Pollution Emissions and Economic Growth in Asia Through the Lens of the Environmental Kuznets Curve

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ABSTRACT

The nonlinear relationship of pollution emissions with economic growth alongside energy consumption variables was examined to test the Environmental Kuznets Curve (EKC) hypothesis using a panel sample comprising 34 Asian economies from 2001 to 2013. Panel Autoregressive Distributed Lag models in the forms of Pooled Mean Group and Mean Group models were estimated and tested against one another using the Hausman test. For robustness checks, the same econometric techniques were applied to disaggregated panel groups based on income classifications. The study reveals that, while the EKC hypothesis holds in Asia, the findings were not robust across the disaggregated panel groups. The turning point in the Asian EKC was estimated to range from USD 32,003 to USD 38,793 per capita. The findings support the argument that the majority of Asian economies are yet to reach the ideal phase where economic growth decouples with environmental degradation.

Keywords: *economic growth, energy, Environmental Kuznets Curve, panel cointegration, pollution emissions*

Introduction

The rapid rising of recorded oceanic and atmospheric temperatures, the constant changing of global water cycle, the declining levels of ice, and the steady rising of global mean sea level are some of the adverse effects of the world's increasing greenhouse gas emissions (Tomas and López 2015). The Intergovernmental Panel on Climate Change (IPCC) claims that the years between 1983 to 2013 had been the period with the highest recorded mean temperatures in the last 1,400 years of the Earth's northern hemisphere (IPCC 2023). For the past three decades, the world has seen its share of climate-related calamities and catastrophes like floods, flash fires, droughts, and storms (Thomas and López 2015). Many have pointed fingers at the rapidly increasing emissions of greenhouse gasses like carbon dioxide, methane, nitrous oxide, and ozone (Dong *et al.* 2018).

To alleviate the dramatically declining quality of the global environment, researchers and policymakers have been rushing to find solutions to mitigate greenhouse gas emissions since the early 90s. The first breakthrough in the field of

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economic growth and environmental pollution studies began in the early 1990s. Grossman and Krueger (1991) investigated the potential environmental damages of the North American Free Trade Agreement (NAFTA) using three different air pollutants as proxies for environmental pollution. Many years later, the EKC hypothesis was formulated and has since then been a significant breakthrough in the field, having been situated and tested in the context of varying issues ranging from endangered species to land deforestation, to nitrogen fertilizers, and other air pollution indices aside from the original pollution variable, i.e., carbon dioxide emissions (Stern 2015).

The EKC hypothesis asserts that there exists an inverted-U relationship between environmental pollution emission and real per capita income. It argues the existence of two possible stages an economy undergoes as it experiences economic growth (Le and Ozturk 2020). The first stage characterizes a direct income-pollution relationship, i.e., increasing real per capita income tends to lead to an increase in the level of environmental pollution emissions, albeit at a decreasing rate. The second stage characterizes an inverse income-pollution relationship, i.e., increasing real per capita income tends to lead to a decline in the emissions of environmental pollution, albeit at an increasing rate. The maximum point along the curve where the relationship between real per capita income and environmental pollution emissions changes direction is often referred to as the turning point.

The EKC hypothesis posits that, initially, as a country experiences economic growth, it tends to emit more pollution, which yields adverse effects on the environment (Dinda 2004). However, the EKC hypothesis also asserts that there exists a turning point in the curve, which signals a decoupling of economic growth and the emission of environmental pollution, i.e., further increasing real per capita income translates to a reduction in environmental pollution, which leads to an improvement in the quality of the environment (Grossman and Krueger 1991, Grossman and Krueger 1995) due to attempts in the use of greener technologies to redress environmental degradation.

There had been a consensus in previous studies concerning the relationship between real per capita income and carbon dioxide emissions with the former positively affecting the latter. However, in line with the EKC debate, there exist contradicting results in the literature. Not all studies have confirmed a consistently positive relationship, since some studies resulted in the negative sign for the squared term of real per capita income revealing the occurrence of an inflection point. Moreover, some studies have also rejected the validity of the EKC hypothesis (Al-Mulali, Saboori, and Ozturk 2015, Aydin and Turan 2020, Erdogan, Okumus, and Guzel 2020, Le and Quah 2018, Özokcu and Özdemir 2017, Sarkodie and Strezov 2018, To *et al.* 2019, Zhang 2019, Zoundi 2017). However, a good number of studies have otherwise validated the EKC hypothesis (Ali *et al.* 2020, Apergis and Ozturk 2015, Aruga 2019, Cetin, Ecevit, and Yucel 2018, Churchill *et al.* 2018, Destek and Sarkodie 2019, Dong *et al.* 2018, Fang, Huang, and Yang 2018, Hanif 2018, Hasnisah, Azlina, and Taib 2019, Sarkodie and Ozturk 2020). The clear divide in the results of previous studies leaves a significant room in the growing debate, i.e., whether the EKC hypothesis universally persists or whether it is just another stylized fact waiting to be disproven by real-world experiences or improved upon by newer mathematical specifications of the income-pollution hypothesis.

The phenomenon of the inverted-U hypothesis of the Environmental Kuznets Curve can generally be explained by three economic phenomena, namely: (a) the scale effect, (b) the composition effect, and (c) the technique effect (Grossman and Krueger 1991, Copeland and Taylor 2004, Stern 2015). The scale effect argues that increasing aggregate economic wealth implies that the pollution an economy emits likewise increases proportionally (Grossman and Krueger 1991). This is more pronounced in the case of pre-industrial economies which are still experiencing rising demand for conventional sources of energy like coal, oil, and natural gas for electricity generation in households and industries. However, the proportion at which pollution emissions increase varies at different phases of the EKC function (Stern 2015).

On the other hand, the composition effect claims that rising real income levels leading to varying pollution intensities from different sectors of the economy, over time, tend to change their output mix, and such that these adjustments in the output mix of different industries tend to favor outcomes with decreased environmental pollution emissions (Copeland and Taylor 2004). Developed economies manifest their awareness and care for their citizens by ensuring that a cleaner living environment is upheld as they further achieve economic development (Sarkodie and Strezov 2018).

Finally, the technique effect signals a shift from conventional and pollutive production technologies to modern production technologies that are not detrimental to the natural environment. This is more evident in developed economies as it is believed that countries with high income levels tend to favor stringent environmental policies, which aim to reduce pollution. Therefore, as an economy grows, manufacturing firms tend to substitute less eco-friendly inputs in their production processes with more eco-friendly inputs due to increasing pressure from environmental experts and state regulations (Stern 2004). Moreover, the development of better technologies gives rise to the emergence of greener production processes. Improvements in the productive capacities of firms, in terms of the utilization of lesser environment-damaging inputs per unit of output, are more pronounced in developing economies (Copeland and Taylor 2004).

Methodology

The analysis employs a panel data approach, a robust methodology that integrates cross-sectional and time-series dimensions to examine the relationships among key variables. Panel data, also known as longitudinal or cross-sectional time-series data, allows for the investigation of individual units (such as countries or regions) over multiple time periods. This approach provides a comprehensive understanding of the dynamics and interactions within the dataset, offering insights that either traditional cross-sectional or time-series analyses may overlook.

IPS Panel Unit Root Test

The Im-Pesaran-Shin (IPS) panel unit root test was employed to determine the level of integration of the relevant variable series used in the analysis, i.e., pollution emission, per capita GDP, square of per capita GDP, fossil fuel energy consumption, and renewable energy consumption. Specifically, it tests for the existence of an individual unit root that allows the autoregressive (AR) coefficient ρ_i in the panel model to vary across the different economies in the cross-panel.

The IPS panel unit root test holds novel value over its predecessor, the Levin-Lin-Chu (LLC) panel unit root test, in the sense that, the autoregressive component in the IPS panel unit root test is panel-specific, thus it allows a certain degree of cross-section heterogeneity (Im, Pesaran, and Shin 2003). On the other hand, the LLC panel unit root test forces the assumption of panel homogeneity by imposing a constant autoregressive component for the entire panel (Levin, Lin, and Chu 2002). Thus, the IPS test is more advantageous since it allows the cross-section economies to be heterogeneous agents. The assumption of country homogeneity is arguably unrealistic as the country samples vary largely in terms of pollution emission volumes, energy consumption, and per capita incomes.

The model described in the IPS test is characterized by the following panel Dickey-Fuller regression model (Banerjee 1999):

$$\Delta y_{it} = \rho_i y_{it-1} + \psi_{it} Z_{it} + \xi_{it}, \quad i = 1, 2, 3, \dots, N; t = 1, 2, 3, \dots, T \tag{1}$$

Where y_{it} represents time series variable of country i at time t; ρ_i represents an autoregressive coefficient, which is allowed to vary across different cross-country units, i = 1, 2, 3, …, N; Z_{it} represents individual unobserved effects, i.e., fixed effects (if correlated with the error term), random effects (if not correlated with the error term), trend component, or a combination of fixed/random effects and a trend component; Δ is a difference operator; and, ξ_{it} represents a stochastic residual term.

The IPS panel unit root test posits a null hypothesis on the existence of a panel unit root. Rejecting this null hypothesis indicates that the variable is stationary. Specifically, if the test yields a significant result in the variable's level form, it implies that the variable is level-stationary, i.e., I(0). Conversely, if the variable is found to be non-stationary in level form but exhibits significance upon first-differencing, it is concluded that the variable is difference-stationary, i.e., I(1). It is important to note that the alternative hypothesis in this context implies that at least one panel is stationary.

Pedroni Panel Cointegration Test

The Pedroni panel cointegration test was employed to assess whether a long-run relationship exists between economic growth and pollution emissions. If a long-run relationship was detected, it can be said that an equilibrium relationship between the variables persisted over time. In this study, the establishment of cointegration is deemed essential, as it suggests a stable and enduring connection between economic growth and pollution emission. The Pedroni panel cointegration test consists of three test statistics $Z, \tilde{Z}$ and $\tilde{Z}*$. The Z statistic is a parametric statistic estimated from a standard Dickey-Fuller test but with the incorporation of higher-order autocorrelations to capture the effect of potential higher-order autocorrelation. On the other hand, $\tilde{Z}$ and $\tilde{Z}$ are Pedroni panel (PP) cointegration and modified PP test statistics, respectively, which are based on a pure unit root test but incorporating a non-parametric correction to the derivation of the test statistic (Pedroni 1999). These three test statistics are claimed to be robust and reliable even in the event of having small sample sizes (Pedroni 1999, Pedroni 2004). The three-panel cointegration Z statistics that were used to test the null hypothesis of no cointegration in the context of the Pedroni Cointegration Test are as follows:

$$Z_{t_{N,T}} = \frac{\sum_{i=1}^{N} \sum_{t=2}^{T} \hat{L}_{11i}^{2} \left(\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i \right)}{\sqrt{\sigma_{N,T}^{2} \left(\sum_{i=1}^{N} \sum_{t=2}^{T} \hat{L}_{11i}^{2} \, \hat{e}_{i,t-1}^{2} \right)}} \tag{2}$$

$$\tilde{Z}_{t_{N,T}} = \sum_{i=1}^{N} \frac{\sum_{t=1}^{T} (\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i)}{(\sum_{t=1}^{T} \hat{e}_{i,t-1}^{2})} \tag{3}$$

$$\tilde{Z}_{t_{N,T}}^{*} = \frac{\sum_{i=1}^{N} \sum_{i=1}^{T} \hat{L}_{11i}^{2} \, \hat{e}_{i,t-1}^{*} \Delta \hat{e}_{i,t}^{*}}{\sqrt{\tilde{s}_{N,T}^{*2} \left(\sum_{i=1}^{N} \sum_{t=2}^{T} \hat{L}_{11i}^{2} \, \hat{e}_{i,t-1}^{*2} \right)}} \tag{4}$$

Where $\widehat{L}_{11i}^2$ is the long-run variance of the predicted residual $\eta_{i,t}$ from the first-differenced regression $\Delta y_{i,t} = \beta_{1,i}\Delta x_{1i,t} + \beta_{2,i}\Delta x_{2i,t} + \cdots + \beta_{M,i}\Delta x_{Mi,t} + \eta_{i,t}$.. On the other hand, $\hat{e}_{it}$ is predicted from $y_{it} = x_{it}'\beta + z_{it}'\gamma + e_{it}$ and $\hat{\lambda}_i = \frac{1}{2}(\hat{\sigma}_i^2 - \hat{s}_i^2)$, where $\hat{\sigma}_i^2$ and $\hat{s}_i^2$ are the individual long-run variance and individual contemporaneous variance of the disturbance term $\hat{e}_{it}$, respectively, and $\hat{\sigma}_{NT} = N^{-1}\sum_{i=1}^{N}\frac{\hat{\sigma}_i^2}{\hat{L}_{11i}^2}$ is the total variance of the whole sample. Parameters that are represented with an asterisk denote modification for non-parametric estimation. If at least two Z test statistics yield statistically significant results, it indicates the presence of cointegration among the variables across all cross-section units in each panel. This implies a robust and consistent confirmation of the sustained relationship between the variables over time.

Panel Autoregressive Distributed Lag

Once it had been established that the variables adhere to long-run equilibrium, the coefficients of the long-run cointegrating relationships were obtained by performing panel ARDL regression model estimations. Pesaran and Smith (1995), Pesaran and Shin (1999), and Pesaran *et al.* (1999) have laid the groundwork for the estimation of non-stationary dynamic panels and have developed the mathematical foundations of the Pooled Mean Group (PMG) estimator and the Mean Group (MG) estimator for the panel ARDL model. Both the PMG and the MG serve as ARDL estimators that cater to panel data, and it was through these two sets of estimators that long-run and short-run relationships between different variables in the model may be explored in a panel context (Munir and Riaz 2019). While being identical in terms of allowing for group-specific short-run coefficients, the two models differ in terms of the assumption of the homogeneity of the estimated long-run coefficients. The PMG estimator assumes that all cross-section units exhibit statistically identical long-run coefficients, while the MG allows for group-specific long-run coefficients (Pesaran and Shin 1999, Pesaran *et al.* 1999). The panel ARDL model that was estimated takes the form of:

$$lnp_{it} = \sum_{j=1}^{p} \boldsymbol{\alpha}_{ij}\, p_{i,t-j} + \sum_{j=0}^{q} \boldsymbol{\beta}_{ij}'\, \boldsymbol{X}_{i,t-j} + \zeta_i + \xi_{it} \qquad (5)$$

Restating the previous equation in a reparametrized form, the following error correction model was obtained:

$$\Delta lnp_{it} = \theta_i\left(lnp_{i,t-1} - \boldsymbol{\lambda}_i'\boldsymbol{x}_{it}\right) + \sum_{j=1}^{p-1} \psi_{ij}\, \Delta lnp_{i,t-j} + \sum_{j=0}^{q-1} \boldsymbol{\eta}_{ij}'\, \Delta \boldsymbol{x}_{i,t-j} + \zeta_i + \xi_{it} \qquad (6)$$

Where lnp_{it} pertains to CO2 emissions growth of country i at time t; $\boldsymbol{X}_{it}$ represents a vector of regressors that may consist of I(0) and I(1) variables, namely: real per capita GDP growth (lny_{it}), squared real per capita GDP growth (lny_{it}^2), fossil fuel energy consumption growth (lnn_{it}) and renewable energy consumption growth (lnr_{it}); ζ_i represents a vector of slope parameters; ζ_i encompasses individual deterministic components, i.e., fixed effects, trend component, or a combination of fixed effects and a trend component; ξ_{it} represents a stochastic disturbance term. Lastly, p and q are optimal lag orders of lnp_{it} and $\boldsymbol{X}_{it}$, respectively. To set a criterion in determining which estimation approach (i.e., PMG vs MG estimation) can better explain the variation in the data set, the econometric procedure of

Pesaran *et al.* (1999) of utilizing a Hausman (1978) specification test was used. This test addresses the problem of determining whether there is heterogeneity on the estimated coefficient or not (Pesaran *et al.* 1996). In the context of the study, rejecting the null hypothesis suggests a preference for relying on the results derived from the PMG estimates. The primary rationale for choosing MG and PMG estimators lies in their ability to capture both cross-sectional and time-series heterogeneities. The individual effects incorporated in these models account for the unique properties of included countries, allowing for a nuanced analysis of how various factors influence the relationship over time. While unobserved effects models may be suitable for longer time series, the choice to focus on MG/PMG in the study stems from the belief that these models better capture the dynamic and diverse nature of the dataset used.

Sources of Data and Data Description

This study utilized panel data of pollution emission, per capita GDP, square of per capita GDP, fossil fuel energy consumption, and renewable energy consumption of 34 Asian economies from the period of 2001 to 2013 (T=13 years). All data used were downloaded from the World Development Indicators (https://data.worldbank.org, accessed February 1, 2021). Thus, the panel data sample comprised a total of 442 observations, which is deemed a sufficiently large sample size given the scope of the study. The full panel sample was further disaggregated into three income groupings, i.e., (a) low to lower-middle income; (b) upper-middle income, and (c) high-income groups, which follow the World Bank classifications (2020). All the tests and regression models were performed on the full panel and disaggregated samples to investigate whether the full panel results were robust across the different income groups.

It can be argued that it is reasonable to believe that the presence of China in the panel sample could significantly influence the results of the panel ARDL regressions due to China's distinctive characteristics in terms of country size and economic development. Consequently, for robustness checks, analyses were conducted both with and without China in the models.

Results and Discussion

Results of the IPS panel unit root test

The degree of integration of all the variables needs to be established to determine if cointegration analysis can be pursued since this analytical technique requires that the variables have to be non-stationary in their level-forms and stationary in their first differences. That is, the variables have to be integrated of order 1 or I(1). The purpose of this is to ensure that the results of the study do not suffer from spurious regression, which yields misleading results (Maddala and Wu 1999).

The Im-Pesaran-Shin (IPS) panel unit root test was performed on the level-forms and the first differences of all the variables. The test statistic was derived from a Dickey-Fuller regression that was augmented for panel data analysis, specifically, through the inclusion of a vector of dummy variables accounting for panel and time fixed effects (Banerjee 1999).

Table 1 presents the summary of the results of the IPS panel unit root test. It was found that there was no sufficient evidence to reject the null hypothesis of the presence of panel unit root in the level-forms of pollution emissions growth, economic growth, squared economic growth, fossil fuel energy consumption growth, and renewable energy consumption growth. All variables then are difference-stationary across all panel samples, i.e., all were found to be I(1) or random walk processes.

Table 1. The results of the IPS panel unit root tests performed on the level form and first difference of the variables

Model	lnP		lnY		lnY2		lnN		lnR	
	level	1st diff	level	1st diff	level	1st diff	level	1st diff	level	1st diff
(1)	1.67	-7.69**	4.13	-4.67**	5.03	-4.86**	0.24	-6.52**	0.59	-7.60**
(2)	1.84	-7.60**	4.16	-4.72**	4.93	-4.86**	0.56	-6.66**	0.76	-7.63**
(3)	2.92	-4.56**	5.11	-3.16**	5.93	-3.34**	-0.85	-5.15**	0.71	-4.57**
(4)	-0.08	-4.67**	0.46	-2.41**	1.05	-2.53**	-2.18	-4.01**	-1.26	-4.45**
(5)	0.15	-4.52**	0.43	-2.48**	0.79	-2.50**	-1.73	-4.25**	-1.05	-4.49**
(6)	-0.18	-4.09**	1.41	-2.52**	1.48	-2.55**	4.34	-1.76**	1.93	-4.18**

(1) – full panel; (2) – full panel without China; (3) – low to lower-middle income group; (4) – upper-middle income group; (5) – upper-middle income group without China; (6) – high-income group
Ho: All panels contain individual unit roots
AR parameter: panel-specific
** denotes significance at $\alpha = 0.01$

Results of the Pedroni panel cointegration test

Before the long-run relationships of pollution emissions growth, economic growth, squared economic growth, fossil fuel energy consumption growth, and renewable energy consumption growth were empirically estimated, it had to be first established that the variables adhere to long-run equilibrium (Zoundi 2017, Le and Quah 2018, Hasnisah, Azlina, and Taib 2019). The study then employed the Pedroni panel cointegration test to establish whether the null hypothesis of no cointegration is present across the panel samples or not (Pedroni 1999, Pedroni 2004). Specifically, the PPC test was implemented to establish if pollution emissions growth has long-run relationships with the economic growth variables and energy consumption. The PPC test reported three test statistics, namely the ADF t-stat, the PP t-stat and the modified PP t-stat that correspond to the three Z statistics mentioned in the methodology section, namely: Z, $\tilde{Z}$, and $\tilde{Z}*$, respectively.

Table 2 showed that the cointegration tests of economic growth and energy consumption variables with pollution emissions for the total panel of Asian countries (with or without China) and all income groupings were generally found to be statistically significant at 1 percent in all three versions of the tests, hence a strong evidence for cointegration. Therefore, it can be concluded that there exists strong evidence for the rejection of the null hypothesis of no cointegration. This means that economic growth, squared economic growth, fossil fuel energy consumption growth, and renewable energy consumption growth exhibited long-run equilibrium concerning pollution emissions growth. This result was found to be robust in the total and disaggregated income panels and consistent even after controlling for the presence of China. Hence, the estimated coefficients of the long-run relationships from the dynamic panel data regressions are reliable.

Table 2.Summary of the results of the Pedroni panel cointegration test for the total Asian panel and by income groups (with and without China).

Regressors	Test Statistic		
	Modified PP t-stat	PP t-stat	ADF t-stat
Full panel with China			
lnn	0.86	-5.11**	-3.76**
lnr	2.18*	-1.97*	0.05
lny, lny2	2.62**	-4.87**	-4.27**
lny, lny2, lnn	4.19**	-6.98**	-6.00**
lny, lny2, lnr	4.26**	-5.69**	-5.96**
lny, lny2, lnn, lnr	5.54**	-9.98**	-9.39**

Table 2. Continued…

Regressors	Test Statistic		
	Modified PP t-stat	**PP t-stat**	**ADF t-stat**
Full panel without China			
lnn	2.04*	-2.21*	-0.25
lnr	0.97	-4.96**	-3.65**
lny, lny2	2.55**	-4.93**	-4.30**
lny, lny2, lnn	4.29**	-5.02**	-4.70**
lny, lny2, lnr	4.27**	-5.50**	-5.84**
lny, lny2, lnn, lnr	5.59**	-8.17**	-8.14**
Group 01			
lnn	1.17	-0.64	-0.50
lnr	0.56	-3.64**	-2.66**
lny, lny2	1.14	-3.71**	-4.06**
lny, lny2, lnn	2.57**	-5.72**	-4.44**
lny, lny2, lnr	2.43**	-5.37**	-5.31**
lny, lny2, lnn, lnr	3.48**	-9.69**	-5.96**
Group 02 with China			
lnn	1.63	-0.56	1.98*
lnr	0.91	-3.63**	-1.61
lny, lny2	1.75*	-2.36**	-2.18*
lny, lny2, lnn	2.43**	-6.32**	-4.97**
lny, lny2, lnr	2.74**	-2.75**	-3.20**
lny, lny2, lnr, lnn	3.43**	-8.05**	-6.93**
Group 02 without China			
lnn	1.42	-0.93	1.56
lnr	1.11	-3.40**	-1.39
lny, lny2	1.64	-2.42**	-2.21**
lny, lny2, lnn	2.60**	-3.16**	-2.86**
lny, lny2, lnr	2.76**	-2.39**	-2.98**
lny, lny2, lnn, lnr	3.52**	-5.13**	-4.91**
Group 03			
lnn	0.74	-2.39**	-1.77*
lnr	0.02	-2.59**	-2.32*
lny, lny2	1.45	-1.75*	-0.85
lny, lny2, lnn	2.37**	-0.89	-0.39
lny, lny2, lnr	2.20*	-1.64	-1.44
lny, lny2, lnn, lnr	2.82**	-2.95**	-2.92**

Regressand: Carbon dioxide emissions growth

Ho: All panels are cointegrated.

AR parameter: panel-specific

** and * denotes significance at $\alpha = 0.01$ and at $\alpha = 0.05$, respectively.

Results of the panel ARDL regression model estimation

Table 3 presents the estimates of the full panel Autoregressive Distributed Lag (ARDL) model with and without China, while Table 4 presents the results of the disaggregated analyses by income groups. The Pooled Mean Group (PMG) and the Mean Group (MG) regression models were both estimated and the Hausman specification test (1978) was performed to choose the better model. The test revealed that the null hypothesis cannot be rejected in both the full and disaggregated panels. This means that the PMG model provided more efficient estimates. Therefore, the foregoing analyses were centered on the results of the PMG model regressions as basis in analyzing the long-run relationships of pollution emissions growth to economic growth, squared economic growth, fossil fuel energy consumption growth, and renewable energy consumption growth, since the parameter estimates from the PMG model are deemed more efficient (Pesaran *et al.* 1999).

According to the results of the full panel regression, economic growth, and its squared form are significantly significant at $\alpha = 0.01$ with their expected signs, i.e., positive and negative, respectively. This supports the hypothesis that the growth of carbon dioxide emissions exhibits an inverted-U relationship with economic growth, which provides proof that the EKC holds in Asia (Le and Quah 2018, Shahbaz and Sinha 2019). That is, a one percent increase in the growth of the real per capita GDP of the Asian economies leads to an approximate increase in its carbon dioxide emissions by 1.5046 percent, holding all other factors constant. Moreover, since the established income-pollution relationship behaved in a quadratic fashion, it must be that the response of per capita emissions diminishes for every percent increase in the growth of real income. Therefore, the rate at which the growth of the emissions of per capita carbon dioxide decreases by 0.1424 percent for every one percent increase in the growth of real per capita GDP.

Concerning the relationships of the growth in carbon dioxide emissions with energy consumption, it was found that a one percent increase in the growth of fossil fuel energy consumption leads to an approximately 1.0850 percent increase in the growth of per capita carbon dioxide emissions, holding all other factors constant. On the other hand, a one percent increase in the growth of renewable energy consumption leads to an approximately 0.3548 percent decrease in the growth of per capita dioxide emissions, holding all other factors constant. The signs exhibited by the energy consumption variables are consistent with what was hypothesized, i.e., positive and negative, respectively. Note that the expected relationships of growth in emissions with the key variables in the model are robust with the omission of China in the sample panel.

Furthermore, the estimation of the impacts of fossil fuel and renewable energy consumption growth was conducted separately, considering the potential issue of multicollinearity between these variables. Given that fossil fuel and renewable energy are substitute goods, an expected negative correlation between them may lead to multicollinearity concerns. Consequently, separate regressions were employed to address this issue. The results showed that the EKC hypothesis was found to be valid only on the following conditions: (a) fossil fuel energy consumption growth and renewable energy consumption growth were both included in the model and (b) only renewable energy consumption growth was included in the model. The model which omitted renewable energy consumption growth failed to provide evidence for the prevalence of the EKC phenomenon. These findings are robust and consistent even when controlling for the inclusion of China in the sample panel.

In the case of fossil fuel consumption, the generation of energy from fossil fuels is expected to emit more carbon dioxide and is thus considered destructive to the atmosphere (Rasiah, Guptan, and Habibullah 2018, Sarkodie and Strezov 2018). Energy generation from renewable sources, on the other hand, is more sustainable for the environment in the sense that such processes emit lesser to no carbon dioxide emissions (Zoundi 2017, Shahbaz and Sinha 2019). The signs of the coefficients of the energy consumption variables are robust even when one energy consumption variable is omitted and also when controlling for the inclusion of China. The turning point level of real per capita income— the level at which real income growth and pollutions emissions decouple (Grossman and Krueger 1991, Grossman and Krueger 1995), was found to correspond to 11 percent economic growth, which in per capita terms translates to USD 38,793.

Table 3. Summary of the results of the full panel ARDL regression model estimations with and without China

Variables	Full Panel With China						Full Panel Without China					
	MG	PMG	MG	PMG	MG	PMG	MG	PMG	MG	PMG	MG	PMG
Long-run elasticity coefficients												
Log per capita GDP	191.09	1.50**	-1.51	-0.55	-33.87	2.59**	197.12	1.50**	-1.33	-2.91**	-34.84	2.64**
Log squared per capita GDP	-16.61	-0.07**	0.11	0.03	1.66	-0.12**	-17.13	-0.07**	0.10	0.15**	1.71	-0.13**
Log fossil fuel energy consumption	-1.75	1.09**	-2.10	1.66**	--	--	-2.04	1.09**	-2.41	1.56**	--	--
Log renewable energy consumption	-63.84	-0.35**	--	--	-0.84**	-0.45**	-65.77	-0.35**	--	--	-0.84**	-0.45**
Short-run elasticity coefficients												
Error correction term	-1.04**	-0.67**	-1.07**	-0.56**	-1.12**	-0.62**	-1.02**	-0.67**	-1.05**	-0.45**	-1.09**	-0.61**
D.(Log per capita GDP)	13.19	-12.97	-24.42	-32.77**	-30.16	-7.62	13.23	-13.18	-25.59	-48.72**	-34.37	-9.15
D.(Squared log per capita GDP)	-1.22	0.69	1.33	1.96**	1.74	0.42	-1.23	0.70	1.40	3.01**	2.00	0.51
D.(Log fossil fuel energy consumption)	-1.01	1.52	-0.15	0.78	--	--	-0.93	1.52	0.02	1.16	--	--
D.(Log renewable energy consumption)	0.63	0.38	--	--	0.15	-0.20	0.63	0.40	--	--	0.13	-0.20
Constant	102.87	-6.99**	3.72	-2.12**	54.64	-6.78	105.99	-7.00**	4.07	3.84**	55.65	-6.83**
Regressand: Carbon dioxide emissions growth												
No. of observations	408	408	408	408	408	408	396	396	396	396	396	396
Log Likelihood	--	825.79	--	743.12	--	743.85	--	800.99	--	711.89	--	718.90
Hausman Test Chi2 statistic (Ho: PMG is a more efficient estimator)	0.11		0.55		1.81		0.11		0.15		0.62	
Resulting model	PMG		PMG		PMG		PMG		PMG		PMG	
Does the EKC hypothesis hold?	Yes		No		Yes		Yes		No		Yes	
Turning point GDP per capita (constant 2010 USD)	38,793		--		36,213		38,751		--		32,003	

** denotes significance at $\alpha = 0.01$

Table 4. Summary of the results of PMG models for the disaggregated panel ARDL regressions by income groups.

Variables		(1)			(2)			(3)			(4)	
Long-run elasticity coefficients												
Log per capita GDP	-1.68	6.90**	6.85**	8.46**	-0.97	3.79**	0.49	-1.43	-1.31	-4.62	-8.39**	16.43
Log squared per capita GDP	0.18	-0.44**	-0.44**	-0.52**	0.06	-0.21	-0.01	0.09	0.12	0.24	0.41**	-0.80
Log fossil fuel energy consumption	0.94**	1.12**	--	-4.13**	3.98**	--	1.03**	3.40**	--	-2.49**	0.09	--
Log renewable energy consumption	-0.61**	--	-0.59**	-0.25**	--	-0.31**	-0.34**	--	-0.35**	-0.26**	--	0.04
Short-run elasticity coefficients												
Error correction term	-0.50**	-0.58**	-0.67**	-0.45**	-0.65**	-0.74**	-0.82**	-0.69**	-0.76**	-0.56	-0.57	-0.55**
D.(Log per capita GDP)	25.31	9.88	-2.94	-56.77**	-42.52**	-47.85**	-36.06**	-46.81	-11.97	-9.80	-40.91	-49.98
D.(Squared log per capita GDP)	-1.88	-0.90	0.13	3.39**	2.45**	2.83**	2.16**	2.71**	0.80	0.51	2.03	2.41
D.(Log fossil fuel energy consumption)	1.60	0.09	--	-0.26	-0.48	--	-1.74	-0.58	--	5.64	3.12	--
D.(Log renewable energy consumption)	0.92	--	-0.48	-0.11	--	-0.08	0.09	--	-0.06	0.16	--	-0.04
Constant	0.67**	-18.22**	-16.45	-6.43**	-8.07**	-11.40**	-5.19**	-5.53**	3.30**	20.02	25.83	-44.86**
Note: (1) – low to lower-middle-income economies (n=13); (2) – upper-middle-income economies (n=13); (3) – upper-middle-income economies without China (n=12); (4) – high-income economies (n=8)												
Regressand: Carbon dioxide emissions growth												
No. of observations	156	156	156	156	156	156	144	144	144	96	96	96
Log Likelihood	310.01	287.66	293.95	330.97	296.08	301.86	317.07	272.06	275.99	185.11	176.93	169.70
Does the EKC hypothesis hold?	No	Yes	Yes	Yes	No	No	No	No	No	No	No	No
Turning point GDP per capita (constant 2010 USD)	--	2,580	2,374	3,594	--	--	--	--	--	--	--	--

** denotes significance at $\alpha = 0.01$

As shown in Table 4, the estimated parameters of the full model for the low to middle-income economies (Group 1) showed that the income growth regressors were found to be both statistically not different from zero, and thus the EKC hypothesis was not verified in this income group. There had been no evidence supporting a functional income-pollution relationship for Group 1 when both energy consumption regressors were included in the model, particularly the growth in fossil fuel consumption. This implies that economies within this group are possibly not yet prioritizing initiatives that aim to minimize environmental pollution emissions, such that their main concern is still biased toward rapid economic growth.

Surprisingly, the EKC hypothesis was found to have been verified in Group 1 regressions whenever the energy consumption regressors lnn (growth of fossil fuel consumptions) and lnr (growth in renewable energy consumption) are included separately in the model. The turning point level of per capita income in the EKC of the low-to-lower-middle income group was found to be approximately USD 2,580 whenever only fossil fuel energy consumption was included, and it was about USD 2,374 whenever only renewable energy consumption was included. For this income group, arguably, the scale effect of the EKC was deemed more dominant than the composition effect and the technique effect. This can be because, for the low-to-lower-middle-income group in Asia, there will always be a proportional increase in pollution emissions whenever economic growth is achieved (Grossman and Krueger 1991, Stern 2004, Stern 2015).

On the other hand, in the case of the upper-middle income Asian economies (Group 2), only the full model in this respective income group provided evidence that support the validity of the EKC hypothesis with a turning point of approximately USD 3,594. Interestingly, it was found that this result was not robust when China was excluded from the panel sample (Group 3). Since China had already surpassed the estimated turning point in the EKC for this particular income group, its absence in the Group 3 sample rendered the remaining economies to be relatively homogeneous in terms of income. Therefore, China was found to be some sort of a leader in the upper-middle income economy group, thus it eventually ushers in the potential decoupling between pollution emissions and economic growth in the Group 2 sample holding all other factors constant. This implies that China had been a significant contributor to the composition effect that signals the potential transition for the upper-middle-income Asian economies to progress toward the second half of their group's EKC (Sarkodie and Strezov 2018, To *et al.* 2019).

Lastly, in the case of high-income economies in Asia (Group 4), the results of the analysis provide no evidence for the validity of the EKC hypothesis across all model variants. In fact, according to the results of the ARDL regressions, only the model where the fossil fuel energy consumption growth regressor was included did the study find evidence for a functional nonlinear income-pollution model. However, it was found to be contradictory to the EKC hypothesis as the results argue a quadratically decreasing income-pollution model. That is, pollution emissions growth has been decreasing at an increasing rate concerning economic growth as being experienced by the relatively affluent economies in Asia. Therefore, whenever only the high-income economies in Asia are considered, it can be said that the technique effect had dominated, such that it began to offset the scale effect in the income-pollution model. The finding that pollution emissions will eventually decrease at an increasing rate is consistent with the argument summarized by the economic phenomenon of the technique effect (Copeland and Taylor 2004, Grossman and Krueger 1991). The technique effect is notably evident in the case of the high-income economies in Asia like South Korea, Hong Kong, Japan, Singapore, and the like, which are known to have integrated environmental initiatives into their development policy frameworks (Hanif 2018, Hasnisah, Azlina, and Taib 2019). Examples of these programs include the Japan-Korea Environmental Policy Dialogue, Singapore's Voluntary National Review (VNR) on the Sustainable Development Goals (SDGs), etc. This supports the argument that these economies are largely prioritizing programs and initiatives which not only curb the emissions of environmental pollution but also the commendable reduction of pollution emissions itself.

Table 5 presents the summary of the turning points that were estimated from each resulting regression run that yielded evidence supporting the validity of the EKC hypothesis. It can be observed that the turning point levels of real per capita GDP in the full Asian panel (with and without China) were estimated to be within the range of USD 32,003 to USD 38,793. Specifically, the estimated turning point level of per capita income in the estimated Asian EKC is approximately USD 38,793 for the full panel with China, USD 36,213 for the full panel with China when fossil fuel energy consumption growth was omitted, USD 38,751 for the Asian panel without China, and USD 32,003 for the Asian panel without China when fossil fuel energy consumption growth. On the other hand, the turning point in the low-income economy group's EKC was estimated to be within the range of USD 2,374 to USD 2,580, while the turning point in the upper-middle income economy group's EKC was estimated to be about USD 3,594.

Table 5. Turning point levels of per capita GDP per panel sample

Panel Sample	Turning point (constant 2010 USD)*
Full panel	38,793
Full panel (lnn was omitted)	36,213
Full panel without China	38,751
Full panel without China (lnn was omitted)	32,003
Low-income economies (lnr was omitted)	2,580
Low-income economies (lnn was omitted)	2,374
Upper-middle income economies	3,594

*Based on the authors' calculations

Given the full panel estimated turning point level of per capita GDP (USD 38,793), it was revealed that only 3 out of 34 Asian economies, specifically, Singapore, Japan, and the United Arab Emirates have reached the benchmark turning point level of per capita income, suggesting that these economies have more environmentally favorable pollution management strategies compared to their other Asian neighbors. On the other hand, some economies like Hong Kong, Israel, Cyprus, and South Korea are almost at the turning point level of per capita income. Unfortunately, those not mentioned are considerably far away from this turning point level of the estimated EKC. This implies that in the context of Asia, pollution emissions will keep on rising alongside economic growth since the turning point level of per capita income are yet to be reached by most Asian economies.

Summary and Conclusions

The study primarily aimed to estimate the long-run relationship between key determinants of environmental pollution emission using a panel cointegration approach. In addition to this, the study attempted to establish empirical evidence supporting the inverted-U hypothesis between economic growth and environmental pollution emissions, i.e., the Environmental Kuznets Curve (EKC) as proposed by Grossman and Krueger (1991, 1995).

The study estimated both a Pooled Mean Group (PMG) model and a Mean Group (MG) model to empirically determine the long-run relationships of carbon dioxide emissions growth to economic growth, squared economic growth, fossil fuel energy consumption growth, and renewable energy consumption growth. Afterwards, the study tackled the estimation of the turning point level of real per capita income from the best-fit model that was identified given that the EKC is observed to be present.

The results obtained from the ARDL regressions revealed that the long-run elasticity coefficients of the linear form of per capita GDP growth and the squared form of per capita GDP growth are significantly positive and negative, respectively. This provides evidence for the validity of the EKC hypothesis in Asia. The results of the full panel regression are robust even when controlling for the presence of China. This implies that, in the long run, there could be a potential decoupling of carbon dioxide emissions and economic growth.

This finding could be attributed to how countries are gradually moving away from generating energy from fossil fuels to generating energy from renewable sources like solar energy, wind energy, hydro energy, tidal energy, geothermal energy, and biomass energy. The transition towards the use of more environmentally sustainable energy generation practices is even intensified by the ratification of intra-country agreements which focused on environmental preservation and climate change mitigation. Famous examples of such agreements are the Montreal Protocol in 1987, the United Nations Framework Convention on Climate Change (UN FCCC) in 1992, the Kyoto Protocol in 2005, and the Paris Agreement in 2015 (Maizland 2021). The Kyoto Protocol and the Paris Agreement are arguably the most important initiatives in this lineup of international agreements as these two are legally binding agreements that aimed to reduce the greenhouse gas emissions of countries to combat the worsening climatic conditions of the world. In addition to this, the Paris Agreement even requires all countries to set emissions-reduction pledges at levels in which the end goal would be to become carbon neutral. Carbon neutrality implies that a country has to have a level of greenhouse gas emissions, which would be no more than the amount of greenhouse gases that is removed from the atmosphere (Maizland 2021).

Recommendations

The results of the study, therefore, highlight a need to transition towards the utilization of energy from traditional sources like fossil fuels to environmentally sustainable alternatives like renewable energy sources without compromising economic growth. The energy generation from fossil fuels can be made to be less destructive for the environment by increasing the energy efficiency output of fossil fuels. This can be done by promoting and funding research and development initiatives, which seek to advance technological innovations in this field. There is also a need for governments to create incentives designed to make agents in the private sector become more stringent when it comes to mitigating their pollution emissions. Governments should look into subsidizing research and development efforts in renewable energy sources like wind energy, solar energy, biomass energy, geothermal energy, and others to make these sources more competitive with their alternatives. Moreover, as a recommendation for future studies, a potential area for future EKC research could be the possibility of making use of different indicators for environmental pollution other than carbon dioxide emissions, especially those with indirect impact on the environment, e.g., municipal waste, energy use from transportation, traffic volumes and other forms of pollutants.

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