frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 18 January 2023
DOI 10.3389/fenvs.2022.1092196

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OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Environmental Economics and Management, a section of the journal Frontiers in Environmental Science

RECEIVED 08 November 2022
ACCEPTED 28 December 2022
PUBLISHED 18 January 2023

CITATION
Zhang T, Yin J, Li Z, Jin Y, Ali A and Jiang B (2023), A dynamic relationship between renewable energy consumption, non-renewable energy consumption, economic growth and CO2 emissions: Evidence from Asian emerging economies. *Front. Environ. Sci.* 10:1092196.
doi: 10.3389/fenvs.2022.1092196

RETRACTED: A dynamic relationship between renewable energy consumption, non-renewable energy consumption, economic growth and CO2 emissions: Evidence from Asian emerging economies

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RETRACTED

This study aims to explore the relationship between renewable energy consumption, non-renewable energy consumption, carbon dioxide emissions and economic growth in China, India, Bangladesh, Japan, South Korea and Singapore using panel Augmented Mean Group (AMG) estimation techniques over the period 1975–2020. The results of the analysis show that renewable energy consumption, non-renewable energy consumption, employed labor force, and capital formation contribute significantly to long-run economic growth. The study also found that non-renewable energy consumption significantly increased long-term carbon emissions, while renewable energy consumption significantly reduced long-term carbon emissions. GDP and GDP^3 have a significant positive impact on environmental degradation, while GDP^2 has a significant negative impact on environmental degradation, thereby validating the N-type EKC hypothesis in selected emerging economies. The countrywise AMG strategy records no EKC in India and Bangladesh, an inverted U-shaped EKC in China and Singapore, and an N-shaped EKC in Japan and South Korea. Empirical evidence from the Dumitrescue-Hurlin (2012) panel causality test shows that there is a two-way causality between renewable energy consumption and economic growth, supporting the feedback hypothesis. Strategically, empirical evidence suggests that higher renewable energy is a viable strategy for addressing energy security and reducing carbon emissions to protect the environment and promote future economic growth in selected Asian countries.

KEYWORDS

renewable energy consumption, non-renewable energy consumption, carbon emission, economic growth, emerging Asian countries

1 Introduction

Carbon dioxide (CO2) emissions have increased substantially by 88% over the past decade, from 25 million kilotons (MKT) in 1990 to 40.84 million kilotons (MKT) in 2020 (World Bank, 2020). The energy crisis and the problems of exacerbating carbon dioxide emissions are embroidered. Non-renewable energy consumption resources such as natural gas, coal and oil are considered to be the main culprits of environmental pollution and global warming (Gyamfi et al., 2021; Usman et al., 2022). The construction of sustainable energy through geothermal energy, solar energy, biomass energy and wind energy is considered to be the basic premise for the sustainable adjustment of total consumption (Assadi et al., 2022; Rahman and Velayutham, 2022). Economic development relies heavily on energy use considered in the era of denationalization and globalization, especially in emerging economies (Ghauri et al., 2021; Zhao, 2021). Industrial growth, output growth, income generation and employment creativity across the economy rely heavily on large amounts of renewable and non-renewable energy sources (Chen et al., 2021; Zahid et al., 2021). Sustainable energy is considered to have many qualities, and the enthusiasm for sustainable energy is due to the continued rise in carbon emissions leading to global ecological imbalances and rising temperatures. Over the past few decades, various researchers have contributed to the literature on energy consumption, growth, and sustainability.

The link between pollution and per capita growth is the main hypothesis of the Environmental Kuznets Curve (EKC). Ecological pollution rises with the expansion of economic growth until it exceeds the peak level, accepted the climax of this phenomenon by Ouyang et al. (2019); Khan et al. (2020); Adedoyin, Alola and Bekun (2020); Wawrzyniak and Doryń (2020). Pollution levels increase rapidly as the country develops, but after reaching the Kuznett U-curve turning point, pollution begins to decline. This empirical evidence fundamentally holds a firm grasp on the use of renewable energy and the country's structure. As suggested by Tang, Peng, and Xu (2018), productive and efficient use of energy consumption is an essential determinant of growth. The literature presents multiple panel studies, but ignores panel selections on the same theme in Asian emerging countries, China, Japan, South Korea, Singapore, India and Bangladesh. However; Liu, Kong, and Zhang (2021) reveal that in 5 selected emerging Asian countries (China, Japan, South Korea, Mongolia, and Russia), disaggregated energy (non-renewable and renewable) and urbanization increase long-term CO2 emissions, while economic growth reduces long-term CO2 emissions. Similarly, another study by Chapman, Fujii, and Managi (2018) selected a panel of Asian emerging countries (China, Japan, the Republic of Korea, the Democratic People's Republic of Korea, Mongolia, and Russia) and found that economic growth boosted carbon dioxide emissions in South Korea and China, decreased in North Korea and Russia, and moderately increased in Mongolia and Japan. Thus, correlating the results of this study with the aforementioned studies is one of the main aims of this study. Emerging Asian countries (China, Japan, South Korea, Singapore, India and Bangladesh) were selected as the main targets for 40% of their total energy consumption and 43% of their carbon emissions. Given the rising cost of imported energy, energy consumption is gradually becoming the focus of attention. Demand for fossil fuels has increased in selected emerging Asian countries over the past 40 years, particularly China, South Korea and Japan, which are the largest single contributors to greenhouse gas emissions, carbon dioxide emissions and other sources. Figure 1 identifies the GDP growth of selected emerging Asian economies, clearly showing that Japan has the highest GDP growth rate, while India and Singapore have the lowest growth rates in 2020. As shown in Figure 2, among the emerging Asian economies panel in 2020, South Korea has the highest carbon emissions and Bangladesh the lowest. India has the highest renewable energy usage in 2020 and Singapore the lowest, as shown in Figure 3. In 2020, China is the country with the highest consumption of non-renewable energy, while Singapore is the country with the lowest consumption in the emerging Asian countries panel, as shown in Figure 4.

This study has a dual goal: investigating the renewable and non-renewable energy consumption and growth nexus is at the forefront of research. The association intends to view economic growth as an increase in total output dependent on renewable and non-renewable energy sources, with more of this two energy consumption being the

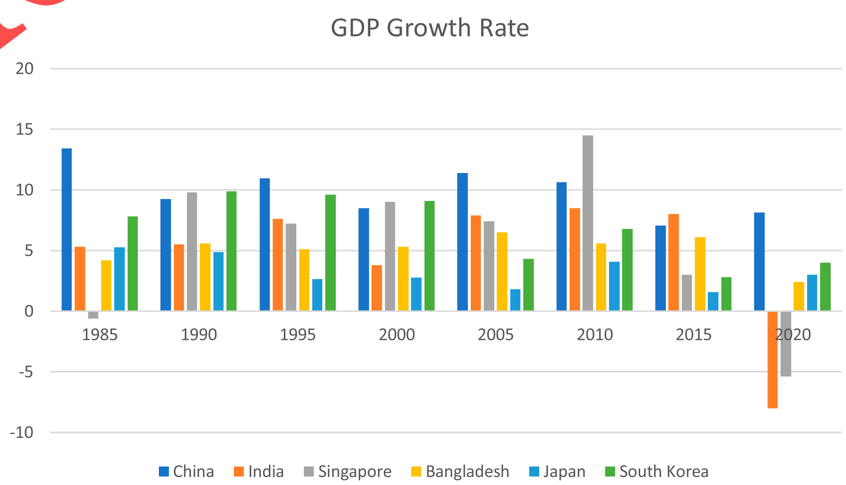

FIGURE 1
GDP growth rate, shown as an annual percentage for emerging Asian economies.

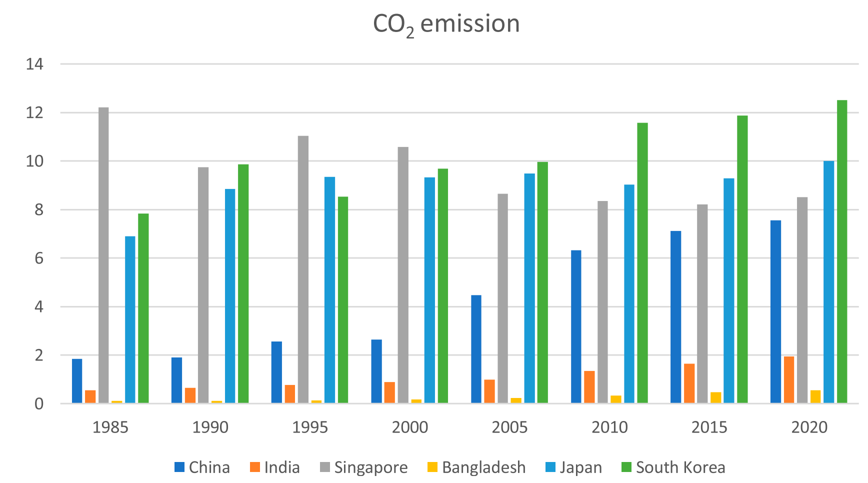

FIGURE 2
CO2 emissions as a percentage of total energy consumption, expressed in metric tons of carbon emissions.

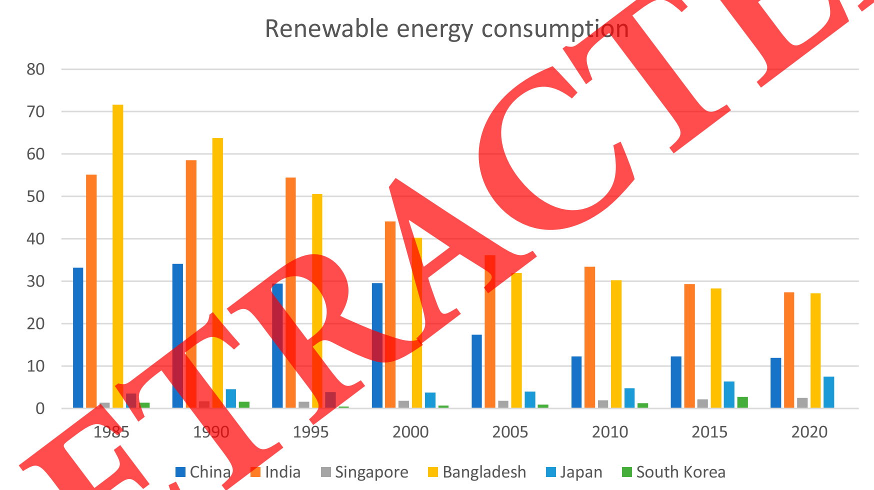

FIGURE 3
Renewable energy consumption in emerging Asian countries, expressed as a percentage of total energy.

determinants of higher growth. Thus, the causal relationship between renewable and non-renewable energy consumption and growth may be a unique contribution to the existing literature, as most early studies have looked at the link with total energy consumption. The second part of this study explores the interrelationship between renewable and non-renewable enenregy consumption and carbon emissions. This relationship clearly shows whether renewable energy consumption and non-renewable energy consumption contribute to or reduce carbon emissions in selected countries. The third part of the study estimates the linkage between economic growth and carbon emission. Finally, the validity of the environmental Kuznets curve (EKC) theory can be tested for the selected emerging Asian countries covering the 1975–2020 data range.

Given the prominence of growth and renewable energy consumption prospects, it is crucial to dynamically grasp the interconnections between renewable energy consumption, non-renewable energy consumption and economic growth. This association may contribute to the literature on sustainable energy futures and energy economics. Thus, the main contributions of this study are as follows: (i) There is a lack of studies identifying the differential impact of renewable and non-renewable energy consumption on growth, while most of the earlier studies looked at the link between total energy consumption and growth. This disaggregation opens avenues for understanding the relative potential of the two energy sources for the growth process. (ii) This will be the first study on emerging Asian countries whose latest data draws crucial insights for regional policymakers. (iii) This study addresses the potential omission of variable bias in the multivariate framework by adding three dimensions of renewable energy, non-renewable energy consumption, and carbon dioxide emissions to the production functions of neoclassical capital and

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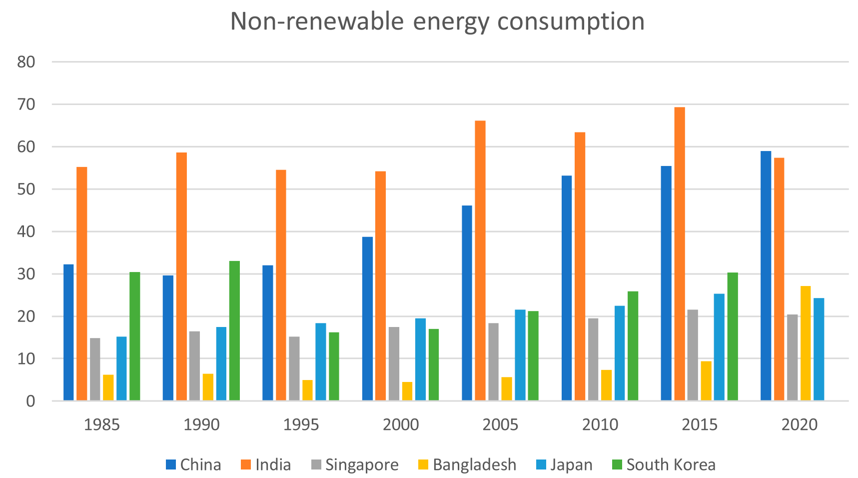

FIGURE 4
Non-renewable energy consumption in emerging Asian countries, expressed as a percentage of total energy.

labour. (iv) This study is the first to test the validity of the Environmental Kuznets Curve (EKC) hypothesis in emerging Asian countries.

2 Literature review

The real fountain of energy and growth is natural resources; however, the fundamental factor measuring growth is the consumption of renewable and non-renewable energy (Xia & Zhang, 2019). Ambec et al. (2020) call on environmental economists to explore research by trying to shed light on hypotheses about the energy-growth relationship. Along these lines, Bilgili, Koçak & Bulut (2020), Yilanci et al. (2021), Shakeel (2021), Mighri and Ragoubi (2020), Ahmad et al. (2020a), Doğan, Balsalobre-Lorente and Nasir (2020) proposed four hypotheses (growth, feedback, conservation, and neutrality) in their seminal work on growth and energy hypothesis research. The causal link from energy to growth is a one-way causal relationship known as the growth hypothesis. In this context, growth in energy consumption is positively correlated with growth, which is likely to strengthen sustainable infrastructure and increase productivity. One-way causality from growth to energy consumption is the second conservation hypothesis. The third feedback hypothesis highlights the bidirectional causality from energy consumption to economic growth and from economic growth to energy consumption. In this case, a higher expansion or contraction of energy consumption corresponds to a gradual or weakening growth outlook, and conversely, an increase or decrease in growth may correspond to a decline or expansion of energy consumption. Finally, the absence of causality between the energy and growth relationship indicates a neutral hypothesis, implying that reducing or increasing energy use does not affect economic growth and *vice versa*. Balsalobre-Lorente and Leitão (2020) used panel fully modified least squares (FMOLS), fixed effects (FE) and panel dynamic least squares (DOLS) to estimate the relationship between energy consumption and economic growth in selected 28 EU countries over the data 1995–2014. The findings show that higher energy use significantly boosts economic growth in selected countries, supporting the growth hypothesis.

Similarly, another study supporting the growth hypothesis by Topcu, Altinoz, and Aslan (2020) used a panel vector autoregressive (PVAR) approach to select 128 countries by income level over the period 1980–2018. Ndlovu and Inglesi-Lotz (2020) use data from 1996 to 2015 to explore causal relationships between renewable energy, non-renewable energy consumption, economic growth, and R&D spending in the BRICS countries. The study findings indicate a unidirectional causality from Non-renewable energy consumption to economic growth in Brazil and South Africa, hence consistent with the growth hypothesis. Similarly, the studies supporting the growth hypothesis are Joshua, Uzuner and Bekun (2020).

The second strand of studies relating to the causal relation between growth to energy use is known as the conservative hypothesis. Banday and Aneja, (2019) applied the Bootstrap Dumitrescu and Hurlin panel causality test to discover the causal relationship between energy consumption and economic growth in the BRICS countries over the period 1990–2017. The findings suggest a one-way causality from economic growth to energy consumption in China, India, Brazil and South Africa. Umurzakov et al. (2020) used the Dumitrescu and Hurlin (2012) panel Granger causality test to examine the relationship between energy and economic growth in post-communist countries, covering data from 1995 to 2014. The results show that there is a one-way causal relationship from economic growth to energy consumption, which is consistent with the conservative hypothesis. Fan and Hao (2020) used annual data from 2000 to 2015 to investigate the relationship between renewable energy consumption, foreign direct investment, and economic growth in 31 provinces in China. The findings suggest that there is a unilateral causal relationship from economic growth to renewable energy consumption. Studies supporting the conservative hypothesis are Ahmed et al. (2022), Singh and Vashishtha, (2020), Munir, Lean and Smyth (2020), Sunde, (2020).

The third hypothesis is feedback, reflecting that the relationship between energy consumption and economic growth is bidirectional. Chontanawat (2020) revealed the dynamic relationship between non-renewable energy consumption and economic growth in ASEAN countries in the 1971–2015 data range. The findings underscore support for the feedback hypothesis that there is a bidirectional causal relationship between energy consumption and economic growth in ASEAN countries. Another study by Le and Sarkodie (2020) used the Dumitrescu and Hurlin method to gain insight into energy and economic growth causality in 45 developing economies over the period 1990–2014. The findings support the feedback hypothesis, strongly agreeing on a pairwise causal relationship between energy consumption and economic growth. Similarly, another study by Agboola, Bekun, and Joshua (2021) used the Toda-Yamamo modified Wald test to examine the direction of causality between energy consumption and economic growth in Saudi Arabia over the period 1971–2016. The results support the feedback hypothesis, clearly indicating a bidirectional causal relationship between energy consumption and economic growth in Saudi Arabia. Others studies supporting feedback hypothesis are Peng and Wu (2020), Ahmad et al. (2020b), Banday and Aneja (2019), Saidi and Omri (2020), Syzdykova et al. (2020), Adams et al. (2020), Koengkan, Fuinhas and Santiago (2020), Alkhars et al. (2020), Pala (2020), Rahman and Vu (2020), Nasreen, Mbarek and Atiq-ur-Rehman (2020).

The neutral assumption involves an independent relationship between energy consumption and economic growth. Krkošková (2021) uses data from 2005 to 2019 to explore the relationship between energy consumption and real GDP in V4 countries. The study analysis found no significant relationship between Poland's energy consumption and real GDP, so the results fit the neutral assumption. Li and Leung (2021) estimated the interlinkage between renewable energy consumption and economic growth in seven European countries from 1985 to 2018. The results of the analysis support evidence of no causal relationship between renewable energy and economic growth in selected European countries.

Vural (2020) found long-term cointegration between renewable energy consumption, non-renewable energy consumption output, trade, and carbon emissions using a second-generation panel cointegration test in eight Saharan African countries during the period 1980–2014. Long-term variable elasticities show that a 1% increase in non-renewable energy consumption expand carbon emissions by 0.09%, while a 1% increase in renewable energy consumption reduces carbon emissions by 0.015% in selected countries. Moreover, the analysis supports the validity of the EKC hypothesis for selected countries. Likewise, Destek and Sinha, (2020) used a second-generation approach to explore the validity of the EKC hypothesis for the ecological footprint of developing countries, covering the period 1980–2014. The results of the group mean method disregard the existence of the inverted U-shaped EKC hypothesis, but there is a U-shaped EKC relationship between ecological footprint and economic growth in the developing economies. Another recent study by Mahmood and Furqan (2021b) revealed an inverted U-shaped relationship between economic growth and CO2, thereby supporting the inverted U-shaped EKC hypothesis in the Gulf Cooperation Council (GCC) region. Zhang, Yang, and Jahanger (2022) used updated fully modified (CUP-FM) and continuously updated bias-corrected (CUP-BC) estimators to test the validity of the EKC hypothesis for the top ten recipient countries of remittances during the period 1990–2018. The results of the analysis demonstrate the validity of the inverted U-shaped EKC hypothesis for selected countries. Jena et al. (2022) used an autoregressive distributed lag (ARDL) model for panel estimation to test EKC validation in China, India, and Japan over the 1980–2016 data range. The recorded findings validate U-shaped EKCs in India and Japan, and an inverted U-shaped EKC in China. Moreover, Mahmood (2020a) explored an inverted U-shaped relationship between GDP per capita and CO2 emissions per capita, thereby validating the U-shaped EKC hypothesis for 6 of 21 North American countries.

Likewise, recent studies have found EKC hypotheses for individual countries and groups of countries, such as Wang et al. (2022a) found an inverted U-shaped EKC hypothesis in China. Luo et al. (2022) explored inverted EKC hypothesis for China, India and Singapore, Ali et al. (2022) documented inverted EKC hypothesis for Pakistan, India, Malaysia and china (PIMC).

The above literature, despite having many panel studies, ignores panel selection on the same topic in emerging Asian countries, Japan, Singapore, South Korea, Bangladesh, India and China. Furthermore, the literature rarely identifies causal relationships among disaggregated renewable energy consumption, non-renewable energy consumption, economic growth, and carbon emissions, and tests the validity of the EKC hypothesis in the proposed panel of emerging Asian countries.

3 Model development, data and methodology

Regarding the relationship between energy consumption and economic growth, two diametrically opposed views have been put forward in the existing literature. The first view that energy consumption has a weak relationship with aggregate output is based on neoclassical growth theory; instead, total production is largely determined by the development of labour, capital, and technology (DeMartino & Grabel, 2020; Katzenstein, 2020). Even the Harrod Domar and Solow-Swan model did not consider energy as an input of production function. The Harrod Domar and Solow-Swan models do not even consider energy as an input to the aggregate production function (Ayres & Warr, 2010; Rahman et al., 2022). Energy may be an important factor of production, a second point of view in the literature presented by Bamati and Raoofi (2020) and Zeqiraj, Sohag, and Soytas (2020). Energy, infrastructure, labour and capital as critical inputs determine the higher growth process (Krausmann et al., 2020; Nieto et al., 2020). Thus, following the work of Shah, Chughtai and Simonetti (2020), Lu et al. (2020), Chi et al. (2021), and Hao et al. (2020), based on the notion that infrastructure, labour and capital are key inputs for economic growth. The theoretical basis of the model is based on the Cobb-Douglas production function, as follows.

$$Y_{it} = K_{it}^{\alpha_{1i}} L_{it}^{\alpha_{2i}} \mu^{e_{it}} \tag{1}$$

Where Y denotes total production, K is capital, L indicate labour, μ is the error term, which includes all other unobserved factors of production, and i and t are country and time subscripts, respectively. Consistent with the aforementioned studies, the model is extended by including renewable energy consumption, non-renewable energy consumption and carbon emissions as the main determinants of total production, as mentioned below.

$$GDP = f\,(REC, NREC, L, CO_2, K), \tag{2}$$

To determine the objectives of the study, the following equations in log-linear form were derived from the above model.

$$lnGDP_{it} = \alpha_0 + \alpha_1 lnNREC_{it} + \alpha_2 lnCO_{2it} + \alpha_3 lnREC_{it} + \alpha_4 lnL_{it} + \alpha_5 lnK_{it} + \varepsilon_{it} \quad (3)$$

$$lnCO_{2it} = \kappa_0 + \kappa_1 lnREC_{it} + \kappa_2 lnNRECit + \kappa_3 lnGDP_{it} + \kappa_4 lnGDP^2_{it} + \kappa_5 lnGDP^3_{it} + e_{it} \quad (4)$$

where GDP stands for Gross Domestic Product, used as a surrogate for economic growth, NREC displays non-renewable energy consumption, REC identifies Renewable energy consumption, CO_2 demonstrates carbon dioxide emission, L indicates labour force, and K displays Gross fixed capital formation. Besides, GDP^2 is GDP squared, GDP^3 is GDP raised to the third power. κ_0, and α_0 are the models intercepts, α_i, and κ_i are the variables model coefficients, i used for country, where t for country and time period. Likewise, in the proposed models, e_{it} and μ_i are the error terms.

Testing of the U-shaped, inverted U-shaped, or N-shaped EKC hypothesis for emerging Asian countries depends on estimates of the following parameters.

$\kappa_3 > 0$, $\kappa_4 < 0$, the legitimacy of the EKC hypothesis is an inverted U shape. $\kappa_3 < 0$, $\kappa_4 > 0$, the acceptability of the EKC assumption is U-shaped $\kappa_3 > 0$, $\kappa_4 < 0$ and $\kappa_5 > 0$, the legitimacy of the EKCs hypothesis is N-type.

This study primarily focuses on empirically exploring the links between renewable energy consumption, non-renewable energy consumption, carbon emissions and economic growth in selected emerging Asian countries from 1970 to 2020. The suggested model variable measurements and descriptions are explicitly highlighted in below. The renewable energy consumption (REC) can be measured for a particular year and country using two variables data, renewable energy consumption as a percentage of total final energy consumption and total energy consumption in kg of oil equivalent (Mtoe). Multiply the total energy consumption in kilograms of oil equivalent (Mtoe) by the renewable energy consumption as a percentage of total energy consumption and divide by 100 to get the renewable energy consumption in kilograms of oil equivalent (Mtoe). That is,

$$\text{Total renewable energy} = \frac{\text{Total energy consumption * Renewable energy consumption expressed as percentage of total energy consumption}}{100}$$

Non-renewable energy consumption (NREC) is measured in a million tons of oil equivalent (Mtoe), carbon dioxide (CO2) emission measured in million metric tons (Mmt), the labour force (L) in million, gross domestic product (GDP) and capital (K) are both in constant 2015 US dollars. Data for the analysis of the above variables can be collected from the World Development Indicators (WDI), World Bank's public website. GDP is the total output of a country in a given year and is used as a proxy for economic growth. Employment labor and capital formation are the control explanatory variables used for growth purposes in the standard growth model of the study.

Cross-sectional dependecy in panel data estimation techniques lead to biased regression analysis and inference. Thus, detecting cross-sectional dependencies in variable models of panel data is an important part of research analysis (Bilgili et al., 2020; Munir et al., 2020). Thus, this study applies the cross-sectional depednece test introduced by Pesaran, (2007) to explore cross-sectional correlation in panel data. After analyzing the initial cross-sectional dependencies, the integral properties of each variable were examined using the cross-sectional enhanced Im-Pesaran-Shin (CIPS) unit root test proposed by Pesaran (2007); Pesaran (2007) modified the standard Dikey-Fuller test to take the cross-sectional country-specific data lags as the mean while taking into account cross-sectional dependencies. Pesaran assumes the following regression to estimate a single cross-section augmented Dickey-Fuller (CADF) statistic.

$$\Delta y_{it} = \alpha_i + \delta_i y_{i,t-1} + \phi_i \bar{y}_{t-1} + \theta_i \Delta \bar{y}_{t-1} + \upsilon_{it} \quad (5)$$

The null hypothesis (H0: $\delta_i = 0$ for all i) reflects that the variables in the model have a unit root, while the alternative hypothesis (H_1: $\delta_i < 0$) states that the variables do not have a unit root.

$$CIPS = \sum_{i=1}^{N} CADF_i \Big/ N$$

After determining the order of integration for each variable, this study examines the robustness of the estimated results by applying the Westerlund cointegration test, Pedroni (1999, 2004) cointegration test and the Kao (1999) cointegration test. Pedroni (1999, 2004) and Kao (1999) cointegration tests based on Engle and Granger (1987) residual-based two-step cointegration tests. The first Pedroni (1999, 2004) residual-based cointegration tests included two-line cointegration tests, panel tests, and group tests. Panel tests include panel ADF statistic, panel PP statistic, panel v statistic, and panel rho statistic, while group tests include group ADF statistic, group rho statistic, and group PP statistic. These seven statistics are derived from the following long-term model and are asymptotically separated or dispersed by the standard normal.

$$Z_{it} = \beta i + \rho i + \sum_{j=1}^{k} \alpha_{ji} X_{jit} + \mu_{it} \quad (6)$$

where it is assumed that the desired variables Z and X are integrated at the first derivative.

The estimated residual structure is highlighted as;

$$\mu_{it} = \lambda_i \mu_{it-1} + \varepsilon_{it} \quad (7)$$

Pedroni (1999), Pedroni (2004) proposed the following panel data cointegration system and assumed no cointegration among the variables in the null hypothesis.

$$Z_{it} = \beta_i + \alpha X_{it} + \mu_{it} \quad (8)$$

The proposed Pedroni seven cointegration tests can be compared with the maximum likelihood based panel cointegration statistic.

Kao's cointegration technique, introduced by Kao (1999), is another test use in this study, which can give long-term cointegration results similar to Pedroni's test, and can be applied under the assumption of cross-homogeneity coefficients. Thus, the Kao and Pedroni cointegration tests are known to be the first generation of cointegration tests because these tests have the weakness of assuming cross-sectional independence, although these two cointegration tests have been widely used by various studies. These first-generation tests cannot account for the existence of cross-

TABLE 1 Result of cross sectional dependence test.

Test	Statistics	Probability
Breusch-Pagan LM	381.82***	0.005
Pesaran scaled LM	99.82***	0.003
Bias-corrected scaled LM	78.86***	0.006
Pesaran CD	9.89***	0.001

Note: ***, indicating that the statistic is significant at the 1% level.

sectional dependence, and thus the results obtained by these tests are invalid. Hence, this study uses the second-generation Westerlund (2007) cointegration test that considers the cross-sectional dependence problem.

After establishing long-term panel cointegration, panel dynamic ordinary least squares (DOLS) and fully modified ordinary least squares (FMOLS) may be the best options for determining long-term variable elasticity, but FMOLS and DOLS strategies ignore cross-sectional dependencies (Rahman et al., 2021). Econometric models are subject to cross-sectional dependencies and country-specific heterogeneity, which can lead to biased or misleading inferences (Simionescu & Schneider, 2022). Thus, the Augmented Mean Group (AMG) method proposed by Eberhardt and Bond (2009) and Teal & Eberhardt (2010). Can produce more robust results than traditional methods while overcoming these problems. The main advantage of the AMG estimator can help achieve more adequate policy-oriented goals and provide country-specific results. The AMG estimation functional form is contained in a two-stage process and can be expressed in Eqs 9, 10 as follows:

$$\Delta Z_{it} = \beta i + \rho_i \Delta x_{it} + \kappa_i g_t + \sum\nolimits_{t=2}^{T} \alpha_i \Delta h_t + \varepsilon_{it} \quad (9)$$

$$\hat{\beta}_{AMG} = N^{-1} \sum\nolimits_{t=2}^{T} \hat{\beta}_i \quad (10)$$

Where βi is the intercept, Zit and Xit represent observed factors and ρi is the cross sectional coefficient estimator, gt shows the unobserved factors with heterogeneous dynamics, α_i represents the dummy coefficient of time. Moreover, $\hat{\beta}_{AMG}$ indicates the augmented mean Group (AMG) estimator and εit expresses the error term.

Although the coefficients estimated by the AMG estimation technique indicate long-term relationships in variable series, these tests cannot detect causal relationships between variables. Thus, the Granger causality test developed by Dumitrescu and Hurlin (2012) can be used to demonstrate causal relationships between variables. This test only applies when the time dimension (T) is below or above the cross-sectional dimension (N) (T > N) or (T < N). This statistical test is compelling with small sample sizes and is based on cross-sectional dependency, Monte Carlo simulation, and Wald statistics (Kaldorf & Wied, 2020; Le & Ozturk, 2020). The Dumitrescu-Hurlin test is an extended version of determining the causality of long-term panel variables and can be written as:

$$z_{ti} = \beta i + \sum\nolimits_{n=1}^{k} \rho_{i_i}^{k} z_{i,t-k} + \sum\nolimits_{n=1}^{k} \lambda_{i_i}^{k} x_{i,t-k} + \mu i, t$$

Where $z_{i,t}$ and $x_{i,t}$ are two stationary variables observations of individual i in period t. k portrays the lag length, $\rho_{i_i}^{k}$ is the autoregressive parameter while $\lambda_{i_i}^{k}$ represent the regression coefficient that vary within the groups. Panel variables must be balanced, and lags K are assumed to be similar for all variables. This test produces a fixed coefficient model of a fixed type, allows for heterogeneity, and is normally distributed.

The null hypothesis of no causality and the alternative hypothesis to test the causality between variables are as follows:

$$Ho: \alpha i = 0 \forall_I = 1, \ldots K$$
$$H1: \alpha i = 0 \forall_I = 1, \ldots K_1$$
$$\alpha i \pm 0 \forall_I = K_1 + 1, K_1 + 2, \ldots K$$

Here, K_1 specifies the unrecognized parameter, but it satisfies condition $0 \leq K_1/K < 1$.

In any case, the ratio of K1/K is inevitably lower than 1, because if Ki = K, this means that for any panel cross-section, there is no causal relationship, so accept the null hypothesis. Conversely, when K1 = 0, this indicates causality for all individuals in the panel.

First, Table 1 below shows the results of the cross-sectional dependence test, clearly showing highly significant statistics at the 1% level for all the tests, thus confirms rejection of the null hypothesis of no cross-sectional dependence and accepts the alternative hypothesis of cross-sectional dependence at the 1% significance level in the panel variables. Thus, second-generation panel data methods, including the Westerlund cointegration test, are feasible due to the acceptance of cross-sectional correlations (Pesaran & Tosetti, 2011). Besides, the presence of cross-sectional correlations allows the use of second-generation panel unit root techniques to test the level of variable integration (Dogan et al., 2020; Yunzhao, 2022; Payne & Apergis, 2021).

The CIPS unit root test is suitable for testing the level of stationarity of variables due to cross-sectional dependence in

TABLE 2 The results of CIPS unit root test.

			LnGDP	lnCO$_2$	lnRE	lnNRE	lnL	lnK
Levels	Constant		−1.31	−1.24	−1.72	−2.38	−1.74	−1.09
	Trend + Constant		−2.42	−1.69	−1.81	−1.10	−1.38**	−1.79
First differences	Constant		−3.99***	−2.28***	−3.91**	−4.57***	−4.54***	−5.52***
	Trend + Constant		−3.12***	−2.62***	−3.45***	−4.63***	−4.95***	−4.03***
Critical Values	−2.10 (10%)	−2.66 (10%)						
	−2.38(5%)	−2.77 (5%)						
	−2.46 (1%)	−2.96 (1%)						

*Note: K = 2 is the maximum lag length chosen, ***, ** and * show significance levels of 1%, 5% and 10%, respectively.*

TABLE 3 Panel descriptive statistics and correlation analysis.

Variables	Average	SD	Max	Min	InGDP	InREC	$InCO_2$	InNREC	InL	InK	VIF
lnGDP	1211.172	739.548	1838.7	474.548	1						
InREC	3.769	.663	7.1397	1.518	−0.877	1					4.66
$InCO_2$	11.833	5.329	27.937	17.869	0.895	−0.983	1				4.48
InNREC	16.831	4.549	25.614	7.542	0.851	−0.942	−0.482	1			4.29
InL	525.48	195.427	927.318	362.718	−0.373	−0.898	0.584	0.926	1		3.47
InK	7424.496	1627.837	13286.473	3678.472	−0.467	−0.584	0.671	0.737	−0.869	1	3.91

Note: SD denotes standard deviation, VIF indicates variance inflation factor, Max and Min are maximum and minimum values respectively.

TABLE 4 The findings of panel Cointegration test by Pedroni (1999,2004), Kao (1999) and Westerlund, (2007) cointegration test.

	Within-dimension	
	Statistics	*p*-value
Panel v-Statistic	1.90**	(0.03)
Panel rho-Statistic	0.83	(0.84)
Panel PP-Statistic	−1.29***	(0.00)
Panel ADF-Statistic	−3.32***	(0.01)
	Between-dimension	
Group rho-Statistic	1.32	(0.89)
Group PP-Statistic	−3.25***	(0.00)
Group ADF-Statistic	−2.38***	(0.00)
Kao (1999) residual co-integration test		
ADF	−3.57***	(0.00)
Westerlund (2007) cointegration test		
Gt	−5.92***	(0.00)
Ga	−5.32***	(0.00)
Pt	9.45***	0.00
Pa	−16.43***	0.00

Note: ** and *** indicates 5% and 1% significance level.

variable data models. The unit root results in Table 2 clearly show that, at level, variables with a unit root of the null hypothesis are accepted. However, the non-stationary variables can be transformed into a stationary state at the first derivative, thereby rejecting the null hypothesis and accepting the alternative hypothesis. Due to the variable homogeneous integral nature of I(1), the cointegration relationship among the proposed model variables must now be explored.

The descriptive statistics in Table 3 show that the average GDP of the selected countries is $1211.172 billion, and shows the large change represented by its standard deviation over the period 1975–2020. Carbon dioxide emissions from these Asian countries averaged 11.833 billion metric tons, with a range of 27.937 to 17.869 billion metric tons. The average renewable and non-renewable energy intensities were 3.769 and 16.831, respectively, reflecting energy use in million tonnes of oil equivalent (Mtoe). Average employed labor force and gross fixed capital formation for selected countries were 525.48 million and $7,424.0 billion, respectively. Correlation coefficient and variance inflation factor (VIF) for each variable to check for multicollinearity issues in the models shown in Table 3. The results show that the model does not suffer from multicollinearity problems, as all values of VIF are lower than 5.

As shown in Table 4, three cointegration tests of Pedroni (1999, 2004), Kao (1999), and Westerlund (2007) have been used to reveal long-term cointegration relationships among variables. The results of Pedroni cointegration analysis based on the 7-panel cointegration tests, including the significance of three statistics within dimensions and the significance of two statistics between dimensions, rejected the null hypothesis of no cointegration. The long-term cointegration relationship results can also be verified by the significant ADF statistic of the Kao panel cointegration test. The current study also employed the Westerlund cointegration test for long-term cointegration, which outperformed first-generation cointegration tests by accounting for cross-sectional dependencies and checking for bias from previous tests. The Westerlund cointegration results support the existence of cointegration because the panel cointegration statistics Pa and Pt, and the group statistics Ga and Gt for individual countries are significant.

Table 5 reports the results of the long-term estimated parameters in the proposed model of Eqs 3, 4. AMG's estimates of variable coefficient elasticity based on economic growth model show that every 1% increase in renewable energy consumption, non-renewable energy consumption, employed labor force and capital accumulation can drive economic growth by 0.882%, 0.659%, 0.605% and 0.985%, respectively. The carbon dioxide emission coefficient is −0.576, that is, for every 1% increase in carbon emissions, economic growth may shrink significantly by 0.576%. The results for the markedly progressive effects of renewable and non-renewable energy consumption on growth are very consistent with Mujtaba et al. (2022); Anwar et al. (2022); Rehman et al. (2022); Vo (2022); Adebayo et al. (2022); Fang et al. (2022); and stanek (2022).

Long-term variable elasticity coefficients based on carbon emission model show that every 1% increase in non-renewable energy consumption can stimulate carbon emissions by 0.614%. Every 1% boost in renewable energy consumption can significantly reduce CO2 emissions by 0.736%. The results of the progressive effect of non-renewable energy consumption on carbon emissions and the opposite effect of renewable energy consumption on carbon emissions

TABLE 5 Results of the panel AMG method for estimating parameters, lnGDP = f (lnCO$_2$, lnNREC, lnREC, lnL, lnK).

Variables	MG		AMG		CCEMG	
	Coeff		p-value		Coeff	
lnNREC	0.534***	(0.000)	0.659***	(0.003)	0.281***	(0.000)
lnREC	0.714***	(0.001)	0.882***	(0.005)	0.629***	(0.003)
lnCO$_2$	−0.465***	(0.004)	−0.576***	(−0.006)	0.372***	(0.000)
lnK	0.832**	(0.042)	0.985*	(0.002)	0.183*	(0.052)
lnL	0.735*	(0.053)	0.605**	(0.004)	0.391*	(0.061)

lnCO$_2$ = f(lnNREC, lnREC, lnGDP.lnGDP^2, lnGDP^3).

Variables	MG		AMG		CCEMG	
	Coeff	p-value	Coeff	p-value	Coeff	p-value
lnNREC	0.647***	(0.003)	0.614***	(0.000)	0.318**	(0.032)
lnREC	−0.659***	(0.000)	−0.736**	(0.031)	0.413***	(0.000)
lnGDP	0.848***	(0.002)	0.506***	(0.003)	0.328***	(0.002)
lnGDP^2	−0.658***	(−0.002)	−0.705***	(0.000)	−0.327	(−0.213)
lnGDP^3	0.284*	(0.064)	0.821*	(0.051)	0.812***	(0.000)

Note: ***, ** and * indicate statistical significance at 1% level, 5% level and 10% level respectively, where inside in the parentheses are probability values.

10.3389/fenvs.2022.1092196

TABLE 6 Country-specific analysis results estimated by the AMG method, lnGDP = f ($lnCO_2$, lnNREC, lnREC, lnL, lnK).

Country	lnK	lnL	lnREC	CO_2	lnNREC	R^2	Adjusted R^2
India	0.832*** (0.003)	0.662*** (0.009)	0.662*** (0.001)	−0.362*** (−0.002)	0.312*** (0.000)	0.98	0.97
China	0.321*** (0.000)	0.373* (0.054)	1.382*** (0.006)	−0.187*** (−0.002)	0.472*** (0.003)	0.96	0.97
Bangladesh	0.213* (0.072)	0.865* (0.083)	0.643*** (0.007)	−0.532* (−0.062)	0.254* (0.062)	0.98	0.99
Japan	0.574*** (0.002)	0.998*** (0.001)	0.532*** (0.005)	−0.731 (−0.372)	0.244*** (0.008)	0.98	0.98
Singapore	0.741*** (0.000)	−0.543 (-0.594)	0.312* (0.063)	−0.95* (−0.052)	0.543 (0.273)	0.98	0.99
South Korea	0.374***	0.727*	0.587***	−0.482**	0.3132***	0.98	0.98
	(0.002)	(0.002)	(0.001)	(−0.032)	(0.002)		

lnCO2 = f(lnNREC, lnREC, lnGDP., lnGDP2)

Country	lnGDP	$lnGDP^2$	$lnGDP^3$	lnREC	lnNREC	R^2	Adjusted R^2
India	0.923***	0.832***	−0.732	−0.952***	0.741***	0.97	0.98
	(0.002)	(0.000)	(−0.322)	(−0.002)	(0.001)		
China	0.543***	−0.482***	−0.256***	−0.313***	0.69***	0.98	0.97
	(0.002)	(−0.005)	(0.002)	(−0.001)	(0.001)		
Bangladesh	0.293	0.878**	−0.815	0.532*	0.253*	0.98	0.99
	(0.983)	(−0.006)	(−0.631)	(−0.073)	(0.071)		
Japan	0.684***	−0.872***	0.218***	−0.843***	0.352***	0.99	0.98
	(0.009)	(−0.002)	(0.006)	(−0.004)	(0.003)		
Singapore	0.851***	−0.634*	−0.582***	−0.274	0.652***	0.99	0.98
	(0.001)	(−0.007)	(−0.005)	(−0.452)	(0.001)		
South Korea	0.48***	−0.823	0.981*	−0.603***	0.464***	0.98	0.99
	(0.000)	(−0.006)	(0.063)	(−0.001)	(0.005)		

Note: *,** and ***, indicate statistical significance at 10%, 5% and 1%, respectively. Inside in the parentheses are probability values.

TABLE 7 Dumitrescu-Hurlic results for panel causality between variables.

Direction of causality	W-Stat	Zbar-Stat	Prob
lnREC → lnGDP	2.72***	1.88***	0.01
lnGDP → lnREC	4.98***	4.49***	0.00
lnNREC → lnGDP	3.93	1.62	0.82
lnGDP → lnNREC	4.63	2.24	0.53
lnK → lnGDP	1.52***	1.34***	0.00
lnGDP → lnK	4.84	4.35	0.83
lnL → lnGDP	3.48	1.43	0.99
lnGDP → lnL	1.40	1.24	0.98
$LnCO_2$ → lnGDP	2.95	−1.48	0.70
lnGDP → $lnCO_2$	2.49**	2.20**	0.02

Note: ** and *** indicate statistical significance at 5% and 1%, respectively.

are in good agreement with Mujtaba et al. (2022); Luo et al. (2022); Adebayo et al. (2022); Rehman et al. (2022); Anwar et al. (2022); Fang et al. (2022); Afroz and Muhibbullah (2022).

According to the analysis of the AMG method, the coefficient signs of GDP and GDP^3 are significantly positive (GDP>0, GDP^3>0), GDP^2 is significantly negative (GDP^2<0), indicating that GDP and GDP^3 have a significant positive impact on environmental degradation, while, GDP^2 has a significant adverse impact on environmental degradation. These results confirm the validity of the N-shaped EKC hypothesis in selected emerging Asian countries. The progressive impact of GDP on environmental degradation reflects the use of more non-renewable energy sources to expand production in selected countries, thereby deteriorating environmental quality. This result shows that after the level of economic growth reaches a certain threshold, the economy realizes that the environment can be protected by using renewable energy to increase productivity levels. The positive effect of cubed GDP on carbon emissions is due to the high demand for industrial goods in external markets, the failure of trade agreements and the environmental conditions for trade liberalization. Selected countries neglect environmental technologies and use non-renewable energy sources to meet external demand for industrial products, thereby deteriorating environmental quality.

Country-wise estimation results by the AMG strategy are reported in the following Table 6. The findings show that

TABLE 8 Results of pairwise causality for individual countries.

	India		China		Bangladesh		Japan		Singapore		South Korea	
Null hypothesis	F-Stat	Prob	F-Stat	Prob	F-Stat	Prob	F-Stat	Prob	F-Stat-	Prob	F-stat	Prob
lnREC → lnGDP	3.26**	0.03	0.95	0.63	0.46	0.92	0.76**	0.04	1.68	0.98	2.25***	0.00
lnGDP → lnREC	1.38***	0.00	4.08***	0.00	2.25*	0.08	2.45* *	0.03	2.37	0.95	1.35**	0.03**
lnNREC → lnGDP	1.24	0.36	0.42***	0.00	0.73	0.36	0.88	0.45	0.56**	0.03	2.45***	0.00
lnGDP → lnNREC	2.62	0.49	1.48	0.34	2.40	0.52	2.37	0.67	1.85	0.45	1.43	0.48
lnK → lnGDP	2.56***	0.00	0.31***	0.00	0.03*	0.08	1.85**	0.04	0.63**	0.04	2.45**	0.04
lnGDP → lnK	1.08	0.31	0.83	0.68	1.79	0.46	1.74	0.73	1.34	0.95	1.43	0.94
lnL → lnGDP	1.27	0.95	0.84	0.45	0.84	0.95	2.43	0.30	1.98	0.98	0.35	0.41
lnGDP → lnL	0.90	0.69	0.79	0.53	2.28	0.48	0.91	0.59	1.93	0.87	1.38	0.89
$LnCO_2$ → lnGDP	1.55	0.48	0.83***	0.00	2.77	0.46	0.91	0.54	2.95	0.56	1.56	0.49
lnGDP → $lnCO_2$	−2.21**	0.00	2.89	0.43	−1.89**	0.09	0.94	0.67	2.25**	0.03	1.48***	0.00

Note: ** and *** indicate statistical significance at 5% and 1%, respectively.

renewable energy consumption and capital accumulation have significantly a positive impact on economic growth in India, China, Bangladesh, Japan, Singapore and South Korea. Likewise, non-renewable energy consumption had a significant positive impact on economic growth in all selected emerging Asian economies except Singapore, documenting that the positive impact of non-renewable energy consumption on economic growth is insignificant. Also the impact of employed labour force on economic growth is significantly positive in India, Japan, Bangladesh, China, Singapore and South Korea. However, the impact of carbon emissions on economic growth is significantly negative in all emerging economies except Japan, where the negative impact of carbon emissions on economic growth is insignificant.

Country-wise estimates of the carbon-emission-based AMG strategy in the second model show that GDPs significantly stimulate carbon emissions in all selected emerging Asian countries. However, GDP^2 significantly reduced carbon emissions in China, Japan, Singapore, and South Korea, while in India and Bangladesh, GDP^2 significantly contributed to carbon emissions, thus validating the absence of EKCs in India and Bangladesh. The cube of GDP has a significant negative impact on carbon emissions in China and Singapore, thus validating the inverted U-shaped EKC hypothesis for these countries. However, the cube of GDP has a significant positive effect on carbon emissions in Japan and South Korea, thus supporting the N-type EKC hypothesis for these countries. The effect of renewable energy consumption on carbon emission is significantly negative in all selected emerging economies. This means that renewable energy consumption reduces environmental degradation in these countries. The non-renewable energy consumption coefficients in China, Japan, Bangladesh, India, Singapore and South Korea are significantly positive, indicating that non-renewable energy consumption contributes significantly to the carbon emissions of these countries.

AMG estimation cannot detect causal relationships between variables. This study applies the recently introduced Dumitrescue and Hurlin (2012) panel causality test, which has two advantages over the traditional Granger causality test in examining causality between variables. The Dumitrescue and Hurlin (2012) panel causality test considers two dimensions of heterogeneity, heterogeneity of causality and heterogeneity of regression models, to examine for Granger causality. Following Koçak and Şarkgüneşi (2017), this study uses Monte-Carlo simulations to estimate probability values and test statistics. The Dumitrescue and Hurlin (2012) panel causality results are shown in Table 7, indicating that only renewable energy consumption and economic growth have a bidirectional causal relationship. The findings of the bidirectional causal relationship between renewable energy consumption and economic growth are in good agreement with the studies of Mukhtarov (2022), Xue et al. (2022), Chen et al. (2022), Wang et al. (2022b), Aslan et al. (2022), Mounir and El-houjjaji (2022).

The results also show a one-way causality from capital formation to economic growth and from economic growth to carbon emissions across Northeast Asian countries. The result for one-way causality from capital formation to economic growth is very consistent with Topcu, Altinoz and Aslan (2020), Shahbaz, Song, Ahmad and Vo (2022). And the finding of one-way causality from economic growth to carbon emissions is very consistent with Doğan et al., 2020, El Menyari (2021), Adedoyin and Zakari (2020), Gao and Zhang (2021).

Table 8 reports the results for pairwise Granger causality for individual countries. The results show a bidirectional causal relationship between renewable energy consumption and economic growth in India, Japan, and South Korea. The causality test also showed one-way causality from capital formation to economic growth across all countries. The study also found that non-renewable energy consumption has a one-way effect on economic growth in China, Singapore and South Korea. In addition, the analysis points out a unidirectional causality from carbon emissions to economic growth in China and from economic growth to carbon emissions in India, Bangladesh, Singapore and South Korea.

4 Discussion

The use of renewable energy can boost economic growth, which in turn supports renewable energy adaptation in China, India, Bangladesh, Japan, Singapore, and South Korea. The causal relationship between renewable energy consumption and economic growth is confirmed in selected emerging Asian countries, thus supporting the feedback hypothesis (Table 7). Country-by-country estimates show no causal relationship between renewable energy consumption and economic growth in Singapore, confirming the neutral hypothesis for Singapore. However, India and Singapore show bidirectional causality between renewable energy consumption and economic growth, thus supporting the feedback hypothesis. Furthermore, a one-way causality exist from economic growth to renewable energy consumption in China and Bangladesh, thus, supporting conservative hypothesis. Finally, there is a one-way causal relationship from capital formation to economic growth across all emerging Asian countries, consistent with the long-run results in Table 5.

6 Concluding remarks

This study aims to estimate the interrelationship between renewable consumption, non-renewable energy consumption, economic growth and carbon emissions in selected emerging Asian countries (India, China, Bangladesh, Japan, Singapore and South Korea) for the period 1975–2020. This study addresses the potential omission of variable bias in the multivariate framework by adding three dimensions of renewable energy, non-renewable energy consumption, and carbon dioxide emissions to the production functions of neoclassical capital and labour. First, the study detects cross-sectional dependencies in variable models of panel data through the cross-sectional dependence test proposed by Pesaran, (2007). The results demonstrate cross-sectional dependencies in the model. After analyzing the initial cross-sectional dependencies, the integral properties of each variable were examined using the cross-sectional enhanced Im-Pesaran-Shin (CIPS) unit root test proposed by Pesaran (2007). After determining the order of integration for each variable, this study examined the robustness of the estimated results by applying the Westerlund cointegration test, Pedroni (1999, 2004) cointegration test and the Kao (1999) cointegration test.

After establishing long-term panel cointegration, the Augmented Mean Group (AMG) method was applied to determine the long-term variable coefficient elasticity. Based on the first economic growth model, long-term parameter estimates suggest that each rise in non-renewable energy consumption, renewable energy consumption, and capital accumulation, respectively, contributes significantly to economic growth. The long-term elasticity estimate for renewable energy is 0.882, compared to just 0.659 for non-renewable energy, suggesting that renewable energy consumption has a much larger impact on growth than non-renewable energy. However, carbon emissions have significant adverse effects on economic growth. The second long-term estimation model is based on carbon emissions. An increase in non-renewable energy consumption leads to a significant stimulus in carbon emissions, and an increase in renewable energy consumption leads to a significant reduction in carbon emissions. According to the AMG method analysis, the signs of the coefficients of GDP and GDP^3 are significantly positive (GDP>0, $GDP^3>0$), while GDP^2 is significantly negative ($GDP^2<0$), indicating that GDP and GDP^3 have a progressive impact on environmental pollution, while GDP^2 has a significant negative impact on environmental damage. These results confirm the validity of the N-shaped EKC hypothesis in selected emerging Asian countries. Country-wise estimation results by the AMG strategy are reported that renewable energy consumption and capital accumulation have significantly a positive impact on economic growth in India, China, Bangladesh, Japan, Singapore and South Korea. Likewise, non-renewable energy consumption had a significant positive impact on economic growth in all selected emerging Asian economies except Singapore, documenting that the positive impact of non-renewable energy consumption on economic growth is insignificant. Also the impact of employed labour force on economic growth is significantly positive in India, Japan, Bangladesh, China, South Korea and Singapore. However, the impact of carbon emissions on economic growth is significantly negative in all emerging economies except Japan, where the negative impact of carbon emissions on economic growth is insignificant. Country-wise estimates of the carbon-emission-based AMG strategy in the second model show that GDPs significantly stimulate carbon emissions in all selected emerging Asian countries. However, GDP^2 significantly reduced carbon emissions in China, Japan, Singapore, and South Korea, while in India and Bangladesh, GDP^2 significantly contributed to carbon emissions, thus validating the absence of EKCs in India and Bangladesh. The cube of GDP has a significant negative impact on carbon emissions in China and Singapore, thus validating the inverted U-shaped EKC hypothesis for these countries. However, the cube of GDP has a significant positive effect on carbon emissions in Japan and South Korea, thus supporting the N-type EKC hypothesis for these countries. The effect of renewable energy consumption on carbon emission is significantly negative in all selected emerging economies. This means that renewable energy consumption reduces environmental degradation in these countries. The non-renewable energy consumption coefficients in China, Japan, Bangladesh, India, Singapore and South Korea are significantly positive, indicating that non-renewable energy consumption contributes significantly to the carbon emissions of these countries.

The Dumitrescu and Hurlin, 2012 panel causality results indicate that only renewable energy consumption and economic growth have a bidirectional causal relationship. The results also show a one-way causality from capital formation to economic growth and from economic growth to carbon emissions. Pairwise Granger causality for individual countries suggests a bidirectional causal relationship between renewable energy consumption and economic growth in India, Japan, and South Korea. The causality test also showed one-way causality from capital formation to economic growth across all emerging economies. The study also found that non-renewable energy consumption has a one-way effect on economic growth in China, Singapore and South Korea. In addition, the analysis points out a unidirectional causality from carbon emissions to economic growth in China and from economic growth to carbon emissions in India, Bangladesh, Singapore, and South Korea.

7 Policy implications

Given the results, policymakers must focus on increasing renewable energy production and consumption in emerging Asian economies, as renewable energy is a viable alternative to addressing the issue of environmental degradation and climate change without compromising economic growth. For energy security and sustainable economic growth, rapid replacement of non-renewable energy sources with renewable energy sources is critical. Hence to develop and simplify market access for renewable energy and capital-incentive technologies, policymakers must take appropriate steps and build the necessary public-private partnerships. These incentives and initiatives will stimulate cleaner and modernize the energy sector for sustainable economic growth. Non-renewable energy consumption still contributes to economic growth in all emerging Asian countries except Singapore, so Singapore should reduce its use of non-renewable energy faster and more gradually than other countries in order to achieve environmental protection and economic growth goals. EKC validity has not been approved in India and Bangladesh, so these countries should shift their economic resources from non-renewable energy to renewable energy to protect the environment.

8 Limitations and future recommendations

Ignoring the heterogeneity characteristics among the selected emerging Asian countries is the main weakness of this study. Thus, a possible extension of this study is to divide the entire emerging Asian countries panel into different subsamples according to income level (i.e., low-, middle- and high-income countries). In addition, follow-up investigation may include other indicators of environmental degradation (greenhouse gas emissions, ecological footprint).

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://databank.worldbank.org/source/world-development-indicators.

Author contributions

AA, TZ, JY, ZL, YJ, and BJ conceptualized and revised the study, software data curation, editing and literature search.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Appendix 1 Variables description and measurement.

TABLE A1 Description and measurement of variables and data sources.

Variables	Description	Measurment	Sources
GDP	Gross Domestic Product	Constant 2015 US$	World Bank, (2020)
NREC	Non-renewable Energy Consumption	Million tons of oil equivalent (Mtoe)	World Bank, (2020)
REC	Renewable Energy Consumption	Million tons of oil equivalent (Mtoe)	World Bank, (2020)
CO_2	carbon dioxide emission	million metric tons (Mmt)	World Bank, (2020)
K	Gross fixed capital formation	2015 constant U.S. dollars	World Bank, (2020)
L	Employed labour force	Millions	World Bank, (2020)