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RETRACTED: An empirical investigation of the impact of renewable and non-renewable energy consumption and economic growth on climate change, evidence from emerging Asian countries

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One of the greatest challenges facing humanity in the current millennium is the need to mitigate climate change, and one of the most viable options to overcome this challenge is to invest in renewable energy. The study dynamically examines the impact of renewable and non-renewable energy consumption and economic growth on climate change, using Augmented Mean Group (AMG) technique in emerging Asian countries during the period 1975–2020. The estimated results show that the consumption of renewable energy sources significantly mitigates climate change, while the consumption of non-renewable energy sources significantly contributes to climate change. Furthermore, economic growth, investment in transport infrastructure, and urbanization significantly accelerate climate change in specific emerging Asian countries. The results further demonstrate the validity of the inverted U-shaped EKC hypothesis in emerging Asian economies. Country-specific analysis results using AMG estimates shows that renewable energy consumption reduces climate change for all specific emerging Asian countries. However, the consumption of non-renewable energy sources and investments in transport infrastructure have significant incremental impacts on climate change in all countries. Urbanization contributes significantly to climate change, with the exception of Japan, which does not have any significant impact on climate change. The significant progressive effect of GDP and the significant adverse impact of GDP^2 on climate change confirm the validity of the inverted U-shaped EKC hypothesis in India, China, Japan, and South Korea. Moreover, the Dumitrescu and Hurlin causality test confirmed a pairwise causal relationship between non-renewable energy consumption and GDP, supporting the feedback hypothesis. According to the empirical analysis of this study, the best strategy for climate change mitigation in specific emerging countries in Asia is to transition from non-renewable energy to renewable energy.

KEYWORDS
renewable energy consumption, non-renewable energy consumption, GDP, climate change, emerging Asian countries

1 Introduction

Energy is critical to achieving the Sustainable Development Goals as it is a key engine of global economic and human development (Nundy et al., 2021). It is well known that both renewable and non-renewable energy sources are the main determinants of socio-economic development on the basis of promoting a wide range of economic production activities to increase productivity and improve living standards (Brini, 2021; Mahalik et al., 2021). Over the past 3 decades, human urbanization and industrialization have largely relied on the growing consumption of non-renewable energy sources (coal, oil, and natural gas) (Islam et al., 2022). In many countries, however, higher expansion of energy use for human development and economic growth has undoubtedly contributed to environmental degradation (Doğanalp et al., 2021). It is a very clear fact that the heavy use of non-renewable fossil fuels releases greenhouse gas (GHG) and carbon dioxide (CO2) emissions and is therefore a major contributor to environmental damage (Kuşkaya & Bilgili, 2020).

Long-term significant changes in the global climate system pattern and related aspects such as precipitation and temperature are considered climate change. According to the latest report by Intergovernmental Panel on Climate Change (IPCC), climate change is a direct warning to sustainable development and human survival, as claimed by many policymakers, researchers and stakeholders across the globe. Climate change poses a serious and growing threat to our wellbeing and a healthy planet. Over the next 2 decades, the world faces 1.5˚C (2.7˚F) of global warming, an inevitable multiple climate hazard (IPCC, 2022). Unsafe carbon emissions from 2010–2019 have never been seen in human history, a new flagship UN report on climate change says, proving the world is on the "fast track" of catastrophe that scientists believe is limit global warming to 1.5˚ "now or never"(UN, 2022).

Greenhouse gases have been the most important driver of observed climate change caused by human activity since the mid-20th century. To avoid environmental catastrophe, greenhouse gas emissions must be reduced by 50%–85% from 2000 levels by 2050, according to a new report from the United States. Environmental Protection Agency. To achieve this goal, many reports estimate that carbon dioxide emissions per person per year must be reduced to 0.8–2.5 tons of carbon dioxide equivalent (EPA, 2022).

More than 60 countries in the Asia-Pacific region have more than 4 billion people and account for more than half of global greenhouse gas emissions. From small Pacific island nations to the densely populated cities of Southeast Asia and the mountainous regions of Central Asia, how can such diverse places cope with climate change and rapidly advance the much-needed renewable energy transition (Asian development Bank, 2022)? Fossil fuels are the main source of energy production in South Asia, accounting for 63% of regional energy production GHG emissions. Limiting emissions in South Asia based on the transition to low-carbon energy sources is a priority and even more critical. However, this transition needs to happen as energy demand increases in South Asia, which has grown by 50% since 2000. Power demand in the region is expected to double within this decade (World Bank, 2021). The leading cause of greenhouse gas emissions is coal, a fossil fuel that contributes to global warming. Coal still produces 50% of Asia's primary energy and 30% of G20 member countries, and global greenhouse gas emissions are set to halve by 2030 until coal is phased out. The world is unlikely to stay below a 1.5-degree rise in global average temperature. Asia is experiencing unprecedented heatwaves, droughts and floods, with global warming already exceeding 1˚C (UN, 2022).

Faced with these threats, many countries such as the United States, the European Union, and China, as well as many countries, including developed and developing countries in the world, have formulated a series of policies aimed at reducing emissions. Thus, as part of the global response to climate change, policies to strengthen renewable energy are being introduced. South Asian countries have pushed electrification as they have made recent strides in bringing electricity to the hardest-to-reach populations (World Bank, 2021). However, it remains critical to consolidate development gains from improving the reliability and availability of renewable, affordable energy. Beside, by 2050, two-thirds of the world's energy supply could be met by renewable energy. Thus, the implementation and development of renewable energy technologies is the leeway for the transition to a low-carbon economy in the future (Slabe-Erker et al., 2022).

With the growing threat of climate change and global warming, the link between energy consumption and environmental pollutants has drawn attention. The literature describes mixed results across countries due to different energy use patterns and modelling techniques (Shen et al., 2020). The study of the growth-energy relationship has been extensively explored (Ozturk et al., 2022). In addition, many studies have focused on the relationship between growth and pollution, showing that pollution levels increase with economic growth until a threshold level is reached, after which economic growth begins to decline, known as the Environmental Kuznets Curve (EKC) (Cheikh et al.,, 2021; Boukhelkhal, 2022). However, as some other studies have explored, the environmental Kuznets curve may not hold for all pollutants and for all countries (Wang et al., 2022a; Boukhelkhal, 2022).

More recently, some existing research has focused on the link between economic growth, energy use, and pollution emissions (Chen F et al., 2022; You et al., 2022). Research on the differential impact of renewable and non-renewable energy consumption on climate change and growth is lacking, with most early studies looking at the link between total energy consumption, climate change and economic growth. This disaggregation opens avenues for understanding the relative potential of the two energy sources for the climate change process. This study is an attempt to fill the gap in the case of selected Asian emerging countries, China, India, Bangladesh, South Korea and Japan. Asian countries were chosen because these regions are considered the most vulnerable to climate change in the world. Furthermore, these regions were chosen because only a limited number of studies have been conducted on selected Asian countries. Also, these countries are urbanizing faster than others and are expected to do so in the coming decades (Anwar et a., 2022). Unfortunately, urban growth is often manifested in sprawl and increasing reliance on transportation (Rao et al., 2021). Although rapid urbanization in Asia has resulted in increased energy use, such high energy use intensity has adversely affected air quality and climate conditions. Increased urbanization leads to increased energy consumption by shifting production from less energy-intensive to more energy-intensive sources. In addition, urbanization due to increased mobility and transportation requires more energy (Destek, 2021; Awan et al., 2022; Virag et al., 2022). Thus, it can be

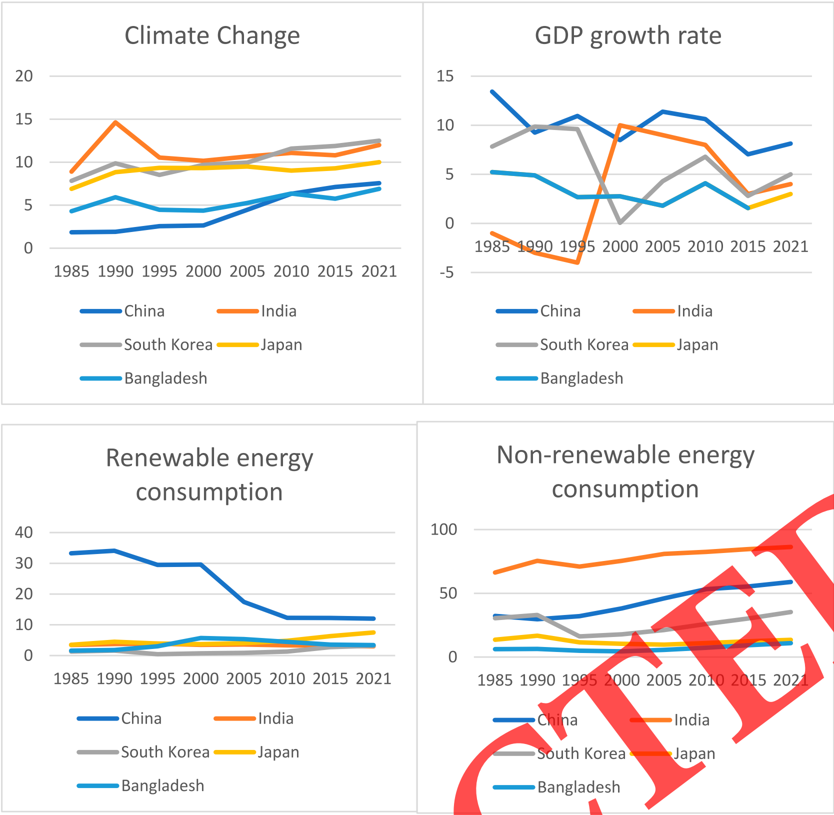

FIGURE 1
Renewable and non-renewable energy consumption, economic growth and carbon emission in Emerging Asian countries. Note: Renewable and non-renewable energy consumption are shown as a percentage of total energy, GDP growth rate is displayed as an annual percentage, and climate change as annual average temperature.

asserted that the combined effects of increased urbanization and the resulting energy consumption are exacerbating climate change. Figure 1.

Given the important scenarios for climate change and renewable energy use, it is decisive to vigorously maintain the network between renewable energy use, non-renewable energy use, economic growth and climate change. Therefore, the strategic contributions of the current study are highlighted as: 1) Most of the earliest research looked at the link between total energy consumption and climate change, but few identified the disaggregated impact of renewable and non-renewable energy consumption on climate change. The openness provided by this disaggregation allows for an understanding of the relative potential of the two energy sources in the climate change process. 2) The link between energy consumption, economic growth, and climate change has been extensively explored in different countries through various econometric techniques (Lu, 2018; Norouzi et al., 2020; Saint Akadiri et al., 2020; Nathaniel et al., 2021). A limited number of studies have tested urbanization as the main cause of increased energy consumption contributing to climate change (Raihan et al., 2022; Pata (2018). 3) This will be the only study to focus on specific Asia's emerging countries, with the latest data providing key insights for regional policymakers. 4) Also, this will be the first study to test the validity of the EKC for the specific emerging Asian country using climate indicators such as average precipitation and average temperature.

2 Literature review

The existing energy literature on the correlation between energy consumption, environmental degradation (pollution) and economic growth fascinates environmental policymakers and economists. Hence, many studies have chosen different empirical methods and countries to explore this relationship. Three main aspects emerged in the literature, with the first part of the study examining the dynamic relationship between energy or electricity consumption and economic growth (Churchill & Ivanovski, 2020; Wang et al., 2022b; Khan A. A et al., 2022; Le, 2022; Wang G et al., 2022). The studies were conducted in the context of individual and country panels, and variable relationships were described as four hypotheses; growth, feedback, conservation, and neutrality (Aslan et al., 2022; Gyimah et al., 2022; Wang W et al., 2022). First, the growth hypothesis proposes that energy consumption contributes to economic growth, so energy is reflected as a progressive input to economic growth. Second, the feedback hypothesis assumes a pairwise causal relationship between energy use and economic growth, that is, energy consumption stimulates economic growth, and economic growth promotes higher energy consumption. Third, the proposition of a one-way link from economic growth to energy consumption is known as the conservation hypothesis, which means that a decline in energy use may not have a significant effect on economic growth. Finally, the neutrality or absence of a causal relationship between energy consumption and economic growth reflects the neutrality hypothesis.

The relationship between energy consumption and economic growth began with the first pioneering work for the United States by Kraft and Kaft (1978), and was later given greater attention by Abosedra and Baghestani (1989) and Hwang and Gum (1991). Empirical analysis of the existing high-level literature on the relationship between energy and growth across countries has yielded mixed results. The study found that energy consumption contributes to economic growth, supporting the growth hypothesis are Ahmed et al. (2022) for G7 countries, using second-generation econometric techniques, Wang et al. (2022a) used a threshold model for OECD countries, Miao et al. (2022) using moment quantile regression (MMQR) techniques for newly industrialized countries and Ozturk et al. (2022) employed FMOLS and DOLS techniques for Saudi Arabia. Feedback hypothesis supported by many studies, e.g., Gyimah et al. (2022) for Ghana, Shahbaz et al. (2022) for China, Shabani et al. (2022) for ECO member countries, Okumus, Guzel and Destek (2021) for Khan I et al. (2022) for South Asian countries, Destek (2015) for Türkiye. Studies that highlight support for conservative assumptions include Wang and Lee (2022) for China, Usman et al. (2022) For eight Arctic countries, Xue et al. (2022) for French and Acheampong et al. (2022) for the European Union. However, studies exposed to the neutrality hypothesis are Amin and Song (2022) for South and East Asian countries, Xu et al. (2022) for China, Hossein et al. (2022) for India, Khan M. B et al. (2022) for G-7 economies, Destek and Aslan (2017) for Colombia and Thailand.

Similarly, many studies have explored the link between renewable energy consumption and economic growth. Chica-Olmo et al. (2020) investigated the spatial dependence between economic growth and renewable energy consumption using a spatial Durbin model for 26 European countries over the period 1991–2015. The results of the analysis show that renewable energy has a significant positive impact on economic growth. Ahmed et al. (2022) using second-generation econometric techniques covering the period 1985 to 2017 to explore the impact of renewable energy on economic growth in G-7 countries. The results show that renewable energy contributes to economic growth in selected G7 countries. Similarly, Wang W et al. (2022) sought to explore the significant contribution of renewable energy to economic prosperity in selected Asian countries, using Augmented Mean Group (AMG) estimates. Steve et al. (2022) used the Common Correlation Effects Mean Group Estimate (CCEMG) for the period 1990 to 2018 to derive the stimulating effect of increased renewable energy consumption on economic growth in Sub Saharan African countries. Dumitrescu-Hurlin Granger causality test results verify that the growth hypothesis is supported in East and West Africa, while the feedback hypothesis is only supported in Central Africa.

In addition to examining the relationship between energy and growth, the second part focuses on the link between economic growth and the environment. The purpose of exploring the link between growth and the environment is to test the validity of the Environmental Kuznets Curve (EKC), the inverted U-shape, or the U-shape hypothesis. The EKC hypothesis states that environmental pollution begins to increase with economic growth until it reaches a certain threshold, and then declines beyond that threshold as the economy grows. The pioneering work of Kao (1999) was the first to test the EKC hypothesis on the relationship between economic growth and carbon emissions, and many other studies followed. However, many of the findings of these studies are controversial; Balsalobre-Lorente et al. (2022) used dynamic ordinary least squares (DOLS) estimator to test the validity of the EKC for PIIGS countries over the period 1990–2019. The results of the analysis confirmed the effectiveness of inverted U-shaped and N-shaped EKC in PIIGS countries. Likewise, Thio et al. (2022) used the STIRPAT model combined with panel quantile regression to examine the validity of the EKC for the world's top ten economies. The findings support the effectiveness of the EKC for the top 10 economies. Wang G et al. (2022) used the VECM model for the period 1995–2017 to support the validity of the inverted U-shaped EKC hypothesis based on the link between CO_2 emissions and industrial output in China. Pata and Samour, (2022) found no inverted U-shaped relationship between CO_2 emissions and income by examining the validity of the French EKC assumption for the period 1977–2017. Liu et al. (2022) support the EKC hypothesis that there is an inverted U-shaped relationship between travel and tourism and the Ecological Footprint in Pakistan during the period 1980–2017. Similarly, Xia et al. (2022) show that higher GDP stimulates carbon emissions, while the squared coefficient of the GDP result is negative, supporting the validity of the EKC hypothesis for 67 developed and developing countries over the period 1971–2018. Onifade (2022) used quantile regression (QR) methods and dynamic ordinary least squares (DOLS) to test the EKC hypothesis for African oil-producing economies over the period 1995–2016. The results of the analysis did not confirm the validity of the EKC assumptions for selected economies. Lu et al. (2022) applied dynamic ordinary least squares (DOLS) and fully modified ordinary least squares (FMOLS) to examine the validity of EKC China, Japan, and South Korea over the period 1995–2020. The results show that GDP significantly promotes environmental degradation and GDP2 significantly reduces environmental degradation, thus validating the inverted U-shaped EKC hypothesis in selected Asian countries. Likewise, Isik et al. (2020) validated the legitimacy of the French EKC assumption among the G7 countries, and Pata and Hizarci (2022) confirmed the validity of the German and Swedish EKC assumptions. Destik and Sinha (2020) also validated the U-shaped EKC assumption for OECD countries.

Finally, the third dimension is the energy-growth-environment nexus, which is based on the aggregation of research from the above two strands. Ali A et al. (2022) used the Dumitrescu and Hurlin (2012) panel causality test to explore the links between energy consumption, carbon emissions, and economic growth in PIMC countries from 1980 to 2020. The analysis results show that there is a two-way causal relationship between carbon dioxide and economic growth, while a one-way causality is running from energy consumption to economic growth. Mughal et al. (2022) explores the link between energy use, carbon emissions, and economic growth in selected South Asian economies, identifying bidirectional causality between economic growth and energy use and unidirectional causality from GDP growth to carbon emissions. Musah et al. (2022) empirically found two-way causality between energy consumption and carbon dioxide emissions, between economic growth and carbon dioxide emissions, and one-way causality from economic growth to energy consumption in North Africa. Khan I et al. (2022) used a fully modified ordinary least squares (FMOLS) technique to reveal the causal relationship between energy use, carbon emissions, and economic growth in South Asian countries over the period 1972–2017. The findings suggest that there is a bidirectional causal relationship between economic growth and energy use, while a unidirectional causal relationship exists from GDP growth to carbon emissions. Sadiq et al. (2022) attempted to use the method of Dumitrescu-Hurlin (2012) to explore the causal relationship between energy use, economic growth and carbon emissions in South Asian countries. Empirical results show that GDP Granger causes CO2 emissions and supports a feedback effect between economic growth (GDP) and energy use.

Recently, a new study on the relationship between renewable energy use, economic growth and environmental damage has become a priority. In this regard, the research initiated by Wang et al. (2022b) applied the Augmented Mean Group (AMG) estimator for panel data analysis and found that renewable energy significantly reduces carbon emissions and promotes economic prosperity. Wang W et al. (2022) used a threshold panel regression model for 120 countries and data from the past 20 years to reveal that global renewable energy can stimulate economic growth and improve environmental quality; Ali U et al. (2022) applied an Augmented Average Group (AMG) approach over the period 1980–2020 and found that renewable energy consumption stimulated economic growth and reduced carbon emissions in PIMC countries.

In addition to this, the latest literature fully proves that renewable energy can reduce environmental pollution and climate change. Regarding this, little research has focused on the links between renewable and non-renewable energy consumption, economic growth, and climate change. Brini (2021) applied the Granger causality test to annual data for the period 1980–2014, revealing a two-way causality between non-renewable energy consumption and climate change, supporting the feedback hypothesis, while one-way causality from climate change to renewable energy. Chen F et al. (2022) used Granger causality tests to assess bidirectional causality between renewable energy cosumption, non-renewable energy consumption, and carbon emissions in China over the period 1980–2014. The results show a bidirectional causal relationship from CO2 emissions and non-renewable energy to renewable energy. A summary of the literature on the impact of renewable and non-renewable energy consumption and economic growth on climate change is presented in Table 1.

The literature on the links between energy consumption, economic growth and environmental degradation is extensive, but also somewhat flawed. Undoubtedly, many studies have used total energy consumption, rather than considering separate renewable and non-renewable energy consumption. Lack of sample studies and disappointment with separate renewable and non-renewable energy consumption is relatively due to the unavailability of renewable energy data for a large number of Asian countries. Besides, the literature shows the use of carbon emissions as a proxy for climate change and environmental degradation, excluding other important factors such as average precipitation and average temperature. Also, we could not find any studies that tested urbanization as the main cause of increased energy consumption contributing to climate change.

3 Model development, data sources and method techniques

This study follows the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model proposed by Dietz and Rosa (1997) to reveal the impact of renewable and non-renewable energy consumption and economic growth on climate change. The exponential form of the basic STIRPAT model can be expressed as follows:

$$I_{it} = \lambda P_{it}^{a} A_{it}^{K} T_{it}^{r} \mu \tag{1}$$

I demonstrate the effect of the environment, with P for county population, A denotes affluence (GDP), T indicates technology (energy efficiency), and μ is the model error term reflecting a stochastic process. The above model is transformed into a log-linear form for empirical analysis as follows:

$$\ln I_{it} = \kappa_0 + \kappa_1 \ln P_{it} + \kappa_2 \ln A_{it} + \kappa_3 \ln T_{it} + \varepsilon_{it} \tag{2}$$

Several researchers have extended the STIRPAT model by adding new explanatory factors (Ghazali & Ali, 2019; Pan & Zhang, 2020; Su et al., 2020; Lu et al., 2021; Usman & Hammar, 2021; Schneider, 2022; Thio et al., 2022).

The extended form of the improved STIRPAT model in our study is expressed in the following form, which is based on the impact of renewable and non-renewable energy consumption, and economic growth on climate change.

$$CC_{it} = f\left(REC_{it}, NREC_{it}, GDP_{it}, TIN_{it}, URB_{it}\right) \tag{3}$$

$$CC_{it} = f\left(GDP_{it}, GDP_{it}^{2}, REC_{it}, NREC_{it}, URB_{it}\right) \tag{4}$$

In the above equations, CC indicates climate change, NREC and REC stand for non-renewable energy consumption and renewable energy consumption, respectively, as indicators to measure technology, GDP is used for affluence, URB reflects urbanization used to measure population impacts, TIN denotes transport infrastructure investment as additional control variable. Studies (Pan et al., 2019; Dogan and Inglesi-Lotz, 2020; Sahu et al., 2022) used energy intensity as a proxy for technology, followed in this study, assuming that better green technologies could improve energy effective use, reducing the consumption of fossil fuels and stimulating more reliance on renewable energy. Converting the above model for empirical analysis into log-linear form is as follows:

$$\ln CC_{it} = \beta_0 + \beta_1 \ln REC_{it} + \beta_2 \ln NREC_{it} + \beta_3 \ln GDP_{it} + \beta_4 \ln TIN_{it} + \beta_5 \ln URB_{it} + \mu_{it} \tag{5}$$

$$\ln CC = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{it}^{2} + \beta_3 \ln REC_{it} + \beta_4 \ln NREC_{it} + \beta_5 \ln URB_{it} + \mu_{it} \tag{6}$$

where β_0 and $\beta_{1\text{-}6}$ are the intercept and coefficients of the variables respectively, i represents the country, t indicates the time period, and μ is the random error term of the model.

Annual variable data for the period 1975–2020 comes from various sources, such as renewable and non-renewable energy consumption, GDP and urbanization data from the World Bank, World Development Indicators (WDI) database. Transportation infrastructure investment data taken from the OECD database, and climate change data sourced from the latest statistics of National Oceanic and Atmospheric Administration (NOAA). The explanatory variables include renewable and non-renewable energy consumption can be measured in kg of oil equivalent (Mtoe). Non-renewable energy consumption data in kilograms of oil equivalent (Mtoe) exists in the World Bank database, but renewable energy consumption data only exists as a percentage of total energy use. Thus, measuring the renewable energy consumption (REC) for a specific year and

TABLE 1 Summary literature of the impact of renewable and non-renewable energy consumption and economic growth on climate change.

Authored	Countries	Method	Time period	Findings
Ali A et al. (2022)	PIMC countries	AMG estimation	1980–2020	Renewable energy consumption reduces
				CO_2 emissions, while non-renewable energy use stimulates CO_2 emissions
Wang et al. (2022a)	120 countries	Panel regression model	2000–2020	Renewable energy use can improve the environmental quality
Brini (2021)	16 African countries	ARDL-PMG	1980–2014	Non-renewable energy consumption and economic growth have detrimental effects, while renewable energy
				consumption has beneficial effects on climate change
Acaroğlu and Güllü (2022)	Turkey	ARDL	1980–2019	Renewable energy use lowers temperatures, non-renewable energy and economic growth raises
				temperatures
Alola, Bekun and Sarkodie (2019)	16-EU countries	PMG-ARDL	1997–2014	Consumption of non-renewable energy reduces environmental quality, while consumption of renewable
				energy increases environmental sustainability
Bhat (2018)	BRICS	Pooled Mean Group	1992–2016	Non-renewable energy consumption and economic growth have detrimental effects, while renewable
				energy consumption has beneficial effects on climate change
Chen, Wang and Zhong (2019)	China	ARDL	1980–2014	non-renewable energy and GDP increases CO_2 emission
				whereas renewable energy and foreign trade have a
				negatively impact on CO_2 emissions
Abbas et al. (2020)	24 emerging economies	ARDL	1995–2014	Renewable energy consumption reduces CO_2 emissions, while non-renewable energy use stimulates CO_2 emissions
Amin and Song (2022)	South Asian countries	CS-ARDL approach	2000–2018	Non-renewable energy consumption and economic growth increase long-term CO_2 emissions
				but renewable energy consumption reduces CO_2 emissions
Usman, Makhdum and Kousar (2021)	15 highest emitting countries	AMG estimation	1990–2017	Renewable energy has made a significant contribution to overcoming environmental degradation
				while economic growth and the use of non-renewable
				energy are more responsible for environmental damage

country using the data of two variables, total energy consumption in kg of oil equivalent (Mtoe) and renewable energy consumption as a percentage of total energy consumption. Renewable energy consumption in kilograms of oil equivalent (Mtoe) can be calculated by multiplying the renewable energy consumption as a percentage of total energy consumption by the total energy consumption in kilograms of oil equivalent (Mtoe) (Mtoe) and then divide by 100. That is,

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

GDP and transport infrastructure investment are other explanatory factors, measured in constant 2015 dollars. Urbanization is a control variable that can be measured as a percentage of the total population. The dependent variable is the climate change used in the model, as measured by mean annual temperature (TEMP). Table A1 below clearly highlights the full details of variable interpretation, measurement, and data sources.

3.1 Cross sectional dependence test

It is crucial to determine the cross-sectional dependence of panel data before moving on to testing variable unit root properties, followed by variable cointegration and elasticity. Panel data estimates with cross-sectional correlations can lead to biased, erroneous, and misleading conclusions (Awad & Warsame, 2022; Boukhelkhal, 2022). Many past studies have used Breush and Pegan's (1980) cross-sectional dependence test, but this test educates many econometric issues. Therefore, this study uses the more robust cross-sectional correlation (CD) test and Langrage multiplier (LM) test proposed by Hashmi (2021) to overcome the shortcomings of the Breush and Pegan tests. The respective expressions for CD and LM tests are highlighted in the following equations.

10.3389/fenvs.2022.1085372

TABLE 2 Results of cross-sectional dependency test.

	Model-1		Model-2	
Test	Statistics	Probability	Statistics	Probability
Breusch-Pagan LM	866.79***	0.000	944.64***	0.002
Pesaran scaled LM	77.81***	0.001	84.33***	0.004
Bias-corrected scaled LM	76.47***	0.005	87.13***	0.001
Pesaran CD	6.31***	0.007	0.994**	0.003

Note: *, **, *** represent statistical significance levels of 10%, 5%, and 1%, respectively.

$$\mathbf{CD} = \sqrt{\left(\frac{2\rho}{\kappa(\kappa-1)}\right)}\left(\sum_{i=1}^{\kappa-1}\sum_{j=i+1}^{\kappa}\hat{\mathrm{T}}_{ij}\right): \ \boldsymbol{\kappa}\,(\mathbf{0},\mathbf{1}) \tag{7}$$

$$\mathbf{LM^*} = \sqrt{\left(\frac{2\rho}{\kappa(\kappa-1)}\right)}\left(\sum_{i=1}^{\kappa-1}\sum_{j=i+1}^{\kappa}\hat{\mathrm{T}}_{ij}\right)\frac{(\rho-n)\hat{\rho}_{ij}^2 - E(\rho-n)\hat{\rho}_{ij}^2}{Var(\rho-n)\hat{\rho}_{ij}^2} \tag{8}$$

The results of the cross-sectional correlation test are clearly highlighted in Table 2, indicating that all coefficients are highly significant at the 1% significance level. Thus, the cross-sectional dependence of the selected sample data has been confirmed in both models.

3.2 Panel unit root test

First-generation panel unit root tests are invalid due to cross-sectional dependencies of selected sample data. Thus, this study uses the second-generation unit root test, which accounts for the cross-sectional dependence proposed by Pesaran (2007).

The basic equation for each variable e_{it} has the following expression:

$$e_{it} = (1 - e_i)\varepsilon_i + \varepsilon_i e_{i,t-1} + \varepsilon_{it},\ i = 1, \ldots\ldots, M;\ t = 1, \ldots\ldots, K \tag{9}$$

Where εit is the error term, which can be expressed as the undetected common factor ft function.

$$\varepsilon_{it} = \kappa_i f_t + \mu_{it} \tag{10}$$

As ε_{it} represents a country-specific factor, thus, we obtain Eq. 11 below from Eq. 9.

$$\Delta e_{it} = \beta_i + \alpha_i e_{i,t-1} + \kappa_i f_t + \mu_{it} \tag{11}$$

Thus, the cross-sectional augmented Dicky-Fuller (CADF) panel unit root test

$$\Delta e_{it} = \beta_i + \alpha_i e_{i,t-1} + d_i \Delta\bar{e}_t + \mu_{it} \tag{12}$$

The null hypothesis of no stationarity associated with each series in Eq. 12 determines the integration order based on the OLS estimator αi. The following Eq. 13 represents the CADF t statistical mathematical expression.

$$t_t(K, \mathrm{T}) = \frac{\Delta y_i \bar{M}_w z_{i,-1}}{\hat{\sigma}_i\left(y_i \bar{M}_w z_{i,-1}\right)^{1/2}} \tag{13}$$

The following specific CIPS tests are derived from the generalized Eq. 13 above, but require critical values and simulations.

$$\mathrm{CIPS}(\mathrm{K},\mathrm{T}) = \bar{t} = k^{-1}\sum_{i=1}^{k} t_i(\mathrm{K},\mathrm{T}) \tag{14}$$

The panel unit root test results shown in Table 3 obviously display that the entire variables at the first derivative transform to a stationary state, which allows us to use panel long term cointegration and long term elasticity estimates.

3.3 Panel cointegration test

After careful examination of cross-sectional correlations and unit root issues, the next step is to apply the state-of-the-art techniques of Westerlund (2007) to determine cointegration relationships between series. The Westernlund cointegration test is an error-correcting test that addresses cross-sectional dependence problems. The technique stands out based on structure rather than residual dynamics, and thus is not affected by unobserved co-factors (Ibrahim et al., 2022; Zhang C et al., 2022). Below is the expression for the econometric model of the Westerlund (2007) cointegration test.

$$\Delta Z_{it} = \delta_i d_t + \beta_i z_{it-1} + \lambda_i y_{it-1} + \sum_{j=1}^{Ki}\beta_{ij}\Delta v_{it-j} + \sum_{j=1}^{Ki}\lambda_{ij}\Delta x_{it-j} + \varepsilon_{it} \tag{15}$$

βi is the adjustment speed in the above Eq. 15, which establishes the adjustment for the long-term fluctuation after the short-term imbalance. Westerlund (2007) proposed four tests to determine cointegration, the first two of which are highlighted below, called the group mean statistics.

$$G_t = \frac{1}{N}\sum_{i=1}^{N}\frac{\hat{\beta}_i}{SE(\hat{\beta}_i)} \tag{16}$$

$$G_\beta = \frac{1}{N}\sum_{i=1}^{N}\frac{\mathrm{T}\hat{\beta}_i}{\hat{\beta}_i(1)} \tag{17}$$

If the two tests are determined to be statistically significant, the null hypothesis that there is no cointegration relationship between the variables in the entire panel can be rejected. Statistics from the other two panels determine to explore cointegration in at least one country.

$$P_t = \frac{\hat{\beta}_i}{SE(\hat{\beta}_i)} \tag{18}$$

$$P_\beta = \mathrm{T}\hat{\beta}_i \tag{19}$$

TABLE 3 Results of the panel unit root tests.

Variables	LCC		IPS		ADF-Fisher		PP-Fisher		CADF		CIPS	
	C	C + T	C	C + T	C	C + T	C	C + T	C	C + T	C	C + T
InCC	−1.97**	−3.46	0.52	−0.47*	31.72	24.31	312.83	21.32	0.12	0.48	−1.72	−0.42
InREC	1.69	4.37	0.58	2.38	24.73	63.24	173.69	31.52	0.92	0.82	−1.35	−1.92
InGDP	1.59	6.37	1.58	3.48	17.92	52.14	39.93	41.42	1.62	1.36	−1.47	−2.71
InURB	7.39***	−1.58	−2.82	4.82	19.28	26.72	79.48	51.73	2.47	2.83	−1.98	−1.62
InTIN	−6.94	−1.38	−4.43	−5.48	29.73	17.92	79.72	32.42	−6.72	−3.82	−0.95	−0.73
InNREC	−6.71	−4.19	−3.59	−0.91	47.82	5.32	96.72	52.62	−5.23	2.51	−1.85	−1.82
ΔInCC	−3.95***	−3.47***	−2.26***	−2.95***	16.72**	134.32**	85.52***	52.92***	−0.62***	−1.72***	−1.39***	−1.72***
ΔInREC	−5.57***	−4.48***	−3.47***	-0.39***	27.69***	213.21**	62.63***	82.31**	−1.72**	−1.82***	−1.94***	−0.81**
ΔInGDP	−3.73***	−0.49***	−5.73**	−1.62***	13.62***	21.34***	27.61**	92.72***	−2.71***	−2.61***	−0.82***	−1.85***
ΔInURB	−6.58***	−7.69***	−3.49***	−1.39***	19.72***	49.32***	72.73**	24.62***	−2.11***	−3.12***	−0.62***	−1.62***
ΔInTIN	−6.47***	−−2.71**	−2.38**	−0.72***	33.82***	93.21***	29.41***	95.73***	−4.12***	−1.67***	−0.12***	−1.25**
ΔInNREC	−7.54***	−3.29***	−3.39***	−1.52***	21.92***	83.25***	28.73***	62.82***	−0.92***	−1.95***	−2.27***	−2.51***

Note: *, **, *** represent statistical significance levels of 10%, 5%, and 1%, respectively, C stands for constant and C + T denotes constant and trend.

3.4 Panel long-term variable elasticity estimation

Panel Fully Modified Ordinary Least Squares (FMOLS) may be the best options for determining long-term variable elasticity after establishing long-term panel cointegration, but FMOLS strategies ignore cross-sectional dependence issues (Nketiah et al., 2022; Shahbaz et al., 2022). Econometric models subject to cross-sectional dependencies and country-specific heterogeneity may produce biased or misleading inferences (Maza & Gutiérrez-Portilla, 2022). Thus, to overcome these problems, Eberhardt and Bond (2009) and Teal & Eberhardt (2010) introduced the Augmented Mean Group (AMG) method, which can produce more robust results than traditional methods.

The main benefits of the AMG estimator can support the achievement of more fully policy-oriented goals and provide country-specific results. The two-stage process of AMG estimation in functional form is shown in Eqs 20, 21 as follows:

$$\Delta Z_{it} = \beta i + \rho_i \Delta x_{it} + \kappa_i g_t + \sum\nolimits_{t=2}^{T} \alpha_i \Delta h_t + \varepsilon_{it} \quad (20)$$

$$\hat{\beta}_{AMG} = N^{-1} \sum\nolimits_{t=2}^{T} \hat{\beta}_i \quad (21)$$

where βi is the intercept, Z_{it} and X_{it} 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, $\hat{\beta}_{AMG}$ is the augmented mean Group (AMG) estimator and ε_{it} display the error term.

3.5 Country-specific analysis by augmented mean groups (AMGs) estimation method

Following Cergibozan (2022), this study also uses Augmented Average Groups (AMGs) to reveal the impact of FDI and institutional quality on economic growth and climate change in individual countries. AMG is a panel autoregressive distributed lag (ARDL) model that allows for cross-sectional correlation and sample heterogeneity, outperforming first-generation panel estimation techniques (Sim and Sek, 2022; Wei and Huang, 2022). This approach incorporates common dynamic effects (CDEs) into a two-stage estimation process to account for cross-sectional dependencies (Hashmi et al., 2021; Maza, 2022). Moreover, this technique does not have the prerequisites for non-stationary series and cointegration of variables (Shan et al., 2021). Thus, AMG method based on these salient features are best suited to examine the national-level impacts of FDI and institutional quality on economic growth and climate change in the form of first-order differences.

3.6 Granger estimation of causality

Careful scrutiny of causal relationships between correlated variables is even more critical for policy guidance and formulation. Thus, this study determined to use the more robust Granger causality test of Dumitrescu and Hurlin (2012) to reveal one-way or two-way causality between variables. Compared to traditional VECM, this approach is more efficient and effective because it also works with small samples, while addressing econometric issues of sample heterogeneity and cross-sectional dependence (Azam et al., 2021; Hashemizadeh et al., 2021; Hashmi et al., 2021). Following Awad and Warsame (2022) and Chen S et al. (2022), this study uses the Heterogeneous Dumitrescu and Hurlin (DH) causality approach with the reverse causality problem as an additional robustness measure. The Dumitrescu and Hurlin (DH) model can be expressed as follows:

$$Z_{i,t} = \beta_i + \sum\nolimits_{i=1}^{K} \rho_i^{(K)} z_{i,\,t-n} + \sum\nolimits_{i=1}^{K} \alpha_i^{(K)} y_{i,\,t-n} + \varepsilon_{it} \quad (22)$$

where ρ and y are variables pair-wise combinations, n represent the maximum lag length, i is cross section and t indicate time. $\rho_i^{(K)}$ and

TABLE 4 Panel descriptive statistics and correlation analysis.

Variables	Average	SD	Max	Min	InCC	InREC	InGDP	InURB	InNREC	InTIN	VIF
InCC	17.25	5.218	38.72	18.64	1						
InREC	3.54	0.441	7.18	1.38	−0.688	1					4.34
InGDP	1195.14	697.32	1728.31	354.32	0.917	−0.816	1				4.95
InURB	39.21	9.32	45.25	15.32	0.879	−0.728	0.216	1			4.69
InNREC	17.38	2.21	25.36	9.253	−0.118	−0.907	0.416	0.828	1		2.51
InTIN	26.38	7.915	36.26	18.26	−0.318	−0.316	0.591	0.672	−0.904	1	2.94

Note: SD, is the standard deviation, Max and Min are the maximum and minimum values, respectively and VIF, stands for the variance inflation factor.

$\alpha_i^{(K)}$ represent the sample country coefficients in the regression. The null and alternative hypotheses of the Dumitrescu and Hurlin (DH) causality method can be expressed as follows:

$$\text{Null hypothesis} \rightarrow H_0 = \alpha_i = 0$$

$$\text{Alternative hypothesis} \rightarrow H_1 = \alpha_i \neq 0, \text{ where } \forall i = 1, 2 \ldots\ldots N \text{ and } \forall i = N+1, N+2 \ldots\ldots N$$

4 Analysis results and interpretation

Table 4 below highlights summary statistics for each variable for the period 1975–2020. Descriptive statistics comprise the average, minimum and maximum values, and standard deviation of the panel variable data. The annual average temperature of selected emerging economies in Asia is 17.25°C, and the fluctuation range is 18.64°C-38.72°C. Average GDP is highlighted at $1,195.14 billion, with its standard deviation fluctuating widely over the period. The average usage of renewable and non-renewable energy are 3.54 and 17.38 million tons of oil equivalent (Mtoe), respectively. The average urbanization rate and investment in transportation infrastructure, stood out at 39.21% and 26.38 billion United States dollars, respectively. The average urbanization rate reflects that 39% of the population lives in urban areas, while the average amount allocated to investment in transport infrastructure in selected emerging Asian countries is US$26.38 billion. Model multicollinearity issues for each variable have been tested with correlation coefficients and variance inflation factors (VIFs), as shown in Table 4. The VIF test obviously shows that the statistic for each variable is less than 5, confirming that the model does not suffer from multicollinearity issues.

The results for the panel unit root in Table 2 above obviously allow the use of the cointegration test since all variables have the integral property of I(1). The current study uses the Westerlund (2007) test and the Pedroni (1999) panel cointegration test benchmark to reveal cointegration relationships among the proposed model variables. The panel cointegration test results of the climate change-based model are shown in Table 5. The Westerlund and pedroni panel test of the specified model rejects the null hypothesis based on no cointegration because both the group and panel statistics are significant at the 1% level, reflecting that the variables in the model are cointegrated.

The results of the long-term estimated parameters in the proposed model of Eqs 3, 4 are reported in Table 6. From the

TABLE 5 Panel cointegration test results from Westerlund (2007) and Pedroni (1999).

Westerlund test			Pedroni test		
CC-model					
	Statistics	*p*-value		Statistics	*p*-value
Gt	−5.467***	0.003	Panel v-Statistic	−2.815	0.813
Ga	−9.795	0.503	Panel rho-Statistic	0.538	0.615
Pt	−6.739***	0.000	Panel PP-Statistic	−3.886***	0.004
Pa	−9.139	0.427	Panel ADF-Statistic	−4.393***	0.000
			Group rho-Statistic	0.118	0.881
			Group PP-Statistic	−2.255***	0.000
			Group ADF-Statistic	−3.711***	0.000

Note: *, **, *** represent statistical significance levels of 10%, 5%, and 1%, respectively.

analysis results in the table, it can be seen that, in the selected emerging Asian economies, the contribution of renewable energy consumption to the mitigation of climate change as measured by the annual average temperature is significant. AMG's estimates of variable resilience based on climate change models suggest that for every 1% increase in renewable energy consumption, there is a significant 0.817% reduction in climate change. This finding is congruent with the latest studies by Ali U et al. (2022), Luderer et al. (2022), Zhang D et al. (2022), Raihan et al. (2022), Chandio et al. (2022), Acaroğlu and Güllü (2022). There is no doubt that the use of fossil fuels is a major source of carbon dioxide emissions, which can be reduced through renewable energy consumption. Carbon dioxide emissions are a major source of global warming because it accelerates heating and evaporation, leading to increased drought duration and intensity. The Asian Development Bank (2021) focuses on Sustainable Development Goal 7, which sets the goal of universal access to sustainable, reliable, rational and modern energy services in Asian economies by 2030. Renewable energy supports the transition to low carbon emissions and climate change, while non-renewable resources rely on fossil fuels with harmful climate, health and environmental consequences.

The results of the research analysis also show that the consumption of non-renewable energy has a significant positive impact on the average temperature. A 1% increase in non-

TABLE 6 Long-term coefficient estimation results using panel MG, AMG and CCEMG estimators. $InCC_{it=}f$ ($InNREC_{it}$, $InREC_{it}$, $InGDP_{it}$, $InTIN_{it}$, InURBit).

	MG		AMG		CCEMG	
Variables	Coeff	*p*-value	Coeff	*p*-value	Coeff	*p*-value
$InREC_{it}$	−0.591***	(0.000)	0.817***	(0.001)	−0.216***	(0.000)
$InNREC_{it}$	0.792***	(0.002)	0.682***	(0.003)	0.681***	(0.002)
$InGDP_{,it}$	−0.429***	(0.003)	0.601***	(0.005)	0.318***	(0.000)
$InTIN_{it}$	0.882**	(0.029)	0.605*	(0.051)	0.117*	(0.062)
$lnURB_{it}$	0.318**	(0.048)	0.985***	(0.002)	0.723*	(0.053)
$InCC_{it}$ = f ($InGDP_{it}$, $InGDP2_{it}$, $InNREC_{it}$, $InREC_{it}$, $InURB_{it}$)						
	MG		AMG		CCEMG	
Variables	Coeff	*p*-value	Coeff	*p*-value	Coeff	*p*-value
$InGDP_{it}$	0.647***	(0.003)	0.628***	(0.000)	0.318**	(0.032)
$InGDP2_{it}$	−0.659***	(0.000)	−0.717**	(−0.031)	−0.413***	(0.000)
$InNREC_{it}$	0.848***	(0.002)	0.736***	(0.003)	0.328***	(0.002)
$InREC_{it}$	−0.284*	(−0.064)	−0.821*	(−0.051)	−0.812***	(-0.000)
$lnURB_{it}$	0.246**	(0.042)	0.325**	(0.023)	0.425**	(0.031)

Note: *, **, *** represent statistical significance levels of 10%, 5%, and 1%, respectively.

renewable energy consumption can significantly stimulate climate change by 0.682. This finding is very consistent with the recent studies by Ali U et al. (2022), Lei et al. (2022), Ali U et al. (2022), Vo and Vo (2022), Udeagha and Ngepah (2022), Mujtaba et al. (2022), Nakhli et al. (2022), Karaaslan and Çamkaya (2022). Findings from emerging Asian countries indicate that the role of fossil fuels in energy consumption in these countries has risen significantly. The study revealed that the use of non-renewable energy sources in selected Asian countries is a major cause of environmental damage and climate change. It is undeniable that the main sources of fossil fuels are coal, oil and natural gas, resulting in massive carbon emissions. However, the growing reliance on oil and gas and the use of old biomass fuels impose enormous environmental constraints and may contribute to climate change.

The results also show that every 1% increase in GDP can significantly contribute 0.601% to climate change. This finding is consistent with Shobande (2022), Ullah et al. (2022), Menegaki et al. (2022), Fitzgerald (2022), Alestra et al. (2022), Destek and Okumus (2017), Acaroğlu and Güllü (2022). The link between economic growth and climate change in emerging Asian countries suggests that the growth process in these countries is heavily polluting, leading to environmental degradation. This deforestation is the result of a confluence of many aspects; chiefly increased urbanization, steady growth in economic activity and rapid population growth. Likewise, for every 1% increase in transport infrastructure and urbanization, climate change increases significantly by 0.605% and 0.985%, respectively.

For every 1% increase in transport infrastructure and urbanization, climate change increases significantly by 0.605% and 0.685%, respectively. Urbanization enlarges energy demand in sectors such as housing, commercial floor space, transport, and goods and services, which in turn leads to increased energy consumption. Urbanization, which fast-tracks energy consumption, is also accelerating climate change, mainly in developing Asia, which is not yet in the same position as advanced economies to achieve low climate change through the adoption of new energy technologies.

Long-term variable elasticity coefficients based on the second model of climate change show that a 1% increase in GDP can stimulate climate change by 0.628%, while a 1% increase in GDP^2 can significantly reduce climate change by 0.717%, validating the inverted U-shaped EKC hypothesis in emerging Asian economies. Massagony and Budiono (2022) validated the EKC hypothesis for Indonesia; Murshed et al. (2022) validated the EKC for Bangladesh, India, Nepal, and Sri Lanka; Frodyma et al. (2022) updated the EKC hypothesis for EU countries, support to the validity of the EKC hypothesis 67 developed and developing countries.

Table 7 below reports country estimates of AMG strategies to see whether renewable and non-renewable energy consumption and GDP in selected emerging Asian countries (India, China, Bangladesh, Japan, and South Korea) show a heterogeneous climate change. The results of the analysis show that renewable energy consumption reduces climate change in selected emerging Asian countries. GDP contributes significantly to climate change in all countries. However, GDP^2 has significant adverse effects on climate change in India, China, Japan, and South Korea, validating the inverted U-shaped EKC hypothesis for all countries except Bangladesh. Likewise, both non-renewable energy consumption and investment in transport infrastructure have had significant progressive impacts on climate change in all countries. Urbanization contributes significantly to climate change, with the exception of Japan, which does not have any significant impact on climate change.

TABLE 7 Country-specific analysis results using AMG estimates.

Country	lnREC	lnNREC	lnGDP	lnGDP^2	lnTI	lnURB	R^2 adjusted R^2
India	−0.898*** (−0.001)	0.618*** (0.002)	0.606*** (0.001)	−0.391*** (-0.002)	0.396*** (0.000)	0.107*** (0.000)	0.87 0.89
China	−0.397*** (−0.000)	0.309** (0.018)	1.318*** (0.006)	−0.191*** (−0.002)	0.418*** (0.003)	0.306** (0.021)	0.94 0.92
Bangladesh	−0.292* (−0.072)	0.818*** (0.002)	0.692*** (0.007)	0.519* (0.062)	0.297* (0.062)	0.283*** (0.000)	0.97 0.95
Japan	−0.508*** (−0.001)	0.918** (0.028)	0.518*** (0.005)	−0.783 (−0.042)**	0.286*** (0.008)	0.293 (0.254)	0.99 0.97
South Korea	−0.318***	0.727**	0.513***	−0.408**	0.385***	0.278*	0.99 0.97
	(−0.006)	(0.022)	(0.001)	(−0.032)	(0.002)	(0.051)	

Note: *, **, *** represent statistical significance levels of 10%, 5%, and 1%, respectively.

TABLE 8 Results of pairwise causal relationships between variables of interest in the proposed model using Dumitrescu and Hurlin causality test.

Direction of causality	W-Stat	Zbar-Stat	Probability
lnREC → lnCC	2.992***	2.673***	0.00
lnCC → lnREC	2.876	2.682	0.12
lnNREC → lnCC	2.836**	1.869**	0.01
lnCC → lnNREC	1.328***	2.471***	0.00
lnGDP → lnCC	2.521***	1.507***	0.00
lnCC → lnGDP	1.018***	4.508**	0.03
lnTI → lnCC	2.616***	1.618***	0.01
lnCC → lnTI	3.317	1.439	0.23
lnURB → lnCC	1.831***	−1.681***	0.00
lnCC → lnURB	3.018	2.482	0.42
lnREC → lnGDP	1.816	2.119	0.37
lnGDP → lnREC	2.827	1.793	0.28
lnNREC → lnGDP	1.831**	1.881**	0.02
lnGDP → lnNREC	2.271***	2.107***	0.00
lnTI → lnGDP	1.092**	3.163**	0.02
lnGDP → lnTI	2.732	1.882	0.72
lnURB → lnGDP	3.782	1.893	0.53
lnGDP → lnURB	1.032***	1.819***	0.00

Note: *, **, *** represent statistical significance levels of 10%, 5%, and 1%, respectively.

The next step is to use the Dumitrescu and Hurlin (2012) causality test, which takes into account panel heterogeneity, to examine pairwise causality between the variables of interest in the proposed model. The results of the pairwise causality between the variables reported in Table 8 reflect a pairwise causal relationship between GDP and annual mean temperature. In addition, there are also bidirectional causal relationships between non-renewable energy consumption and annual average temperature, and between non-renewable energy consumption and GDP, supporting the feedback hypothesis. This result proposes that the growth process in selected emerging Asian countries is pollution-intensive. The results also show unidirectional causality from renewable energy consumption to annual average temperature, transport infrastructure to annual average temperature, GDP to non-renewable energy consumption, transport infrastructure to GDP, and GDP to urbanization.

5 Concluding remarks and policy implications

The current study aims to examine the effects of renewable and non-renewable energy consumption and economic growth on climate change in five emerging Asian countries during the period 1975–2020. First, the panel second-generation unit root test results clearly show that the entire variables in the models transform into a stationary state at the first derivative, which allows us to use panel long term cointegration and long term elasticity estimates. Second, the Pedroni cointegration test and the Westerlund cointegration test confirmed long-term cointegration among variables. The long-term estimated parameters of the Augmented Average Group (AMG) method show that renewable energy consumption significantly reduces the mean annual temperature, while non-renewable energy consumption, transport infrastructure investment, GDP, and urbanization contribute significantly to climate change. Long-term variable elasticity coefficients results based on the second model of climate change show that an increase in GDP can stimulate climate change, while an increase in GDP^2 can significantly reduce climate change, thus validating the inverted U-shaped EKC hypothesis for emerging Asian economies.

Results of country-specific analyzes using AMG estimates show that renewable energy consumption reduces climate change, while non-renewable energy consumption, transport infrastructure investment, and GDP contribute to climate change in selected emerging Asian countries. However, GDP^2 has significant adverse effects on climate change in India, China, Japan, and South Korea, validating the inverted U-shaped EKC hypothesis for all countries except Bangladesh. Urbanization contributes significantly to climate change, with the exception of Japan, which does not have any significant impact on climate change.

Finally, the results of the Dumitrescu and Hurlin (2012) causality tests report pairwise causality between GDP and mean annual temperature, non-renewable energy consumption and mean annual temperature, and non-renewable energy consumption and GDP, supporting the feedback hypothesis. The results also show unidirectional causality from renewable energy consumption to annual average temperature, transport infrastructure to annual average temperature, GDP to non-renewable energy consumption, transport infrastructure to GDP, and GDP to urbanization.

Specific and important policy implications emerge from the above results. Reducing energy use and pollutant emissions can mitigate climate change, and this will likely be combined with urbanization if governments in these countries take the following steps. 1) Encourage renewable energy expansion plans and promote renewable energy production and distribution infrastructure. 2) Promote the construction of industrial bases with high energy efficiency and emission reduction. 3) Establish a free trade system for clean technology transfer from developed countries. 4) Stimulate urbanization through low-carbon urban infrastructure and transport systems to reduce climate change and promote sustainable growth in these emerging Asian economies.

The model used in this study can be extended to a wider scope by increasing the sample size and the number of Asian emerging economies for future research. Furthermore, the validity of the N-shaped EKC hypothesis could also be tested in future studies on the proposed emerging Asian countries. This study tested urbanization as the main driver of energy use and carbon emissions leading to climate change, and likewise, another study would need to test transport infrastructure investment as the main driver of energy consumption and thus climate change.

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

J.Z. (Zhao), T.Z. (Zhang), J.C. (Chen), H.J. (Ji) and T.W. (Wang) conceptualized and revised the study, software data curation, analysis and final approval for publication.

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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.

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Appendix:

TABLE A1 Variable data sources, measurements and descriptions.

Variables	Description	Measurment	Sources
CC	Climate Change	Average annual temperature	National Oceanic and Atmospheric Administration (NOAA)
GDP	Gross Donestic Product	Constant 2015 US$	WDI, World Bank
TIN	Transport infrastructure investment	Constant 2015 US$	OECD database
URB	Urbanization	Percentage of total population	WDI, World Bank
REC	Renewable energy consumption	Million tons of oil equivalent (Mtoe)	WDI, World Bank
NREC	Non-renewable energy consumption	Million tons of oil equivalent (Mtoe)	WDI, World Bank