initial hypothesis on a long-term trend for the economies located in the Asia Pacific region assumes that a relationship could be found between the variables GDP per inhabitant and CO_2 per inhabitant. The results suggest that the series can cointegrate so that both have information that allows knowing and predicting their behavior. Although, the assumption that both variables adjust to a U-shaped relationship in the long term, the heterogeneity of the economies analyzed must be taken into account, as well as their productive structures. With the available information, it was possible to corroborate that the analysis of panel data and cross-section for the period analyzed indicates that valid and unbiased information for the EKC was produced.

The importance of the Asia Pacific region lies, among other things, in the growing trade flow in the region driven by the economies of China and the United States. Therefore, it is relevant to identify the terms and conditions adopted by international trade in this macro-region of the planet. If the commercial relationship integrates various aspects such as environment, the flow of people, technology transfer, and financing for development in strategic areas of countries with greater backwardness. The information on how development is configured will be transcendent and for this, this article showed the relationship between two key elements for the future commercial relationship: income and polluting emissions. One of the greatest challenges for the region will be precisely to reduce the disparity between the economies to continue fostering the commercial expansion of the APEC region.

One of the elements that remain pending and probably for the next few years will be of vital importance, will undoubtedly be the energy policy of the countries. In the case of the Asia Pacific region, which at the moment is heterogeneous in the use of free sources of fossil fuels, the trend is towards decarbonization and the promotion of renewable and alternative energies (wind, solar, hydroelectric, nuclear and tidal wave, etc.) which is likely to drive a pollution reduction.

The behavior of CO2 emissions about GDP shows a clear difference between developing economies and developed economies. While there is an elastic relationship in the former, with GDP per inhabitant increasing more proportionally than CO2 per inhabitant, this is not the case in developing economies. However, CO2 emissions in developed economies continue to exceed emissions in developing economies by 1.5 times.

Finally, the growth of GDP per inhabitant has advanced in terms of efficiency, emitting less CO2 per unit of product, however, in absolute values this is reflected in air pollution of capital magnitudes, which is multiplying emissions by three in a few more than 50 years. However, China and the United States participate with 70% of the emissions of the APEC region, although adding Russia and Japan the figure grows to 83% of the APEC sample, as well as the wealth generated. In APEC there is a high concentration in a few economies that generate the highest proportion of both variables (GDP and CO2). It is because of this situation that these countries should be the ones promoting the use of cleaner technologies and stricter environmental regulations, which will have implications for areas such as trade and regional and world production.

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