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CO_2 Emissions in Asia–Pacific Region: Do Energy Use, Economic Growth, Financial Development, and International Trade Have Detrimental Effects?

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Abstract: Global warming has become the main concern in the current world; increased CO_2 emissions are believed to be the main reason for this climate change. Therefore, this study investigates the impacts of energy consumption, economic growth, financial development, and international trade on the CO_2 emissions of 17 Asia–Pacific countries. Using unbalanced panel data for 61 years (1960–2020), the Driscoll and Kraay's standard error and panel-corrected standard error (PCSE) models are employed to observe the effect of the studied variables on the CO_2 emissions. The obtained results reveal that energy consumption, financial development, economic growth, and international trade have adverse effects on the environment of the panel countries by increasing the CO_2 emissions, whereas the square of economic growth reduces it, and results eventually confirm the evidence of the presence of the environmental Kuznets curve (EKC) hypothesis. Bidirectional causality is found between international trade and CO_2 emissions, and unidirectional causal association from CO_2 emissions to energy consumption and economic growth is also revealed. To maintain sustainable economic growth and to improve environmental quality, an increase in green energy consumption is being recommended.

Keywords: CO_2 emissions; energy consumption; economic growth; financial development; international trade

JEL Classification: C33; F18; O44; Q43; Q53

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1. Introduction

Over the past few decades, climate change has been the most serious and challenging environmental issue worldwide, as it has various economic, social, and ecological impacts. With rapid globalisation, economic development, growing population, and financial development, carbon dioxide (CO_2) emissions are also continuously increasing. The increased level of CO_2 emissions is considered the main cause of climate change and global warming; hence, the issue has drawn the attention of researchers, international organisations and policy makers (Rahman [1]; Acheampong [2]; Heidari et al. [3]). According to BP statistics, global CO_2 emissions grew by 1.4% per annum from 2009 to 2019, which creates stern alarm for the living condition of the earth [4]. Thus, reduction in CO_2 emissions is still a top-most priority for the policy makers, and seeks unanimous and effective steps agglomerating important elements such as energy consumption, economic growth, trade, and financial development in an articulated way.

Therefore, the matter of CO_2 emissions is still a vital area of research to promote environmental quality and sustainable economic development. The dilemma is that CO_2 has negative consequences, but is also directly linked to economic growth and energy consumption (Rahman [1]; Hossain [5]). Hence, researchers and policy makers have different opinions in relation to dealing with CO_2 emissions. The general view is that, irrespective of the level of development, each country can attempt to reduce CO_2 emissions as a way to improve environmental quality. Since the consumption of fossil fuels increases CO_2 emissions, the demand for energy can be decreased to mitigate CO_2 emissions (Lamb et al. [6]; Rahman [1]; Acheampong [2]). In contrast, it is also argued that mitigation of CO_2 emissions has macroeconomic costs (Acheampong [2]; Fan et al. [7]) and quick implementation of emission reduction policies by reducing energy use will negatively affect economic growth, as energy is a vital factor in the production process (Nain et al. [8]; Ahmad et al. [9]; Omri et al. [10]; Sadorsky [11,12]). Many empirical studies such as Shahbaz et al. [13], Andersson and Karpestam [14], Wang et al. [15], and Narayan and Smyth [16] supported this latter sentiment, implying that emission reductions alone will not bring a positive outcome for sustainable economic growth if low-carbon technologies are not properly developed (Rahman [1]). These conflicting arguments provide the rationale for further empirical investigation on the links between CO_2 emissions, energy consumption, and economic growth to ease the current debate on economic, environmental, and energy conservation policies, and help in achieving sustainable economic development.

Financial development in both developed and developing countries is rapidly occurring, with the increase in economic growth. Many scholars and policy makers consider the financial sector as a vital element for ensuring economic growth (Goldsmith [17]; McKinnon [18]; King and Levine [19]). The improvement of the financial sector can also affect CO_2 emissions by stimulating different developmental activities. If financial development is identified to be a significant variable affecting CO_2 emissions, this will have important implications in climate change and sustainable development policies (Shen et al. [20]; Wang et al. [21]). Therefore, it is logical to include financial development as a significant variable in any investigation of the nexus between energy use, economic growth, and CO_2 emissions.

Furthermore, international trade is also connected to energy consumption and CO_2 emissions (Rahman [1]). Nasir and Rehman [22] and Haq et al. [23] viewed trade as a significant variable for environmental quality, and the former found detrimental effects of trade to the environment while the latter considers that environmental quality may be improved if environmentally friendly commodities are traded. On the other hand, the study of Rahman and Mamun [24] found no nexus between international trade and energy consumption in Australia. Given this controversy, it is still important to consider trade as an explanatory variable in the empirical investigation of CO_2 analysis.

This research, therefore, endeavours to investigate the effects of energy consumption, economic growth, international trade, and financial development on the CO_2 emissions of 17 Asia–Pacific countries. The reasons for selection of Asia–Pacific countries are: (i) the share of CO_2 emissions of this region is 52.4%, which is the highest compared to other regions of the world such as North America (16.6%), Europe (11.2%), the Middle East (6.3%), and Africa (3.7%) in 2020 [4]; (ii) the annual growth rate of CO_2 emissions is also the highest (2.7%) in the Asia–Pacific region in 2020 against the figures of −0.4% for North America, −1.1% for Europe, 2.7% for the Middle East, and 2.0% for Africa [4]; (iii) the share of energy use of the Asia–Pacific region is also the highest in the world in comparison to other regions; this region used 45.5% of the world's energy consumption in 2020 against the consumption share of North America (19.4%), Europe (13.9%), the Middle East (6.5%), and Africa (3.3%) [4]; (iv) the growth rate per annum of energy consumption in 2020 was also the highest (3.3%) in this region compared to North America (0.6%), Europe (−0.2%), the Middle East (3.1%), and Africa (2.5%) [4]; (v) this region experienced the highest GDP growth rate, which was 5.8% in 2017 (UN [25]) compared to advanced economies (3.1%), Europe and Central Asia (4.1%), and the Middle East and North Africa (1.2%) [26]; (vi) the global merchandise trade share of this region was 38.5% in 2017, with the growth rates of exports and imports of 11.5% and 15%, respectively (UN [27]); and (vii) the regional distribution of domestic credit to private sector (as a proxy of financial development) is 167.08% of GDP [26].

This study is unique and contributes to the contemporary literature in a number of ways. First, this is the first experimental research of its type in the Asia–Pacific region that covers 17 countries of the region and uses a long period of updated data (61 years) covering 1960–2020 to analyse the CO_2 emissions–energy–growth link in a multivariate framework. Second, the study incorporates 'financial development' and 'trade' as additional important variables along with energy consumption and economic growth, which will diminish the potential omitted variable bias, so that consistent combined effects are found. Third, autocorrelation, heteroscedasticity, and cross-sectional dependence problems are properly addressed by using improved estimation techniques: Driscoll and Kraay's [28] standard error and panel-corrected standard error (PCSE) models, which provide efficient estimates. Finally, the obtained results on the linkage between the variables of interest and the test of the environmental Kuznets Curve hypothesis for the Asia–Pacific countries will provide insights to policy makers to assist them to adopt correct growth, energy, and climate policies.

The reminder of the paper is organised as follows: Section 2 analyses the related previous literature; Section 3 explains methodology, model, and data; Section 4 presents and analyses the obtained results. Section 5 concludes the study with policy implications.

2. Literature Review

Researchers have tried to identify the factors causing CO_2 emissions for a long time (Ertugrul et al. [29]), where individual-country studies with a bivariate framework have received central attention in the literature, though some multivariate panel studies are also available (see Rahman [1,30]; Farhani and Rejeb [31], Rahman et al. [32], Rahman and Alam [33], for example). However, the obtained results of past studies are inconclusive and are not fully satisfactory to formulate and execute proper development and environmental policies. The past empirical studies can be discussed under the following four categories of nexus.

2.1. *Economic Growth–CO_2 Emissions Nexus*

This first strand of research explores the linkage between CO_2 emissions (proxy for environmental quality) and economic growth. Basically, this strand explores the evidence of the EKC hypothesis, which describes that CO_2 emissions and growth are positively linked at the early level of development, and when the economy is matured with a fixed level of income, CO_2 emissions start falling with the increase in income as the country is able to buy carbon-friendly technologies. This implies that EKC is an inverted U-shaped, non-linear curve. Many studies (see Rahman [30] and [1]; Pao et al. [34]; Shahbaz et al. [35]; Dinda and Condoo [36]; Zoundi [37]; Akbostanci et al. [38]; Lean and Smyth [39]; Ozturk and Acaravci [40]; He and Richard [41], Tiwari et al. [42]; Ertugrul et al. [29], among others) tested this hypothesis, but failed to unanimously establish the existence of the EKC hypothesis for all countries. While several of the mentioned studies found the existence of the EKC, including Rahman [1], Dinda and Condoo [36], He and Richard [41], Akbostanci et al. [38], Ozturk and Acaravci [40], and Pao et al. [34], others found the opposite results: Rahman [1] found a U-shaped affiliation for Asian populous countries; He and Richard [41], Ozturk and Acaravci [40], Pao et al. [34], and Rahman et al. [32] observed no significant confirmation of the EKC hypothesis for the Canadian economy, Turkey, Russia, and Newly Industrialised countries, respectively. Akbostanci et al. [38], Kashem and Rahman [43], and Rahman and Alam [33], Rahman [30], and Rahman and Vu [44] exposed the growing long-run linear connection between CO_2 emissions and economic growth in Turkey, Bangladesh, top 10 electricity-consuming countries, Australia, and Canada, respectively, whereas the falling effect is also uncovered by Rahman [45] for India. In terms of causal association, the unidirectional causal nexus between economic growth and CO_2 emissions was found by Mbarek et al. [46] for Tunisia, and bidirectional causality was also revealed by Saidi and Rahman [47], and Rahman et al. [48] in four out of five OPEC countries, and five South Asian countries, respectively. Thus, more investigation of the role of economic growth in CO_2 emissions is needed.

2.2. Economic Growth, Energy Consumption, and CO_2 Emissions Nexus

The second strand of research focuses on the dynamic link between CO_2 emissions, economic growth, and energy consumption, and empirical findings are not unanimous in the literature. Among the studies in this group, Alam et al. [49] found bidirectional causality between CO_2 emissions and energy use without any link between CO_2 emissions and economic growth in India. A bidirectional nexus between CO_2 emissions and energy consumption is also confirmed by Alam et al. [50] for Bangladesh, with a unidirectional causality from emissions to economic growth. On the other hand, Shahbaz et al. [13], Uddin et al. [51], Ang [52], Hossain [5], Kasman and Duman [53], and Rahman and Kashem [54] established a unidirectional causal link from economic growth to energy use and CO_2 emissions for Malaysia, Indonesia, Japan, the EU member and candidate countries, Sri Lanka, and Bangladesh, correspondingly. Furthermore, no causal link between CO_2 emissions and income and between energy and income is revealed by the study of Soytas et al. [55] for the USA. Li et al. [56] also found that reduction in energy intensity and CO_2 emissions do not significantly hamper economic growth in the case of 20 Asia–Pacific countries, whereas Nyiwul [57] found insignificant association between energy consumption and CO_2 emissions in 10 African countries. Nyiwul [58] also noted that the renewable energy is linked with the climate change concern generated by pollutants such as CO_2 emissions in the Sub-Saharan African countries. Therefore, the further analysis of the role of economic growth and energy consumption on CO2 emissions is essential for better policy making.

2.3. Trade–CO_2 Emissions Nexus

The third strand of research deals with the nexus between trade and CO_2 emissions. Theoretically, the net effect of international trade on CO_2 emissions could either be positive or negative (Rahman [1]). The positive effect stems from the fact that free trade enables a country to have larger admission to international markets and thus increases the power of the competition and competence to import cleaner and efficient technologies that decrease carbon emissions (Shahbaz et al. [13]). The counter argument for inverse effects is that trade increases industrial manufacturing activities and depletes natural resources that ultimately worsen environmental quality by increasing CO_2 emissions. The empirical findings of Jebli et al. [59] in 22 Central and South American countries, Halicioglu [60] in Turkey, Tiwari et al. [42] in India, and Mongelli et al. [61] in Italy support the positive effect of international trade on CO_2 emissions. In contrast, the findings of Shahbaz et al. [62] show the negative outcome of trade in Pakistan while no, weak, and inconclusive effects are also revealed by two recent studies of Haug and Ucal [63] and Hasanov et al. [64] in Turkey, and oil exporting countries, respectively. Rahman and Alam [33] observed no impact of trade on CO_2 emissions in Bangladesh. These inconclusive impacts of trade on CO_2 emissions seek more attention.

2.4. Financial Development–CO_2 Emissions Nexus

The fourth strand of research describes the association between financial development and carbon emissions, where the researchers are of different opinions about the linkage. Zhang [65] and Jiang and Ma [66] take the view that financial development generates more CO_2 emissions. Conversely, some other researchers such as Zaidi et al. [67] and Dogan and Seker [68] argue that CO_2 emissions can be reduced with the increase in financial development through the efficient use of developmental process concerning environment. Empirically, the positive consequence of financial development on CO_2 emissions is revealed by Zhang [65] and Shen et al. [20] in China, Jiang and Ma [66] for 155 countries, Boutabba [69] in India, Ehigiamusoe and Lean [70] in 122 countries, Ali et al. [71] in Nigeria, and Wang et al. [21] for G7 countries.

In contrast, the negative outcome of financial development on CO_2 emissions is also revealed by Zaidi et al. [67] in APEC countries, Vo and Zaman [72] in 101 countries, Odhiambo [73] in 39 sub-Saharan African (SSA) countries, Dogan and Seker [68] in top renewable energy countries, and Sheraz et al. [74] in G20 countries. Moreover, Ozturk and Acaravci [75] found no linkage between financial development and CO_2 emissions in Turkey. Table 1 summarises the findings of studies noted in these four strands.

Table 1. Summary of outcomes of previous empirical studies.

First Strand of Research: CO_2 Emissions–Economic Growth Nexus		
Authors	**Countries of Study ***	**Findings**
Tiwari et al. [42]; Shahbaz et al. [35]; Rahman [30]; Ertugrul et al. [29]	India; France; 10 top electricity-consuming countries 10 developing countries	Existence of EKC
Ozturk and Acaravci [40]; He and Richard [41]; Zoundi [37]; Rahman et al. [32]; Pao et al. [34]	Turkey; Canada; 25 African countries; Newly industrialized countries; Russia	Non-confirmation of EKC
Rahman [1]	11 Asian countries	U-shaped association
Lean and Smyth [39]	5 ASEAN countries	CO_2 emissions influence economic growth
Akbostanci et al. [38]; Kashem and Rahman [43]; Rahman and Alam [33]; Rahman [30], Rahman and Vu [44]; Rahman [45]	Turkey; Bangladesh; top 10 electricity-consuming countries; Australia and Canada; India	Economic growth affects CO_2 emissions
Dinda and Condoo [36]	88 countries	CO_2 emissions and economic growth affect each other
Mbarek et al. [46]; Saidi and Rahman [47]; Rahman et al. [48]	Tunisia; 4 out of 5 OPEC countries; 5 South Asian countries	Unidirectional and bidirectional causal association between economic growth and CO_2 emissions
Second Strand of Research: CO_2 Emissions–Economic Growth–Energy Consumption Nexus		
Alam et al. [49]; Alam et al. [50]	India; Bangladesh	Bidirectional relationship between energy use and CO_2 emissions in both countries; no link between CO_2 emissions and economic growth in India, but unidirectional association from CO_2 emissions to economic growth in Bangladesh
Uddin et al. [51]; Shahbaz et al. [13]; Ang [52]; Hossain [5]; Kasman and Duman [53]; Soytas et al. [55]; Rahman and Kashem [54]	Sri Lanka; Indonesia; Malaysia; Japan; the EU member and Candidate countries; the USA; Bangladesh	Unidirectional causal association from economic growth to energy consumption and CO_2 emissions
Soytas et al. [55]	The USA	No causal link between economic growth and energy use, and between economic growth and CO_2 emissions
Li et al. [56]	20 Asia–Pacific countries	The reduction in energy intensity and CO_2 emissions do not significantly hamper economic growth
Nyiwul [57]	10 African countries	Insignificant association between energy consumption and CO_2 emissions
Nyiwul [58]	Sub-Sahara African countries	The renewable energy is linked with the climate change concern generated by pollutants such as CO_2 emissions

Table 1. *Cont.*

Third Strand of Research: CO_2 Emissions–International Trade Nexus		
Jebli et al. [59]; Mongelli et al. [61]; Tiwari et al. [42]; Halicioglu [60]	22 Central and South American countries; Italy; India; Turkey	Positive effect of trade on CO_2 emissions
Shahbaz et al. [62]	Pakistan	Negative impact of trade on CO_2 emissions
Hasanov et al. [64]; Rahman and Alam [33]	Oil exporting countries; Bangladesh	No effects of trade on CO_2 emissions
Haug and Ucal [63]	Turkey	Inconclusive results
Fourth Strand of Research: CO_2 Emissions–Financial Development Nexus		
Zhang [65]; Shen et al. [20]; Jiang and Ma [66]; Boutabba [69]; Ehigiamusoe and Lean [70]; Ali et al. [71]; Wang et al. [21]	China; China; 155 countries; India; 122 countries; Nigeria; G7 countries.	Positive effect of financial development on CO_2 emissions
Zaidi et al. [67]; Dogan and Seker [68]; Vo and Zaman [72]; Odhiambo [75]; Sheraz et al. [74]	APEC countries; top renewable energy countries; 101 countries; 39 Sub-Saharan African (SSA) countries; G20 countries	Negative effect of financial development on CO_2 emissions
Ozturk and Acaravci [75]	Turkey	No link

* Following the authors, countries of studies are noted, respectively.

Clearly, the existing empirical findings on the link between CO_2 emissions and other variables are diversified, and the researchers disagree not only about the presence of the link but also about the direction of causality direction between the variables. The root cause of inconclusive results is because of the differences in the use of data periods, methodological approaches, and country/region heterogeneity. Therefore, research on this important issue with updated data and improved methodology will continue and is justified. To address the issue, the combined effect of energy consumption, economic growth, trade, and financial development on CO_2 emissions in the Asia–Pacific regions is quite vital as it has not been discussed in the past literature. Our present objective is to fill-up such gaps and provide efficient policy guidelines for articulating better sustainable environmental policy.

3. Methodology, Model, and Data

3.1. Econometric Approach

There are several steps involved in econometric approach to deal with the unbalanced panel data. The first step is to check for heteroscedasticity, autocorrelation, and cross-sectional dependence in the panel dataset, as their existence may produce inefficient and spurious outcomes (Rahman et al. [32]; Qiu et al. [76]). The Wooldridge [77] test is performed to examine the autocorrelation, whereas Modified Wald statistics for group-wise heteroscedasticity is conducted to diagnose the presence of heteroscedasticity (Baum [78]; Wooldridge [77]; Simpson [79]; Attari et al. [80]; Khan et al. [81]; and Rahman et al. [32]). In the same way, the cross-sectional dependence (CD) test developed by Pesaran [82] is applied to test the cross-sectional dependence (Hoechle [83]; Rahman et al. [32]). The model for the CD test is as:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\sqrt{T_{ij}\hat{p_{ij}}^2}\right) \quad (1)$$

where the coefficients of residuals of the pairwise cross-sectional correlation are specified by $\hat{p_{ij}}^2$, and the cross-sectional dimensions and time of the panel are shown by N and T, respectively. The null hypothesis (H_0) is the prevalence of cross-sectional independence with CD ~ N (0, 1).

The standard fixed effect model is not able to provide robust results with the presence of heteroscedasticity, autocorrelation, and cross-sectional dependence complexities (Magalhães and Africano [84]; Rahman et al. [32]). In this context, the Hoechle [83] methodology of Driscoll and Kraay's [28] standard error technique is suitable for a linear panel model to generate efficient and unbiased outcomes by mitigating the issues of heteroscedasticity, autocorrelation, and cross-sectional dependence (Baloch et al. [85]; Baloch and Meng [86]; Sarkodie and Strezov [87]; Rahman et al. [32]). Among many other models, the Driscoll and Kraay's [28] standard error technique contains many special and unique features: first of all, it is very much applicable in the unbalanced panel dataset; missing values of the dataset can also be dealt with in this approach; another special characteristic is that it is a non-parametric method which has flexibility, and larger dimensions; lastly, it is quite effective in addressing the complications of the estimations arisen due to heteroscedasticity, autocorrelation, and cross-sectional dependence (Hoechle [83]; Baloch et al. [85]; Baloch and Meng [86]; Sarkodie and Strezov [87]; and Rahman et al. [32]).

It is important to check the robustness of the estimated outcomes by using another similar efficient and sophisticated approach. In this study, the robustness will be verified by using the renowned technique as panel-corrected standard error (PCSE) model following the methodology of Beck and Katz [88]. This technique is also efficient and adept in addressing the problems of autocorrelation and heteroscedasticity, as well as cross-sectional dependence problems (Cameron [89]; Ikpesu et al. [90]; Le and Nguyen [91]; and Rahman et al. [32]).

The information on the direction of causality between the variables of interest will be useful for policymakers in shaping the appropriate policies. This study adopts the pairwise Granger [92] causality test to explore the causality direction, as noted below:

$$Y_t = a_0 + a_1 Y_{t-1} + \ldots + a_p Y_{t-p} + b_1 X_{t-1} + \ldots\ b_p X_{t-p} + U_t \quad (2)$$

$$X_t = c_0 + a_1 X_{t-1} + \ldots + c_p X_{t-p} + d_1 Y_{t-1} + \ldots\ d_p Y_{t-p} + V_t \quad (3)$$

Testing null hypothesis, H_0: $b_1 = b_2 = \ldots = b_p = 0$

As opposed to alternative hypothesis, H_1: Not H_0 is a test where X_t does not Granger-cause Y_t.

Further, testing H_0: $d_1 = d_2 = \ldots = dp = 0$ against H_1: Not H_0 is a test where Y_t does not Granger-cause X_t.

A rejection of the null hypothesis indicates that Granger causality exists between the variables. There could be four possible results, available from the pairwise Granger causality test, namely, unidirectional causality from variable X_t to variable Y_t, unidirectional causality from variable Y_t to variable X_t, bi-directional causality, and no causality.

3.2. Theory, Model, and Data

For analysis in the current study, the environmental Kuznets curve (EKC) hypothesis is adopted as a base for theoretical ground. Grossman and Krueger [93] applied the EKC concept in the field of environmental pollution borrowing from the notion of Simon Kuznets [94], who detected the inverted U-shaped affiliation between per capita income and inequality (Rahman [1], Zoundi [37], Dong et al. [95], and Rahman et al. [32]). Three important channels of nexus between growth and environment are observed by researchers (Rahman et al. [32]; and Sahoo et al. [96]; Mosconi et al. [97]; Shahbaz and Sinha [98]; Kiliç and Balan [99]). They are scale, composition, and technique effects. The scale effect exacerbates the environmental quality by generating more pollution for augmenting rapid economic growth in the earlier period of development. At this stage, countries are less concerned about environment and exploit natural resources mercilessly only for increasing development. After some certain periods, as development increases, the composition effect is found with increased attention by policy makers towards the environment. They suggest that countries use more environment-friendly technologies, and a clean and renewable energy mix, so that pollution may be reduced and the quality of the environment may be improved. At the final stage, the technique effect dominates the countries' policies as development is highest, which further reduces pollution. The policy makers introduce new and innovative techniques by advancing more scientific research and development, and making growth, trade, and financial policies to have better environmental quality keeping pace of the development. In these ways, the scale effect positively affects pollution, whereas composition and technique effects negatively affect pollution, and as a whole contribute to an inverted-U shaped affiliation between growth and pollution.

Following the study of Rahman [1,30] and Dong et al. [95], our multivariate regression model for exploring the effects of studied variables on CO_2 emissions can be written as follows:

$$CO_2 = \alpha + \beta_1 ENG_{it} + \beta_2 GDP_{it} + \beta_3 {GDP^2}_{it} + \beta_4 TRA_{it} + \beta_5 FD_{it} + \varepsilon_{it} \quad (4)$$

The Equation (4) can be re-written after taking natural logarithms to reduce the presence of heteroscedasticity (Rahman et al. [32]; Rahman and Alam [33]; Rahman and Alam [100]).

$$lnCO_2 = \alpha + \beta_1 lnENG_{it} + \beta_2 lnGDP_{it} + \beta_3 ln{GDP^2}_{it} + \beta_4 lnTRA_{it} + \beta_5 lnFD_{it} + \varepsilon_{it} \quad (5)$$

where CO_2 is the carbon emissions, in metric tons per capita, which are generated from burning of fossil fuel and production of cement; ENG is the energy use (kg of oil equivalent per capita) counted before the transformation to other end-use fuels; GDP is the gross domestic product per capita (proxy for economic growth); TRA stands for international trade per capita calculated from the sum of export and import dividing total population; and FD represents financial development (measured by domestic credit to private sector (% of GDP) in the form of loans, purchases of nonequity securities, and trade credits and other accounts receivable, etc. The coefficients β_1, β_2, β_3, β_4, and β_5 denote the long-run elasticities of CO_2 with respect to energy use, economic growth, square of economic growth, international trade, and financial development, respectively. The subscripts i and t denote country and time, respectively.

The study uses annual unbalanced panel data over the period of 1960–2020, and are collected from the World Development Indicators (WDI [29]), World Bank, and BP statistical review (BP [4]) for 17 Asia–Pacific countries, namely, Australia, Bangladesh, China, India, Indonesia, Japan, Korea Republic, Malaysia, Nepal, New Zealand, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam, and the Russian Federation. Due to data unavailability, we had to limit this study to only 17 countries. The data are unbalanced because some data are not available for all the countries for all years.

4. Results and Discussion

4.1. Descriptive Statistics

The Table 2 provides the descriptive statistics of the studied variables. The values of mean, median, standard deviation, Jarque–Bera and corresponding probabilities of the natural log of CO_2 emissions, energy, GDP, GDP^2, trade, and financial development are reported in Table 2. The skewness displays that the CO_2 emissions and financial development are negatively skewed, whereas the GDP, GDP^2, and trade exert positive skewness. In terms of Kurtosis, all the variables expose platykurtic observation. Therefore, all the outcomes are consistent for further estimation.

Table 2. Descriptive statistics.

Descriptions	$LNCO_2$	LNENG	LNGDP	$LNGDP^2$	LNTRA	LNFD
Mean	0.675	6.909	7.800	63.873	7.520	3.853
Median	0.588	6.496	7.601	57.774	7.448	3.767
Maximum	3.640	9.617	11.129	123.865	12.329	5.399
Minimum	−2.691	4.559	4.617	21.314	3.505	0.651

Table 2. *Cont.*

Descriptions	$LNCO_2$	LNENG	LNGDP	$LNGDP^2$	LNTRA	LNFD
Std. Dev.	1.533	1.211	1.741	28.069	2.062	0.836
Skewness	−0.192	0.136	0.256	0.516	0.094	−0.182
Kurtosis	1.826	1.760	1.879	2.054	2.357	2.673
Jarque–Bera	36.947	39.026	36.742	47.475	10.866	5.798
Probability	0.000	0.000	0.000	0.000	0.004	0.055
Sum	392.368	4014.036	4532.072	37,110.330	4369.281	2238.834
Sum Sq. Dev.	1362.636	850.133	1758.042	456,974.000	2467.124	404.986
Observations	581	581	581	581	581	581

4.2. The Results of Autocorrelation, Heteroscedasticity, and Cross-Sectional Dependence

The results of heteroscedasticity and autocorrelation tests are reported in Table 3. The heteroscedasticity assumes the null hypothesis (H_0): there is no heteroscedasticity, and the alternative hypothesis (H_1): there is heteroscedasticity. Similarly, the autocorrelation case postulates the null hypothesis (H_0): there is no autocorrelation, and the alternative hypothesis (H_1): there is autocorrelation. The values of both Modified Wald test for group-wise heteroscedasticity and Wooldridge test for autocorrelation in panel data are 3859.440 and 284.336, respectively, which are significant at the 1% level, specifying the rejection of null hypotheses. Thus, the results suggest that the data used in this study have significant levels of autocorrelation and heteroscedasticity.

Table 3. The results of heteroscedasticity and autocorrelation tests.

Test	Test Statistic	*p*-Value	Presence
Modified Wald test for group-wise heteroscedasticity	χ^2 = 3859.440	0.000	Yes
Wooldridge test for autocorrelation in panel data	F-statistic = 284.336	0.000	Yes

The outcomes of cross-sectional dependence testing are reported in Table 4. The null hypothesis (H_0) of no cross-sectional independence is rejected at the 1% level of significance, suggesting acceptance of the alternative hypothesis (H_1) that there is strong cross-sectional dependence in these data.

Table 4. Cross-sectional dependence test results.

Variables	Pesaran (2004) CD Test	*p*-Value
$LNCO_2$	46.369 ***	0.000
LNENG	51.994 ***	0.000
LNGDP	79.667 ***	0.000
$LNGDP^2$	77.23 ***	0.000
LNTRA	63.281 ***	0.000
LNFD	37.037 ***	0.000

Note: *** denotes 1% significance level.

4.3. The Results of Driscoll and Kraay Standard Error Estimation

Considering the existence of heteroscedasticity, autocorrelation, and cross-sectional dependence in our sample panel data series, we perform estimations using Driscoll and Kraay's [28] standard error technique to address these issues and to obtain long-run links among the variables. In this case, the null hypothesis (H_0) is that there is no significant relationship of the explanatory variables with the CO_2 emissions, whereas the alternatives hypothesis (H_1) rejects the null hypothesis. The obtained results of panel estimation under this technique are reported in Table 5. The coefficient of energy consumption is positive and significant, indicating detrimental effects on CO_2 emissions that deteriorate the environmental quality. This research also finds a positive and significant impact of economic growth on CO_2 emissions, implying that higher economic growth leads to a higher CO_2 emissions level. The coefficient of squared economic growth is negative and significant at 1% level, indicating a matured growth level decreases CO_2 emissions. The positive and negative effect of economic growth and square of economic growth for the sample countries, respectively, support the EKC hypothesis. That means that CO_2 emissions increase with the increase in economic growth in the earlier stage of development, and after a certain level of development, when the countries are able to afford green technology, CO_2 emissions start to decline. The positive sign of the coefficient of international trade suggests that international trade negatively affects environmental quality. Finally, the effect of financial development on CO_2 emissions is positive, which indicates that more development of financial sectors ignoring environmental issues deteriorates the environmental quality.

Table 5. The results of Driscoll and Kraay standard errors model.

Variables	Coeff. (Prob.)
LNENG	0.358 *** (0.000)
LNGDP	1.235 *** (0.000)
$LNGDP^2$	−0.072 *** (0.000)
LNTRA	0.070 * (0.069)
LNFD	0.251 *** (0.000)
Constant	−8.306 *** (0.000)
within R-squared	0.844
F (5, 60)	540.81
Probability	0.000
Number of observations	581
Number of groups	16 (New Zealand has very low financial development data and the system may ignore this.)

Note: *** and * denote significance level at 1% and 10%, respectively.

The results of Table 5 indicate the significant influence of energy consumption, economic growth, trade, and financial development in the study areas. The energy consumption generates more emissions in the air through different direct and indirect channels, especially non-renewable energy. The burning of fossil fuel in the process of energy consumption exacerbates the air quality by increasing CO_2 emissions and hampers environmental sustainability and also the health condition of people. This outcome is in line with the findings of Balli et al. [101], Rahman and Vu [102], and Jamel and Derbali [103]. The economic growth in the primary stage of development degrades the environment by producing more CO_2 emissions. However, at the developed stage as shown by the coefficient of GDP, economic growth lessens CO_2 emissions due to the adoption of green innovations, green technologies, use of clean energy, environment friendly trade relations, green financial development, and environment-related higher health concern. These findings confirm the EKC hypothesis, which is pertinent to the findings of Tiwari et al. [42], Shahbaz et al. [35] and Rahman et al. [104], but not pertinent to the observations of Ozturk and Acaravci [40], He and Richard [41], and Zoundi [37]. Similarly, the development of international trade without environmental concern contributes to the degradation of environment by generating more CO_2 emissions. This result is consistent with the results of Jebli et al. [59] and Tiwari et al. [42], but not consistent with the findings of Shahbaz et al. [62] and Hasanov et al. [64]. Finally, financial development encourages more economic activities and industrial production, which cause more CO_2 emissions, thereby deteriorating environmental quality and human health. This finding is in line with the findings of Shen et al. [20] and Ehigiamusoe and Lean [70], but contradictory to the findings of Zaidi et al. [67] and Dogan and Seker [68].

4.4. Robustness Check: The Results of PCSE Regression

The robustness of the findings is checked by the reputed panel-corrected standard error (PCSE) model, which is shown in Table 6. All the findings are quite similar and relevant to the findings of Table 5. All the variables have rejected the null hypothesis (H_0) of no association and affirmed the alternative hypothesis (H_1) of prevailing association among them. Thus, Table 6 verifies that the energy consumption, economic growth, international trade, and financial development, positively, and square of economic growth, negatively, affect the CO_2 emissions.

Table 6. Panel-corrected standard error (PCSE) model results.

Variables	Coeff. (Prob.)
LNENG	0.569 *** (0.000)
LNGDP	0.472 *** (0.000)
LNGDP^2	−0.026 *** (0.002)
LNTRA	0.251 *** (0.000)
LNFD	0.124 *** (0.002)
Constant	−7.603 *** (0.000)
R-squared	0.692
Wald chi^2 (5)	1167.62
Probability	0.000
Number of observations	581
Number of groups	16

Note: *** denotes 1% significance level.

4.5. The Results of Pairwise Granger Causality Tests

Table 7 reports the causal links between economic growth, energy use, international trade, financial development, and CO_2 emissions based on the Granger [92] causality test. In this case, the rejection of the null hypothesis (H_0) of no causality affirms the alternative hypothesis (H_1) of causality within the variables. This study finds that there is a bidirectional causal relation between international trade and carbon emissions, and unidirectional causality from CO_2 emissions to energy use, economic growth, and square of economic growth, but no causality with financial development.

Table 7. The results of causality test.

Null Hypothesis	F-Stat.	Prob.	Decision
LNENG does not cause LNCO$_2$	0.158	0.854	LNCO$_2$→LNENG (unidirectional causality)
LNCO$_2$ does not cause LNENG	5.448 ***	0.005	
LNGDP does not cause LNCO$_2$	0.061	0.940	LNCO$_2$→LNGDP (unidirectional causality)
LNCO$_2$ does not cause LNGDP	8.935 ***	0.000	
LNGDP^2 does not cause LNCO$_2$	0.034	0.967	LNCO$_2$→LNGDP^2 (unidirectional causality)
LNCO$_2$ does not cause LNGDP^2	7.234 ***	0.001	
LNTO does not cause LNCO$_2$	16.530 ***	0.000	LNTO↔LNCO$_2$ (bidirectional causality)
LNCO$_2$ does not cause LNTO	16.357 ***	0.000	

Table 7. *Cont.*

Null Hypothesis	F-Stat.	Prob.	Decision
LNFD does not cause $LNCO_2$	0.475	0.622	No causality
$LNCO_2$ does not cause LNFD	1.284	0.278	

Note: *** denotes 1% significance level.

5. Conclusions and Policy Implications

This study investigates the impacts of energy consumption, economic growth, financial development, and international trade on the CO_2 emissions of 17 Asia–Pacific countries. Using unbalanced panel data for 61 years (1960–2020), the Driscoll and Kraay's [28] standard error and panel-corrected standard error (PCSE) models are employed to observe the effect of the studied variables on the CO_2 emissions. The obtained results reveal that energy consumption, economic growth, financial development, and international trade have adverse effects on the environment of the panel countries by increasing the CO_2 emissions, whereas the square of economic growth reduces it. The study also found evidence of the presence of the EKC hypothesis. Bidirectional causality is found between international trade and CO_2 emissions; a unidirectional causality from CO_2 emissions to energy consumption, economic growth, and square of economic growth is also revealed.

Therefore, the following policy implications can be drawn based on the obtained results. Firstly, energy, trade, financial development, and economic growth policies can be adopted jointly to ensure efficient and rational energy use and obtain sustainable long-run economic growth in the studied countries. Secondly, as energy use and economic growth negatively affect the environmental quality (positive impacts on CO_2 emissions), in principle, energy use and growth aspiration can be reduced in these countries; however, this is not a desired policy option. The best way for these countries is to explore integrated renewable and clean energy sources further to reduce the CO_2 emissions. Thirdly, although trade is also found to be detrimental to the environment, a reduction in trade and trade-related activities will yield negative growth effects in these countries; therefore, to produce tradeable goods, an increased use of clean and environment-protecting technologies will be a rational decision. Fourthly, financial development also increases CO_2 emissions, implying the urgent need for sustainable financial systems to be developed by considering green methods. Finally, carbon pricing in the form of taxes or a trade system or a cap, and research and development for clean energy and technological improvement, can also be helpful in reducing CO_2 emissions.

Despite the efficient and robust estimated results derived from the panel estimation technique (Sadorsky [12]), this research has the following limitations: (i) the conclusion and policy implications drawn here are applicable for the panel of 17 countries as a whole but may not be applicable for individual countries; and (ii) other potential factors such as population growth, FDI, and urbanisation are not considered here, which may also affect CO_2 emissions. Therefore, further research can be directed to explore the environmental issues on a country-by-country basis using time series data, considering all potential variables that have environmental effects.

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Abbreviations

Acronyms

APEC	Asia–Pacific Economic Cooperation
ASEAN	Association of South East Asian Nations
BP	BP statistical review
CD	Cross-sectional Dependence
CO_2	Carbon dioxide
EKC	Environmental Kuznets curve
ENG	Energy use
EU	European Union
FD	Financial development
GDP	Gross Domestic Product
OPEC	Organization of the Petroleum Exporting Countries
PCSE	Panel-corrected standard error
SSA	Sub-Saharan African
TRA	International trade
UN	United Nations
USA	United States of America
WB	World Bank
WDI	World Development Indicators

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