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A step towards a sustainable environment in top Asian countries: the role of higher education and technology innovation

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ABSTRACT

The present study aims to examine a step toward a sustainable environment in top Asian Countries by incorporating the role of higher education and technology innovation. The sample data were collected from (1995 to 2019). However, the most-suited methodological approach i.e., the CS-ARDL technique is used to assess the long-run and short impact of these variables on each other; in addition, the modern theory of the EKC model is applied in the study to enhance the credibility of the results. As per the short-run estimation, determinants of higher education, GDP^2, and technology innovation are negatively associated with the environment ($CO2$ emission). Although the long-run results of CS-ARDL signify that technology innovation (GIN) represents a −0.312*** coefficient value which indicates a negative and significant relationship with the environment, whereas, HE & GDP shows a positive association with the environment ($CO2$ emission) having the coefficient values of 0.249*** and 0.437***, respectively. While the factor of GDP^2 is negative in the long-run and positive in the short run, thus the EKC model is supported under this theoretical framework. Based on these explorations, the relevant implications are prescribed by the authors to get a sustainable environment in these top Asian countries.

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1. Introduction

Due to the increased eccentricity in the climatic conditions and the continuous process of industrialization, the natural phenomena of the universe experience a rapid increase in global warming, depletion of natural resources, deforestation, and increased carbon dioxide pollution. These are the leading destructive issues of an economy that make it challenging for the governing authorities to attain a sustainable environment successfully. However, environmental researcher Sarkis (2020) claims

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that markets are more concerned about growing the marvels of industrialization and less likely to take preventive stability majors that must meet the adverse effects of poverty, economic recession, unemployment, and degradation. Although it's a prime responsibility to assess the environmental risk before any industrial advancement destroys the decorum of a sustainable environment. Thus mainly established countries follow the guidance of the Environmental protection agency (EPA) (Chen et al., 2020; Kostetska et al., 2020) to secure the globe and support the health and well-being of civilians as per their social, economic, and environmental conditions. Among the fundamental proposed ideologies of sustaining ecological sustainability, higher education has played a crucial role over the past several decades in diagnosing the detrimental aspects of green contamination. In addition, Płotka-Wasylka et al. (2018) explained that education provides awareness about the non-eco-friendly elements such as emission of CO2 gas and other detrimental energies, which brings economic instability.

Similarly, to enhance the knowledge of higher education (UNESCO) announced the international Environment Education program (IEEP) to build a significant relationship between higher education and environmental sustainability. For instance, the projected global population will reach 9.7 billion by 2050, which requires almost 2.3 earthly planets, as explored by (Žalėnienė & Pereira,2021). Currently, the renaissance of this much earth space seems impossible due to the rising economic recession in terms of natural resources, energy usage, and waste production, which increases the ecological footprint, and harms the sustainable environment of the world. Thus, premium quality of knowledge and information is required to develop efficient and effective strategies that should be transferred globally to minimize environmental instability (Bautista-Puig & Sanz-Casado, 2021). In an account of this, UNESCO (2020) declared that under the reform of the United Nations Decade of Education for Sustainable Development, several programs were initiated to promote comprehensive education. These include relative courses introduced that cover the primary agendas of education and environmental issues, the enclosure of new approaches to learn technical skills, the engagement stakeholders to invest in higher education development incentives, the inclusion of numerous institutions that offer professional degrees of specific professions, and the assimilation of education for sustainability in formal education. However, Chankseliani and McCowan (2021) examined that higher education development plays a dominant role in achieving (SDGs-Sustainable development goals) that are planned to acquire a sustainable environment by providing peaceful, organic, and justifiable life for everyone now and in the future.

Therefore, to get ease from macro and micro-level environmental issues, the approach toward academic education should be modified, as addressed by SDGs. According to Cerf (2019), SDGs goals issues are mainly related to technological advancements adopted by the universe to gain the luxuries of an ultra-modern world, primarily produced from the extreme emission of C02 gas. Hence, Zafar et al. (2020) described that OCED countries struggle towards the quality of education via professionalized academic courses, developing the habit of critical and systematic thinking, adopting innovative skills, and assertiveness towards empowering the coming generations to endure the necessary transformational changes that are eco-friendly, and (Findler et al., 2019) highly sustainable and carbon-free. The characteristics mentioned earlier promote that when educational institutions provide opportunities for students to enroll in professional-level programs, universities offer innovative courses that provide information related to a green environment and encourage mobilization to gain technical expertise from renowned developed countries, which lessens the power of environmental degradation (Kim et al., 2019). Nonetheless, established economies like the USA are much more focused on higher education development activities (Işık et al., 2019), and that's how they industrialized their market through evolving nature-friendly technology innovations that omit the emission of C02 gas. Higher educational expertise enables them to implement green innovation technology tactics in their businesses to gain competitive advantages and acquire a sustainable environment from all over the orb.

Correspondingly, the role of technology innovation in supporting a sustainable environment can be analyzed through the previous publication on environmental issues, where numerous scholars (Khan et al., 2020; Shahbaz et al., 2020) enlightened the markets to gain proficiency in advanced technical policies for mitigating various aspects of ecological humiliation significantly reducing the emission of carbon dioxide. However, the typical and complex association between a sustainable environment and technology innovation was found because different types of implications are required that influence business productivity (Hashmi & Alam, 2019). In this scenario, economies should be educated enough to understand the efficient use of technology innovation with scarce resources. However, the World Bank (2020) reported that the adoption of technological innovations in emerging countries arises from 0.11 to 1.74 million (1980–2016); such progression highlights the significance of technological innovations in economic growth. Mainly, Asian countries are less responsive to adopting the procedures of technology innovation that are implemented without hurting the quality of the sustainable environment (Chen & Lei, 2018). For instance, transitioning from traditional technologies to eco-friendly technologies with the essence of green supply chain procedures helps optimize the usage of non-renewable resources that stabilize economic growth (Sohail et al., 2021). Still, the localities of Asian countries are affected adversely by any environmental uncertainties such as COVID-19; the forecasted GDP growth of Asian nations declined from 5.2% to 4.6% in 2022, and increases the inflation rate from 3.7% to 4.2% in 2022 (Our World in data, 4 July 2022), these consequences show the inadequacy in sustain the sustainability in Asian countries.

In this vein, the present authors ascertained Asian countries to investigate the performance of sustainable development concerning social, economic, and environmental issues. Though in Asian states besides deforestation and urbanization, 95% destruction of coral reefs occurred due to industrial works, marine and water-based contaminations, and overfishing. In addition, the highest rate of EVI-Environmental Vulnerability Index in Asian regions was investigated, thus these realms face challenges to balance environmental quality, conserve resources, and maintain sustainability (Younis & Chaudhary, 2020). Therefore, inspecting the ecological concerns in Asian republics under the significant insight of higher education development and technology innovation for a sustainable environment is one of the leading distinctiveness of the current study. Because very few prior peers highlight the importance of higher education in terms of a sustainable environment and as such no evidence found for awareness in Asian people through higher education and transference towards technical advancements, thus the present authors by using qualitative and quantitative methods to evaluate the worth of education for attaining a sustainable environment in top Asian countries such as China, Japan, Korea, Russia, Indonesia, Malaysia, Philippines, Singapore, Thailand, and Vietnam. According to Chen and Lee (2020), a transfiguration of technologies enhances productivity, decreases the time duration, and effectively cuts down the extra cost entitled to the products and services, such practices alleviate economic growth. Thus, hiring highly experienced and knowledgeable people is compulsory to make profitable and rational long-term decisions that will heighten economic growth and mitigate environmental pollution in Asian nations.

Similarly, in previous studies, the theoretical concept of economic growth was proposed by Grossman and Krueger in 1995, where they suggested the conceptual model by using the inverted U-shape structure of the economy in which standards of environmental conditions are measured. Though the existent study rises the aspect of value-addition by utilizing the EKC framework in the Asian countries surrounding via linking the factor of sustainable environment, higher education development, and technology innovation, which are not been collectively studied before under the data of top Asian countries between 1995 and 2019. A further uniqueness relies on the statistical tool which is the CS-ARDL technique, the analysis done to determine cross-sectional dependency between the countries on the macro-level; however, such methodological approaches that ensure the short-run and long-run results associations of environmental sustainability are missing from the prior literature. Hence the method of CS-ARDL is used to generate genuine outcomes. Usman et al. (2022) advised researchers to apply the CS-ARDL method for both short-run and long-run estimation, this technique is convenient for heterogeneous and homogenous panel data. Although past publications of Mehmood (2022) provide positive feedback between EKC theory and the CS-ARDL method as it was proved beneficial in terms of accurate prediction based on the results, therefore according to the authors CS-ARDL method seems suitable for analyzing the sustainable environment and its impacting factors, i.e., higher education development and technology innovation on the panel data of top Asian countries.

The remainder of this study is planned as follows; this section describes the recent work on econometric factors such as higher education, technology innovation, economic growth, and sustainable environment. After this, Section 2 explains the latest literature reviews that present the relationship between the variables, and Section 3 describes the methodological technique to run the analysis of top Asian countries. Then, Section 4 represents the estimations of the CS-ARDL method and the interpretations of the results, and finally, Section 5 explains the conclusion and implications of the study.

2. Literature reviews

Nowadays, the tussle towards the organic environment rises abruptly as industrialization grows; due to these economic expansions, detrimental consequences on the environment emerge, which deteriorate the sustainable environment (Ahmad et al., 2021). However, numerous investigations have been published in the context of a sustainable environment to provide ways for mitigating the emission of carbon dioxide gas. Thus, this study accumulated relevant and recent publications on the related variables such as higher education development, technology innovation, and sustainable environment to develop a better acquaintance with the recent worldly goings-on.

2.1. Higher education and sustainable performance

After various testifications, it is obvious that if any deviation occurs in the climatic conditions, environmental pollution, and resource-based activities, the sustainable performance of the economies fluctuates. While to mitigate the repercussion of environmental-affected variables thousands of factors were introduced by environmentalists, among those higher education is one of the influential factors of environmental sustainability. However, thru EKC theory the role of education in a sustainable environment is tested by many prior scholars (Katircioglu et al., 2020) because EKC theory adequately represents the dependabilities of environmental determinants. Based on this notion, the conceptual framework adopted by present researchers is the Environmental Kuznets Curve theory (EKC) proposed by Grossman and Krueger in 1995. Here authors identified that the initial level of higher education harms the environmental quality and environmental Kuznets represent instability. Still, after continuing growth, the positive influence of education on the economic conditions seems apparent, so the inverted u-shaped structure is approved. Similarly, Li et al. (2021) engrossed the EKC framework to justify the direct linkage between education and environmental performance, here they analyzed the inverted U-shaped connection. According to Cerf (2021), illiteracy or non-qualified residents in the economy become the reason for inflation, unemployment, poverty, low self-esteem, a higher number of crimes, a decrease in the inflow and outflow of incomes, and a lot of socio-economic issues that arise and harm the overall sustainable environment. Therefore, the element of education directly impacts economic stability; in this scenario, Findler et al. (2019) study investigated the effects of higher education on sustainable development by reviewing peer-reviewed journal articles between 2005 and 2017. The finding shows that higher education has a direct and indirect impact on the sustained environment and provide a more holistic understanding of how higher education educates the learners to consume less CO2 gas but still, there is a lack of an all-inclusive assessment approach that may lead to future research to clarify the impact of higher education on sustainable development. Jiang et al. (2021) also demonstrated identical results when the EKC model tested the analysis of environmental pollution and higher education in China.

However, Žalėnienė and Pereira (2021) conducted a study on higher education in comparison with CO2 emission to present the mechanism for a society to be more aware of sustainable problems in the countries. They described that a sustainable environment and lifestyle can be achieved when higher education consistently establishes programs to secure the world from the emission of harmful energies. Likewise, other socioeconomic variables have an impact on CO2 emissions and on the sustainability of the environment. Majeed et al. (2022) addressed the crucial part that political instability plays in CO2 emission and decrease. The study also demonstrated the importance of other elements i.e.; health and education. The study was carried out in Pakistan using panel data from 1990 to 2019. It was determined that political instability promotes a decline in energy use and creates obstacles to the expansion of the green economy. Still, barriers affect the successful contribution to making a better environment. That's why there is a need for a transformation in the attitude toward ethical practice and implementing effective policies for eco-friendly environments. Similarly, Novo-Corti et al. (2018) highlighted the importance of economic studies and how they can influence Romania's sustainable environment. Findings show that the studies conducted in the twenty-first century connect education and economic and social development. Furthermore, it is also revealed that Romania is making efforts in economic higher education by making slight adaptations of green technologies to improve the environmental degradation in their society. Additionally, Xu et al. (2022) suggested that students can innovate efficient and effective ways of manufacturing goods and services without deteriorating the healthy and clean environment through higher studies.

Another research is given by Demssie et al. (2020), who discussed the importance of higher education for the development of a sustainable environment in Ethiopia and Africa, where there is an extreme need to reform and transform the higher education system to develop scientific and technological advancement, the main idea of this article is to show that how Ethiopia face challenges an in renovating the higher education sector for a sustainable environment in terms of economy, political, technology progress. Still, they must continue to struggle to make higher education a centerpiece to reducing CO2 emissions. However, a study by Di et al. (2019) explained the strategical ways to enhance the higher education developmental programs which motivate the youth to alleviate the increased consumption of non-renewable energies, fossil fuels, and toxic gases, which damage economic growth.

Moreover, Abad-Segura and González-Zamar (2021) stated that higher education is vital as it prepares most professionals who develop, manage, work, teach and influence societies. This research study focuses on the transformation of higher education from theoretical to practical level in the period (1990–2018) that may positively impact thinking ability to promote the economic and technological development of society as higher education have a responsibility to create a sustainable environment. He et al. (2019) inspected the paper through the ARDL method to provide a deeper understanding of scientific, economic, technological and socio-economic policies, which help mitigate the environmental consequences that arise in OCED and China countries.

Above mentioned reviews concluded that sustainable development is the current issue on which higher education must begin to focus its mission. Similarly, a significant association between a sustainable environment and higher education is analyzed to ensure organic life for future generations. While Yang et al. (2019) agreed that educational institutions are vested by society with the task of discerning truth, imparting values, and preparing students to contribute to social progress and the advancement of knowledge that will transform economic conditions. Primarily through academic expertise, unique ways are introduced to regulate business operations without spoiling a sustainable environment.

2.2. Green technology innovation and sustainable environment

After the Paris climate conference, the expansions in technological innovations were observed around the globe because innovations increase economic growth and decrease CO2 emissions. For instance, Yıldırım et al. (2022) used the EKC model to investigate the role of technical advances, CO emissions, and the GDP growth of the OECD countries, here they supported the EKC framework and show the positive contribution of technologies to economic sustainability. When possible, sustainable energy options adapt, and all negative consequences on each sector are reduced (Ma & Lee, 2019). Similarly, initiatives for a sustainable environment via technological innovations can significantly contribute to the country's economy. Based on these findings, Guo et al. (2020) studied sustainable development with reference to green technology. The study was applied to 20 countries, and their Sustainable development goals index was compared to the Averaging sustainable development index. According to the results, significant carbon emissions were noted in the brown industries of the Arab Emirates, Korea, the US, Russia, and Kazakhstan. Russia was observed to have a positive trend in green technology development apart from Switzerland and Kazakhstan since its average sustainable development index was higher than its Sustainable development goals index due to its intensive management of water and sanitation. Moreover, Russia was the only developed country with a higher average sustainable development index. The study concludes that it is unfavorable for developing countries to adopt green technology compared to developed countries. In another journal, the positive role of technology innovation, renewable energies, and globalization in mitigating the environmental degradation in Pakistan is examined by Chien et al. (2021) by using the QARDL method on time series data from 1980 to 2018.

Furthermore, the importance of green technology on the total energy factor was shown by Wang et al. (2021); they used the panel threshold model and analyzed the influence of green technology along with its influence mechanism. The influence was calculated by using the mainland data of China from the year 2015 to 2018. After data collection, the mediating test based on the data was influenced by the mechanism. According to the results, a threshold impact of innovation in green technology on the energy total factor exists. The up-gradation in the industry structure sector affected the total energy factor. The effect was seen to be differentiating in different regions of China. Thus, heterogeneity in the impact was observed. The threshold effect was only found in the western region and not central and eastern since both areas have crossed certain levels of developmental stages. Whereas, Sohail et al. (2022) stated that sometimes governments are having difficulty coping with economic expansion or unchecked environmental damages due to the technical enhancements, that disturb the economic performance. In addition, Khattak et al. (2022) studied the cyclic impact of green technology innovations and a sustainable environment on CO2 emissions in OECD economies. According to the results, there exits long-run cointegration among the used variables. Moreover, it was proven that there occurs significant long-term negative nexus between renewable energy usage, positive shocks to green and sustainable technology innovation, and CO2 emissions. GDP per capita and negative shocks to green and sustainable technology innovation contributed to Carbon dioxide emission, which was also determined.

A similar concept prevailed by Khattak et al. (2021), which determined the counter-cyclical relationships between green technology innovations and sustainable technologies and CO2 emissions. During the study, it was observed that green and sustainable technology shocks contribute to CO2 emissions, but the positive shocks mitigate the economic boom periods. Moreover, it was also found that carbon dioxide emissions are reduced more due to renewable energy consumption than gross domestic products. It is clear from the previous literature that information and communication technologies boost work prosperity and also enhance and utilize the trade sector (Ahmed & Ridzuan, 2013). In order to demonstrate how ICT degrades the environment and to comprehend the intricate relationship between ICT, the effectiveness of governance, and financial development, Andlib and Khan (2021) conducted a study. In their research, ICT and the COE connection were also emphasized. The findings successfully demonstrated that, whereas financial development positively impacts COE, ICT has a negative impact on CO2 emission. Additionally, a number of suggestions were made to enhance environmental values through efficient governance.

Another review by Bakar et al. (2011) studied Malaysia for its compliance with green technology for sustainable business development. According to them, in developing countries, there is a need for massive growth in renewable energy so that drastic cuts in fossil fuels can be made. One such country is Malaysia, in which the economy, population, and industrialization growth demand a drastic increase in renewable energy. This demand is the reason for the promotion of green technology. A parallel study conducted by AlZgool (2020) also analyzed the EKC hypothesis. A quadratic model was developed to survey the data collected from 1980 to 2018 in Bahrain. ARDL technique was used. The variables were energy consumption and financial development. Besides, trade liberalization was another supporting variable. Moreover, carbon emission is found to be dependent on GDP2 and GDP. Outcomes showed the validity of EKC as the relationship between economic growth and CO2 emissions was found positive, where GDP2 change negatively affects co2 emission. It was further confirmed in both long and short-run settings that economic growth positively affects financial development. Fujii and Managi, (2019) conducted a study to find the determinants of sustainable green technology inventions. For this purpose, the study was conducted in China, and a focus was imposed on the study of differences observed in green technology developmental priorities in 5 years using patent publications. The contribution is considered to be due to the promotion of environmental protection and the development of the economy. The study's results demonstrated an increase in sustainable green patent publications, which was observed to improve efficiency, economic growth, and increased R&D expenditure shares. Development switched from renewable energy technology to pollution control and other sustainable green technologies.

In comparison to the above studies, Ali et al. (2021) researched solar power projects in Pakistan. They evaluated the strategies used in green technologies (solar power projects) to determine sustainable development. According to them, energy is an essential element for the sustainable development of an economy. In the study, data were collected from 44 respondents by using the survey method. According to the results, it was observed that there was a positive relation between green technologies on the sustainable development of solar projects. Moreover, it was also found that the approaches' cost and riskiness significantly modify the relationship between capital budgeting strategies and the performance through the finance of solar power plants.

To conclude the above findings, it is analyzed that through technical advancement, economic growth increases but environmental degradation rises (Konur, 2021; Andlib & Khan, 2021). In emerging states like Asian countries, gigantic companies and businesses lack innovative technical skills that produce extraordinary carbon fumes and utilize an extensive amount of natural resources that will increase environmental depletion (Abid et al., 2019). Although, modification in the traditional process to innovative manufacturing procedures can lead to a sustainable ecological system.

2.3. Data

To explain the relationship of parameters, the data of top Asian countries, i.e., China, Japan, Korea, Russia, Indonesia, Malaysia, Philippines, Singapore, Thailand, and Vietnam, is selected; the data comprises between the periods of 1995 to 2019. The stream of data on Higher Education and GDP has been collected from the source of the World Bank, where the number of employment of students in universities is measured. However, from the website of OCED, the technology innovation (GIN) is measured via the number of registered patents related to the environment, and the environment is measured by CO2 emission from the website of British petroleum.

3. Methodology

3.1. Unit root test

For analysis, first CD between the factors was done. Testing for cross-sectional dependence CD before specific root tests from the 1st, 2nd, and 3rd generation facilitates the dealing of cross-section dependence. Cross-section dependency is related to economic and financial integration, residual interdependence, diverse stocks for example; oil price shocks, crises related to global finance, omitted observable and unobserved standard components, and globalization. The addressing of cross-section dependency must be done since ignoring it can lead to results that are false, size distortion, biased stationarity, and cointegration results. The Pesaran (2015) CD test is used to determine the presence of cross-section dependence concerns. Once the cross-section dependency findings are acquired, the next step is to verify the stationarity of the data. Many researchers are concerned about non-stationarity in panel data. There are 3 categories of non-stationary in panel data in the literature. These generations are categorized into; 1^{st}, $2^{n,d}$, and 3^{rd}, these divisions are defined based on the concerns addressed by each technique, such as the problems of non-stationarity towards homogeneous panels handled by (Levin et al., 2002; Choi, 2001), and heterogeneous panels held by (Im et al., 2003). In the same way, Llus Carrion-i-Silvestre et al. (2005) addresses the concern of numerous structural breakdowns but neglect the issue of cross-sectional.

Second-generation devised by Pesaran (2007), and Moon and Perron (2012) addresses not just heterogeneity but also cross-section dependency between units not like Levin et al. (2002). In contrast, if the global and local issues due to the too occurrence of structural breaches in the series happen, the performance of first and second-generation will deteriorate and will lose power. In the existence of structural breakdown, third-generation tests are applicable with probable structural breaks in the data of the panel but also consider heterogeneity and cross-section dependency difficulties. However, to address the issue related to comparison of non-stationarity with cross-section dependency, as the existence of cross-section dependence renders t incorrect use of 1st generation panel unit root tests (Jalil, 2014). Furthermore, we use the Llus Carrion-i-Silvestre et al. (2005) experiment for each cross-section to account for the influence of time dimension structural fractures.

3.2. Cointegration testing

After completing CD, we use a test (Swamy, 1970) modified by Pesaran and Yamagata (2008). This test was used for the determination of homogeneity or heterogeneity of slope. According to the test, alternative and homogeneous slope parameters are considered null hypotheses. The first-generation cointegration tactics by Pedroni (2004), and Larsson et al. (2001) were not able to result in accurate figures. The reason for such failure was distortion in properties of size. The assumption of cross-section dependence is not even carried out by Pedroni (2001) but difficulties in non-stationarity, cross-section dependency, and heterogeneity in the data, the methods to estimate heterogeneity such as Westerlund and Edgerton (2008) are used in this study (2017).

The methods mentioned above are good for identifying breaks in structure in co-integration, apart from discussing the mentioned issues. The issues of parameters of the heterogeneous slope problems related to cross-section dependence are discussed by Westerlund (2007). Still, there are no mentioned possible structural breaks and rejection of null hypothesis. In contrast to 1st and 2nd generation tests, Westerlund and Edgerton (2008) approach takes into account not just cross-sectional dependency, heterogeneous slopes, and some errors that are serially correlated but also probable structural breakdowns at various sites for each cross-section. Another technique comparable to the one employed in this study for assessing the cointegrating connection between variables was devised in 2017 by persons named as 'Banerjee' and 'Carrion-i-Silvestre'. The technique employs the concept of Common Correlated Effects Mean Group i-e; CCEMG. The significance of using this method relies on the fact that it can be used for weak as well as strong dependency, heterogeneity, panel data that is non-stationary, and parameters, which can be consistently calculated in the framework of spurious regression.

3.3. Cross-sectional (ARDL) technique

Oil prices and the crisis related to global finance, serve as common shocks that can create cross-sectional dependence. If such factors are left unobserved while correlating them with the regression model, it can result in misleading outcomes. The cross-section ARDL can be used in the presence of slope heterogeneity and cross-section dependency. To address these difficulties, this test employs an estimator that correlates common dynamic effects (Yao et al., 2019, Çoban & Topcu, 2013). The following Eq. (2) is the starting point for CS-ARDL:

$$A_{i,t} = \sum_{I=0}^{p_A} \gamma_{I,i,} A_{i,t-1} + \sum_{I=0}^{p_C} \beta_{I,i,} C_{i,t-1} + \varepsilon_{i,t}$$

The above Eq. (3) is a model for ARDL. With the help of averages of a cross-section of each regressor, Eq. 4 is derived from Eq. 3. This helps overcome the unfitting conclusion about the threshold effect produced by cross-section dependency (Chudik & Pesaran, 2015). In cross-section dependency, Eq. (7) will produce misleading results.

$$A_{i,t} = \sum_{I=0}^{p_A} \gamma_{I,i,} A_{i,t-1} + \sum_{I=0}^{p_C} \beta_{I,i,} C_{i,t-1} + \sum_{I=0}^{p_B} \alpha'_{i,} I\overline{X}_{i,t-1} + \varepsilon_{i,t}$$

$\overline{X}_{i,t-1} = (A_{i,t-1}, C_{i,t-1})$ Illustrated above, denotes the average obtained from dependent and independent variables. At the same time, p is the lags for each variable. 'Sustainable environment' is denoted by A (the dependent variable), and independent variables; higher education, technology innovation, and economic growth are characterized by C&B. To avoid the cross-sectional dependence due to spillover effects, cross-sectional averages are indicated by $\overline{X}$ excluding the time dummies and trends (Liddle, 2018a, 2018b). Long-run coefficients are calculated by CS-ARDL based on coefficients that are short-run. The following equation explains the long-run coefficient and mean group estimator:

$$\pi_{CS-ARDL,i} = \frac{\sum_{I=0}^{pC} \hat{\beta}_{I,i}{}^{PA}}{1 - \sum I = 0} \gamma_{I,\mathrm{i}}$$

The equation for the Mean group is:

$$\pi_{MG} = \frac{1}{N} \sum\nolimits_{i=0}^{N} \hat{\pi}_i$$

The equation for the short-run is:

$$\begin{aligned}\Delta A_{i,t} =& \vartheta_i [A_{i,t-1} - \pi_i C_{i,t}] - \sum\nolimits_{I=1}^{PA-1} \gamma_{I,i}, \Delta_I A_{i,t-1} \\ &+ \sum\nolimits_{I=0}^{PC} \beta_{I,i}, \Delta_I C_{i,t} + \sum_{I=0}^{p_B} \alpha'_{i,} I\overline{X}_{i,t} + \varepsilon_{i,t}\end{aligned}$$

where

$$\Delta_I = t - (t-1)$$

$$\tau_i = -\left(1 - \sum\nolimits_{I=1}^{pA} \gamma_{I,i}\right)$$

$$\hat{\pi} = \frac{\sum_{I=0}^{PC} \beta_{I,i}}{\tau_i}$$

$$-\hat{\pi} = \frac{1}{N}\sum_{i=0}^{N} \hat{\pi}_i$$

ECM (1) denoted for 'The term Error Correction Mechanism' is used to describe the duration required by economy to gain equilibrium. In other words, it is the adjustment of speed towards the equilibrium point for CS-ARDL and PMG which is the pooled mean group.

3.4. Robustness tests

With the use of traditional techniques, there may be a chance of occurrence of slope heterogeneity along with cross-sectional dependency. (Yao et al., 2019; Çoban & Topcu, 2013). Common correlated effect means group i–e; CCEMG is employed here with reference to two factors described before and some structural features (2006). Furthermore, CCEMG outperforms, even with standards that are non-stationary and factors that remain unobserved. The CCEMG considers time-variant unobservable with diverse slope parameters while simultaneously overcoming the identification problem. (Liddle, 2018a, 2018b) observed that CCEMG imposes averaging results on all the cross-sections of dependent and independent variables in order to eliminate the effect of spillover induced due to cross-section dependency, rather than only adding time dummies or trends (Liddle, 2018a, 2018b). Whether weak or strong the variable is, CCEMG is resilient to it for finite and numbers that are infinite as well, with global shocks such as financial crises, effects due to local spillovers, and prices for oil shocks (Pesaran & Tosetti, 2011)

4. Data Analysis

The foremost statistical estimation of the cross-section dependence test reported in *table 1*, Pesaran (2015), based on the p-values results, indicates that cross-section dependence is present in the panel data of Asian countries. In addition, the null hypothesis of no (CD) of all the factors is rejected at 1%. This estimation is necessary for the forthcoming tests because if cross-section dependence is not examined, the other values projected are biased and missing (Salim et al., 2017).

Table 1. Results of cross-sectional dependence analysis.

Variable	Test statistics (p-values)
CO2	43.148*** (0.000)
GDP	37.005*** (0.000)
GDP2	22.164*** (0.000)
HE	52.019*** (0.000)
TIN	49.185*** (0.000)

CO2 represents Carbon dioxide emission, GDP explains the Gross domestic product, HE denotes higher education development, and TIN reflect Technology innovation.
Note: *** explains the level of significance at 1%, whereas the values are in parentheses contains P-values.
Source: Authors estimations.

Table 2 uses the (Pearson 2007) approach of a unit root. The test was carried out in the presence of data with CD, heterogeneity, and structural fractures. The null hypothesis of unit root and non-stationarity is supported since Z is smaller than 1.96, which accounts for structural breakdowns, cross-section dependency, and variability. Pearson (2007) describes a strategy in which all variables under test are stationary at a level. As a result, the Bai & Carrion-I-Silvestre (2009) approach was used for first-order differencing. According to the findings of this technique, the null hypothesis was rejected. So it can be inferred that all of the variables (Carbon dioxide (environmental pollution CO2), economic growth-GDP, GDP2, higher education-HE, and green innovation-GIN) are stationary at first difference or are integrated at 1, in the presence of CD, heterogeneity, and structural halts.

Table 3 describes the results obtained from the slope heterogeneity test. The test aims to compare the distance between the coefficients obtained from cross-sectional unit-specific regression. Thus, the slope heterogeneity technique detects whether a slope is homozygous or heterozygous. Furthermore, it is expected that homozygous slope coefficients might produce misleading findings. According to the Null hypothesis, there exist homozygous slope coefficients. The *p*-value of the findings shows that the null hypothesis is rejected at 1.5% and 10% levels, indicating that there are heterogeneous slope coefficients and no misleading results can be derived.

Co-integration analysis was done in Table 4 in order to determine the existence of co-integration among factors in the occurrence of cross-section dependence, serial correlation, structural breaks, and heterogeneity. For this purpose, a null hypothesis was generated, stating that no co-integration exists among the variable provided the

Table 2. Results of unit root test with & without structural break Pesaran (2007).

	Level I(0)			First Difference I(1)		
Variables	CIPS	M-CIPS			CIPS	M-CIPS
CO2	−3.185***	−6.009**			–	–
GDP	−6.011***	−3.174**			–	–
GDP2	−4.172***	−5.038**			–	–
HE	−5.060***	−3.162**			–	–
GIN	−3.191***	−4.155**				
Bai & Carrion-I-Silvestre (2009)						
	Z	P_m	P	Z	P_m	P
CO2	0.254	0.168	16.174	−5.048***	4.153***	91.001***
GDP	0.310	0.245	20.051	−3.169***	6.010***	63.148***
GDP2	0.179	0.192	17.183	−6.007***	3.174***	87.059***
HE	0.238	0.330	21.049	−4.158***	5.061***	54.183***
GIN	0.161	0.176	18.166	−5.041***	4.195***	72.110***

Note: The significance level is determined by 1, 5, and 10% indicated through ***, **, and *, respectively.
Source: Authors' estimation.

Table 3. Results of slope heterogeneity analysis.

Statistics	Test value (p-value)
Delta tilde	80.143*** (0.000)
Delta tilde adjusted	73.199*** (0.000)

Note: ***, ** & * explain the level of significance at 1%, 5% and 10%, respectively, whereas the values are in parentheses contains *p*-values.
Source: Authors estimations.

Table 4. Results of Westerlund and Edgerton (2008).

Test	No break	Mean shift	Regime shift
Dependent variable: EFP			
$Z_{\varphi}(N)$	−12.138***	−10.155***	−11.032***
P_{value}	0.000	0.000	0.000
$Z_{\tau}(N)$	−9.426***	−9.141***	−10.261***
P_{value}	0.000	0.000	0.000

Source: Authors' estimation.

assumptions described before. The figures of the *p*-value are at a 1% level of significance. The test results rejected the null hypothesis since the p-value is less than 0.05. Thus it can be stated that there exists co-integration among the variable Ecological Footprint (EFP), Carbon dioxide emissions (environmental pollution), economic growth (GDP; GDP2), Higher education (HE), and Green innovation (GIN). An identical view is represented before in the studies of (Ahmad et al., 2021; Abid et al., 2021)

Table 5 represents the CS-ARDL long-run analysis results. Hence, economic growth (GDP) positively influences the environment with a coefficient value of (0.437), which is significant at 1%, 5%, and 10%. This signifies that a 1% increase in the economic growth of top Asian countries causes environmental degradation by (0.43%). This means that when stability in the economies is augmented consumption of C02 emission in Asian countries rises, damaging the organic environment. Similarly, It is observed by Khan et al. (2020) that whenever components of GDP such as import exports, expenditures, investments, and consumption in terms of C02 emission attain progress overall environment deteriorates. Such circumstances lead to unstable economic conditions by harming the sustainable environment (Andlib & Khan, 2021).

Although, the factor of GDP^2 extracted from the theory of EKC-the (the Environmental Kuznets curve) represents the negative association with C02 emission with a coefficient value of (0.075) which is significant at 1% and supports the theory of EKC model. Therefore, the results provide that Asian countries (China, Japan, Korea, Russia, Indonesia, Malaysia, Philippines, Singapore, Thailand, and Vietnam) successfully sustain environmental stability in the long run; for instance, when the gross domestic product doubles, the repercussion of CO2 emission decrease. This outcome was previously supported by Saint Akadiri et al. (2019) when an investigation of economic growth and a sustainable environment in Africa was conducted. Other scholars Shahsavari and Akbari (2018) stated that developing nations contribute a more significant number of goods and services that may contain a larger portion of carbon production. Still, through technical advancements, consumption of non-renewable energies transits to renewable energies.

Table 5. Results of CS-ARDL analysis (long run results).

Variables	Coefficients	t-statistics	p-values
GDP	0.437***	4.005	0.000
GDP^2	−0.075***	−2.969	0.002
HE	0.249***	4.173	0.000
GIN	−0.312***	−3.071	0.000

Source: Authors' estimation.

Alike economic growth, the factor of higher education development embodies a positive relationship in the long run with the emission of C02 gas with a significant value of (0.249). Hence, the results indicate that in Asian countries, the quality of higher education is usually not enlightened or common in developing countries; people are reluctant to enroll in higher education programs due to the educational expenses, higher rate of unemployment, and rare source of income. Even though Sharma et al. (2021) expressed the situation of Asian countries that a higher rate of population increases the ecological footprint day by day and increases the rate of inflation, thus people are more concerned over the income productive resources rather than getting professional education that focuses on environmental issues. Similar valuation suggested by Masron and Subramaniam (2019), their results elaborate on the causes of environmental pollution in Asian countries, and fewer education institutes, poor quality of education, and non-qualified teachers are responsible for not providing innovative technical knowledge that helps to restrain the environmental degradation in Asian countries.

Furthermore, the variable of GIN, i.e., technology innovation, shows a negative relationship with the coefficient value of (0.312), which is significant at (0.01) with the environment variable. This elaborates that the technical innovations negatively impacted the environmental deprivation in selected Asian states in the long run. While the past research of Ullah et al. (2021) also supports the present identification in terms of a sustainable environment. In addition, Chen and Lee (2020) also investigated that after adopting transform processes and procedures in technical developments, the consumption of non-renewable energies decreases, ultimately stabilizing the developed countries' economic industries. Moreover, Razzaq et al. (2021) explored that in the long run, the negative impact of green technology innovation on CO2 emission is specific because all the ingredients used to manufacture the products are nature friendly. Also, Doğan et al. (2021) determined that the revolution of lower consumption-based carbon items results in a stable socioeconomic condition and provides a sustainable environment in the future.

After CS-ARDL analysis, in the long run, the estimation illustrated short-run analysis in Table 6. Thus, the factor of GDP represents the same results as it is in the long run. Like positive contribution in CO2 emission with a figure value of (0.129) observed whenever the economic growth intensifies with the ratio of 1%. Deceleration of authentic results obtained from the studies of Akram et al. (2020), where they all supported the present outcomes in terms of CO2 emission and GDP of Asian countries. In addition, Usman et al. (2021) second the present estimations. However, the factor of GDP2 negatively affiliated with environmental sustainability in the short-run also signifies that with the pace of time the stability in terms of

Table 6. Results of CS-ARDL analysis (short-run CS-ARDL Results).

Variables	Coefficients	t-statistics	p-values
GDP	0.129***	4.982	0.000
GDP^2	−0.024***	−3.331	0.000
HE	−0.085***	−6.003	0.000
GIN	−0.094***	−3.477	0.000
ECM (-1)	−0.286***	−4.103	0.000

Source: Authors' estimation.

environmental degradation attains in Asian countries. Katircioglu et al. (2020) stated that moderate consumption of energy resources lessens the emission of CO2 gas. But still, lack of resources and technical skills in emerging countries are facing extreme environmental issues that severely affect their organic life of them even after the positive influence of economic growth (Doğan et al., 2021).

Similarly, in Asian countries, higher education development represents a negative link with CO2 emission and a significant coefficient value of (0.085) in the short run of the CS-ARDL method. Thus, the outcome elaborates that in Asian countries professional experts play a vital role in decreasing the adverse effects of environmental pollution. Such outcomes are also explored by Rose et al. (2019). Also, it is observed that people of developing countries migrated more to different places to acquire a higher level of professional education which surely stabilize their economic health. Furthermore, the determinant of technology innovation represents the negative association with the environment and has a significant coefficient value of (0.094). This indicates that Asian countries are making the most from technological innovation in spreading the strategic procedures of traditional developments to green developments as cited by (Sun et al., 2022). In the paper by Khan et al. (2020), corresponding results are shown by using the CS-ARDL method. Finally, the factor of ECM (-1) reflects the adjustment speed towards an equilibium which is (-0.286) for Cross-sectional augmented autoregressive disturbed lags (CS-ARDL). However, it is noticed that the values in the short-run are comparably lower than in the long-run, mostly the reason is these Asian countries are still in the phase of development and struggling hard to overcome the adverse issues environment to sustain their economic sustainability.

In Table 7, the reported results of (CCEMC) are statistically tested to direct the situation of Asian countries in terms of GDP, GDP^2, HE, and GIN. As per the results, GDP is positively associated with the environment; for instance, if there is a 1% increase in GDP, the robustness of the environment increases by (0.372%) in Asian regions, similar identifications found earlier in the study of (Mughal et al., 2022) while stimulating the impact of environmental externalities on economic growth. Whereas the GDP^2 represents the same results in the long-run and short-run, a negative influence with a coefficient of (0.176%) on the environment of Asian countries. Under this declaration, former scholars Chen et al. (2022) tested the impact of environmental contamination as per the progression in economic growth measured. Thus, their results stated the negative correlation between GDP^2 and ecological sustainability. Furthermore, the factor of higher education indicates a positive affiliation with the environment in the short run; hence it is approved that Asian nations have failed to collaborate the aspects of higher education in mitigating environmental

Table 7. Results of CCEMG for robustness check.

	A common correlated effect mean group (CCEMC)		
Dependent variables	Coefficients	t-stats	p-values
GDP	0.372***	3.584	0.000
GDP^2	−0.176**	−2.736	0.018
HE	0.135***	6.143	0.000
GIN	−0.237***	−5.386	0.000

Source: Authors' estimation.

degradation. However, Radianti et al. (2020) second the previous statement regarding higher education with environmental stability. Likewise, Di et al. (2019) empower emerging economies to bestow higher education facilities to gain positive ecological sustainability. Lastly, the factor of GIN (technology innovation) represents the contrary results in the short-run; the element is positively significant to an environment; this signifies that in the initial stages of technology adoption, the severe amount of environmental pollution increases which deteriorates the sustainability of Asian countries such as China, Japan, Korea, Russia, Indonesia, Malaysia, Philippines, Singapore, Thailand, and Vietnam. However, Sun et al. (2022) investigated the MENA regions and declared that due to the inefficiency of green technologies the countries are unwillingly involved in trading activities that raise environmental pollution there. Present estimations of GIN are parallel to the studies of (Lin et al., 2022; Jiao et al., 2021), where the positive association of technology innovation with environmental sustainability has been investigated in emerging nations.

5. Conclusion and policy implications

To reduce the ecological issues, contemporary approaches are emerging relentlessly around the globe, but still, comprehensive strategies are necessary to mitigate the environmental hazards. Hence, the present study aims to examine a step toward a sustainable environment in top Asian Countries by incorporating the role of higher education and technology innovation. For future research, the authors collected data from the period (1995 to 2019) in the selected countries such as China, Japan, Korea, Russia, Indonesia, Malaysia, Philippines, Singapore, Thailand, and Vietnam. Therefore, the methodology of the CS-ARDL is used to assess the long-run and short impact of these variables on each other; in addition, the modern theory of the EKC model is applied in the study to enhance the credibility of the results. Furthermore, before the CS-ARDL method, the identification of CD is detected, and other tests like (Cross-sectional augmented autoregressive disturbed lags) are applied to lessen the consequences of false data. Although the results signify that technology innovation is negatively significant to the environment in both the short and long run, higher education detected positive outcomes in the long run. However, the economic growth factor GDP is positively significant to the environment; other than that, the EKC model is supported under this theoretical framework. Based on these explorations, the implications are the relevant approaches prescribed by the authors to get a sustainable environment in these top Asian countries.

5.1. Policy implications

Though, the CS-ARDL method, in the long run, indicates a positive association with the environment (CO2 emission) for specific reasons. In alignment with these results, a study by Franco et al. (2019) for South Asian countries suggested that policies for sustainable development using higher education need to be in alignment with the agenda of sustainability in understudied countries but these efforts are not properly encouraged by a governing approach to Higher education for sustainable development, nor are they effectively integrated to address social and environmental sustainability. So, there is a need to integrate higher education into policy, and curriculum, and should be practiced in alignment with sustainable development goals being carried out globally. One of the most prominent reasons is the policymakers' lack of rationality in integrating education with the environment. In Asian countries, governmental authorities are not that educated to ensure that the relevance of knowledge prevailed in academics is environmental-oriented or not. However, one of the implications is that heads of the educational sectors must assimilate their academic agendas by concerning the future aspects of the environment. Second, educational corporations must collaborate with the professionals of environmentalists who deliver technical skills on the topic, such as energy transition, the transformation from non-renewable to renewable, and the usage of less reactive gases in the production of technologies.

Third, as the results indicate the negative affiliation of technology innovation with the environment, thus policymakers develop systematized programs and procedures for implementing eco-friendly techniques in production. Khan et al. (2020) recommended policies that encourage technological innovations, which can ensure cleaner production along with cleaner consumption at home of renewable energy. Even though previous explorations showed favorable environmental outcomes, when green practices are adopted in technological innovations, thus, by engrossing the critical factors of green techniques such as green bonds, green credit cards, and green loans. Similarly, Yuan and Zhang (2020) found that technology innovation is highly affected by environmental policies and is positively related to industrial sustainable development so, environmental regulatory enforcement can contribute to the promotion of technological innovations in the eastern region of China. Moreover, technological innovations can improve Chinese sustainable development. So, other Asian regions must improve firms' ability to innovate independently, their government should encourage industrial and mechanical enterprises to increase their research and development intensity along with large and medium-sized industrial enterprises to develop carbon-free equipment and also establish institutions or academic forums of scientific research institutions. These intellectual implications nourish the Asian country's economic condition by alleviating the severe consumption of CO emissions and may become successful in attaining a sustainable environment.

5.2. Limitations and recommendations for future studies

The current study inclusively covers all the aspects but still, some specific limitations are there. For instance, future researchers may include more robust techniques such as the QARDL method to get results on quantile basis. Also existing study has incorporated few independent variables as a proactive environmental factors, thus if more modern econometric factors such as FDI and tourism are assimilated, the more rational outcomes demonstrated. Similarly, the Asian nations are selected to analyze their sustainability problems, if the comparison analyses done between Norden countries and Asian countries the more vivid depiction revealed in regard to sustainability concerns.

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References

Abad-Segura, E., & González-Zamar, M. D. (2021). Sustainable economic development in higher education institutions: A global analysis within the SDGs framework. *Journal of Cleaner Production*, *294*, 126133. https://doi.org/10.1016/j.jclepro.2021.126133

Abid, A., Majeed, M. T., & Luni, T. (2021). Analyzing ecological footprint through the lens of globalization, financial development, natural resources, human capital and urbanization. *Pakistan Journal of Commerce and Social Sciences (PJCSS)*, *15*(4), 765–795.

Abid, M., Abid, Z., Sagin, J., Murtaza, R., Sarbassov, D., & Shabbir, M. (2019). Prospects of floating photovoltaic technology and its implementation in Central and South Asian Countries. *International Journal of Environmental Science and Technology*, *16*(3), 1755–1762. https://doi.org/10.1007/s13762-018-2080-5

Ahmad, M., Khan, Z., Rahman, Z. U., Khattak, S. I., & Khan, Z. U. (2021). Can innovation shocks determine CO2 emissions (CO2e) in the OECD economies? A new perspective. *Economics of Innovation and New Technology*, *30*(1), 89–109. https://doi.org/10.1080/10438599.2019.1684643

Ahmed, E. M., & Ridzuan, R. (2013). The impact of ICT on East Asian economic growth: panel estimation approach. *Journal of the Knowledge Economy*, *4*(4), 540–555. https://doi.org/10.1007/s13132-012-0096-5

Akram, R., Chen, F., Khalid, F., Ye, Z., & Majeed, M. T. (2020). Heterogeneous effects of energy efficiency and renewable energy on carbon emissions: Evidence from developing countries. *Journal of Cleaner Production*, *247*, 119122. https://doi.org/10.1016/j.jclepro.2019.119122

Ali, S., Yan, Q., Sajjad Hussain, M., Irfan, M., Ahmad, M., Razzaq, A., Dagar, V., & Işık, C. (2021). Evaluating green technology strategies for the sustainable development of solar power projects: Evidence from Pakistan. *Sustainability*, *13*(23), 12997. https://doi.org/10.3390/su132312997

AlZgool, M. R. H. (2020). Impact of energy consumption and economic growth on environmental performance: implications for green policy practitioners. *670216917*

Andlib, Z., & Khan, A. (2021). The role of information and communication technologies (ICT) in environmental quality: An empirical analysis for South Asian Economies. *International Journal of Economic and Environmental Geology*, *12*(2), 80–86. https://doi.org/10.46660/ijeeg.Vol12.Iss2.2021.591

Bai, J., & Carrion-I-Silvestre, J. L. (2009). Structural changes, common stochastic trends, and unit roots in panel data. *Review of Economic Studies*, *76*(2), 471–501. https://doi.org/10.1111/j.1467-937X.2008.00530.x

Bakar, K. A., Sam, M. F. M., Tahir, M. N. H., Rajiani, I., & Muslan, N. (2011). Green technology compliance in Malaysia for sustainable business development. *Journal of Global Management*, *2*(1), 55–65.

Bautista-Puig, N., & Sanz-Casado, E. (2021). Sustainability practices in Spanish higher education institutions: An overview of status and implementation. *Journal of Cleaner Production*, *295*, 126320. https://doi.org/10.1016/j.jclepro.2021.126320

Carrion-I-Silvestre, J. L., del Barrio-Castro, T., & Lopez-Bazo, E. (2005). Breaking the panels: An application to the GDP per capita. *The Econometrics Journal*, *8*, 159–175. https://www.jstor.org/stable/23113636

Cerf, M. E. (2019). Sustainable development goal integration, interdependence, and implementation: The environment–economic–health nexus and universal health coverage. *Global Challenges (Hoboken, NJ)*, *3*(9), 1900021. https://doi.org/10.1002/gch2.201900021

Cerf, M. E. (2021). Health worker resourcing to meet universal health coverage in Africa. *International Journal of Healthcare Management*, *14*(3), 789–796. https://doi.org/10.1080/20479700.2019.1693711

Chankseliani, M., & McCowan, T. (2021). Higher education and the sustainable development goals. *Higher Education*, *81*(1), 1–8. https://doi.org/10.1007/s10734-020-00652-w

Chen, J., Hu, X., Razi, U., & Rexhepi, G. (2022). The sustainable potential of efficient air-transportation industry and green innovation in realising environmental sustainability in G7 countries. *Economic Research-Ekonomska Istraživanja*, *35*(1), 3814–3835. https://doi.org/10.1080/1331677X.2021.2004190

Chen, T. L., Kim, H., Pan, S. Y., Tseng, P. C., Lin, Y. P., & Chiang, P. C. (2020). Implementation of green chemistry principles in circular economy system towards sustainable development goals: Challenges and perspectives. *The Science of the Total Environment*, *716*, 136998. https://doi.org/10.1016/j.scitotenv.2020.136998

Chen, W., & Lei, Y. (2018). The impacts of renewable energy and technological innovation on environment-energy-growth nexus: New evidence from a panel quantile regression. *Renewable Energy*, *123*, 1–14. https://doi.org/10.1016/j.renene.2018.02.026

Chen, Y., & Lee, C. C. (2020). Does technological innovation reduce CO2 emissions? Cross-country evidence. *Journal of Cleaner Production*, *263*, 121550. https://doi.org/10.1016/j.jclepro.2020.121550

Chien, F., Ajaz, T., Andlib, Z., Chau, K. Y., Ahmad, P., & Sharif, A. (2021). The role of technology innovation, renewable energy and globalization in reducing environmental degradation in Pakistan: A step towards sustainable environment. *Renewable Energy*, *177*, 308–317. https://doi.org/10.1016/j.renene.2021.05.101

Choi, I. (2001). Unit root tests for panel data. *Journal of International Money and Finance*, *20*(2), 249–272. https://doi.org/10.1016/S0261-5606(00)00048-6

Chudik, A., & Pesaran, M. H. (2015). Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. *Journal of Econometrics*, *188*(2), 393–420. https://doi.org/10.1016/j.jeconom.2015.03.007

Çoban, S., & Topcu, M. (2013). The nexus between financial development and energy consumption in the EU: A dynamic panel data analysis. *Energy Economics*, *39*, 81–88. https://doi.org/10.1016/j.eneco.2013.04.001

Demssie, Y. N., Biemans, H. J., Wesselink, R., & Mulder, M. (2020). Combining indigenous knowledge and modern education to foster sustainability competencies: Towards a set of learning design principles. *Sustainability*, *12*(17), 6823. https://doi.org/10.3390/su12176823

Di, W., Danxia, X., & Chun, L. (2019). The effects of learner factors on higher-order thinking in the smart classroom environment. *Journal of Computers in Education*, *6*(4), 483–498. https://doi.org/10.1007/s40692-019-00146-4

Doğan, B., Driha, O. M., Balsalobre Lorente, D., & Shahzad, U. (2021). The mitigating effects of economic complexity and renewable energy on carbon emissions in developed countries. *Sustainable Development*, *29*(1), 1–12. https://doi.org/10.1002/sd.2125

Findler, F., Schönherr, N., Lozano, R., Reider, D., & Martinuzzi, A. (2019). The impacts of higher education institutions on sustainable development: A review and conceptualization. *International Journal of Sustainability in Higher Education*, *20*(1), 23–38. https://doi.org/10.1108/IJSHE-07-2017-0114

Franco, I., Saito, O., Vaughter, P., Whereat, J., Kanie, N., & Takemoto, K. (2019). Higher education for sustainable development: Actioning the global goals in policy, curriculum and practice. *Sustainability Science*, *14*(6), 1621–1642. https://doi.org/10.1007/s11625-018-0628-4

Fujii, H., & Managi, S. (2019). Decomposition analysis of sustainable green technology inventions in China. *Technological Forecasting and Social Change*, *139*, 10–16. https://doi.org/10.1016/j.techfore.2018.11.013

Guo, M., Nowakowska-Grunt, J., Gorbanyov, V., & Egorova, M. (2020). Green technology and sustainable development: Assessment and green growth frameworks. *Sustainability*, *12*(16), 6571. https://doi.org/10.3390/su12166571

Hashmi, R., & Alam, K. (2019). Dynamic relationship among environmental regulation, innovation, CO2 emissions, population, and economic growth in OECD countries: A panel investigation. *Journal of Cleaner Production*, *231*, 1100–1109. https://doi.org/10.1016/j.jclepro.2019.05.325

He, P., Ning, J., Yu, Z., Xiong, H., Shen, H., & Jin, H. (2019). Can environmental tax policy really help to reduce pollutant emissions? An empirical study of a panel ARDL model based on OECD countries and China. *Sustainability*, *11*(16), 4384. https://doi.org/10.3390/su11164384

Im, K. S., Pesaran, M. H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, *115*(1), 53–74. https://doi.org/10.1016/S0304-4076(03)00092-7

Işık, C., Ongan, S., & Özdemir, D. (2019). Testing the EKC hypothesis for ten US states: An application of heterogeneous panel estimation method. *Environmental Science and Pollution Research International*, *26*(11), 10846–10853. https://doi.org/10.1007/s11356-019-04514-6

Jalil, A. (2014). Energy–growth conundrum in energy exporting and importing countries: Evidence from heterogeneous panel methods robust to cross-sectional dependence. *Energy Economics*, *44*, 314–324. https://doi.org/10.1016/j.eneco.2014.04.015

Jiang, Q., Khattak, S. I., & Rahman, Z. U. (2021). Measuring the simultaneous effects of electricity consumption and production on carbon dioxide emissions (CO2e) in China: New evidence from an EKC-based assessment. *Energy*, *229*, 120616. https://doi.org/10.1016/j.energy.2021.120616

Jiao, Z., Sharma, R., Kautish, P., & Hussain, H. I. (2021). Unveiling the asymmetric impact of exports, oil prices, technological innovations, and income inequality on carbon emissions in India. *Resources Policy*, *74*, 102408. https://doi.org/10.1016/j.resourpol.2021.102408

Katircioglu, S., Katircioĝlu, S., & Saqib, N. (2020). Does higher education system moderate energy consumption and climate change nexus? Evidence from a small island. *Air Quality, Atmosphere & Health*, *13*(2), 153–160. https://doi.org/10.1007/s11869-019-00778-6

Katircioglu, S., Saqib, N., Katircioglu, S., Kilinc, C. C., & Gul, H. (2020). Estimating the effects of tourism growth on emission pollutants: Empirical evidence from a small island. *Air Quality, Atmosphere & Health*, *13*(4), 391–397. https://doi.org/10.1007/s11869-020-00803-z

Khan, Z., Ali, M., Jinyu, L., Shahbaz, M., & Siqun, Y. (2020). Consumption-based carbon emissions and trade nexus: Evidence from nine oil exporting countries. *Energy Economics*, *89*, 104806. https://doi.org/10.1016/j.eneco.2020.104806

Khan, Z., Ali, M., Kirikkaleli, D., Wahab, S., & Jiao, Z. (2020). The impact of technological innovation and public-private partnership investment on sustainable environment in China: Consumption-based carbon emissions analysis. *Sustainable Development*, *28*(5), 1317–1330. https://doi.org/10.1002/sd.2086

Khan, Z., Ali, S., Umar, M., Kirikkaleli, D., & Jiao, Z. (2020). Consumption-based carbon emissions and international trade in G7 countries: The role of environmental innovation and renewable energy. *The Science of the Total Environment*, *730*, 138945. https://doi.org/10.1016/j.scitotenv.2020.138945

Khattak, S. I., Ahmad, M., Khan, S., & Li, H. (2021). The cyclical and asymmetrical impact of green and sustainable technology research (GSTR) on carbon dioxide emissions (CO2) in BRICS economies: Role of renewable energy consumption, foreign direct investment, and exports.

Khattak, S. I., Ahmad, M., Ul Haq, Z., Shaofu, G., & Hang, J. (2022). On the goals of sustainable production and the conditions of environmental sustainability: Does cyclical innovation in green and sustainable technologies determine carbon dioxide emissions in G-7 economies. *Sustainable Production and Consumption*, *29*, 406–420. https://doi.org/10.1016/j.spc.2021.10.022

Kim, D. H., Suen, Y. B., & Lin, S. C. (2019). Carbon dioxide emissions and trade: Evidence from disaggregate trade data. *Energy Economics*, *78*, 13–28. https://doi.org/10.1016/j.eneco.2018.08.019

Konur, O. (2021). Biodiesel and petrodiesel fuels: Science, technology, health, and the environment. *Biodiesel Fuels* (pp. 3–36). CRC Press.

Kostetska, K., Khumarova, N., Umanska, Y., Shmygol, N., & Koval, V. (2020). Institutional qualities of inclusive environmental management in sustainable economic development. *Management Systems in Production Engineering*, *28*(1), 15–22. https://doi.org/10.2478/mspe-2020-0003

Larsson, R., Lyhagen, J., & Löthgren, M. (2001). Likelihood-based cointegration tests in heterogeneous panels. *The Econometrics Journal*, *4*(1), 109–142. https://doi.org/10.1111/1368-423X.00059

Levin, A., Lin, C. F., & Chu, C. S. J. (2002). Unit root tests in panel data: Asymptotic and finite-sample properties. *Journal of Econometrics*, *108*(1), 1–24. https://doi.org/10.1016/S0304-4076(01)00098-7

Li, H., Khattak, S. I., & Ahmad, M. (2021). Measuring the impact of higher education on environmental pollution: new evidence from thirty provinces in China. *Environmental and Ecological Statistics*, *28*(1), 187–217. https://doi.org/10.1007/s10651-020-00480-2

Li, L., Li, G., Ozturk, I., & Ullah, S. (2022). Green innovation and environmental sustainability: Do clean energy investment and education matter? *Energy & Environment*, 958305X2211150. https://doi.org/10.1177/0958305X221115096

Liddle, B. (2018a). Consumption-based accounting and the trade-carbon emissions nexus. *Energy Economics*, *69*, 71–78. https://doi.org/10.1016/j.eneco.2017.11.004

Liddle, B. (2018b). Consumption-based accounting and the trade-carbon emissions nexus in Asia: A heterogeneous, common factor panel analysis. *Sustainability*, *10*(10), 3627. https://doi.org/10.3390/su10103627

Lin, L., Chang, H. L., Shahzad, I., & Waseem, N. (2022). A nexus between the rule of law, green innovation, growth and sustainable environment in top Asian countries: Fresh insights from heterogeneous panel estimation. *Economic Research-Ekonomska Istraživanja*, *35*(1), 5434–5452. https://doi.org/10.1080/1331677X.2022.2028177

Ma, L., & Lee, C. S. (2019). Investigating the adoption of MOOC s: A technology–user–environment perspective. *Journal of Computer Assisted Learning*, *35*(1), 89–98. https://doi.org/10.1111/jcal.12314

Majeed, M. T., Mazhar, M., Samreen, I., & Tauqir, A. (2022). Economic complexities and environmental degradation: Evidence from OECD countries. *Environment, Development and Sustainability*, *24*(4), 5846–5866. https://doi.org/10.1007/s10668-021-01687-4

Masron, T. A., & Subramaniam, Y. (2019). Does poverty cause environmental degradation? Evidence from developing countries. *Journal of Poverty*, *23*(1), 44–64. https://doi.org/10.1080/10875549.2018.1500969

Mehmood, U. (2022). Examining the role of financial inclusion towards CO2 emissions: Presenting the role of renewable energy and globalization in the context of EKC. *Environmental Science and Pollution Research International*, *29*(11), 15946–15954. https://doi.org/10.1007/s11356-021-16898-5

Moon, H. R., & Perron, B. (2012). Beyond panel unit root tests: Using multiple testing to determine the nonstationarity properties of individual series in a panel. *Journal of Econometrics*, *169*(1), 29–33. https://doi.org/10.1016/j.jeconom.2012.01.008

Mughal, N., Arif, A., Jain, V., Chupradit, S., Shabbir, M. S., Ramos-Meza, C. S., & Zhanbayev, R. (2022). The role of technological innovation in environmental pollution, energy consumption and sustainable economic growth: Evidence from South Asian economies. *Energy Strategy Reviews*, *39*, 100745. https://doi.org/10.1016/j.esr.2021.100745

Novo-Corti, I., Badea, L., Tirca, D. M., & Aceleanu, M. I. (2018). A pilot study on education for sustainable development in the Romanian economic higher education. *International Journal of Sustainability in Higher Education*, *19*(4), 817–838. https://doi.org/10.1108/IJSHE-05-2017-0057

Pedroni, P. (2001). Purchasing power parity tests in cointegrated panels. *Review of Economics and Statistics*, *83*(4), 727–731. https://doi.org/10.1162/003465301753237803

Pedroni, P. (2004). Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econometric Theory*, *20*(03), 597–625. https://doi.org/10.1017/S0266466604203073

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*(2), 265–312. https://doi.org/10.1002/jae.951

Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econometric Reviews*, *34*(6–10), 1089–1117. https://doi.org/10.1080/07474938.2014.956623

Pesaran, M. H., & Tosetti, E. (2011). Large panels with common factors and spatial correlation. *Journal of Econometrics*, *161*(2), 182–202. https://doi.org/10.1016/j.jeconom.2010.12.003

Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of Econometrics*, *142*(1), 50–93. https://doi.org/10.1016/j.jeconom.2007.05.010

Płotka-Wasylka, J., Kurowska-Susdorf, A., Sajid, M., de la Guardia, M., Namieśnik, J., & Tobiszewski, M. (2018). Green chemistry in higher education: State of the art, challenges, and future trends. *ChemSusChem*, *11*(17), 2845–2858. https://doi.org/10.1002/cssc.201801109

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, *147*, 103778. https://doi.org/10.1016/j.compedu.2019.103778

Razzaq, A., Wang, Y., Chupradit, S., Suksatan, W., & Shahzad, F. (2021). Asymmetric inter-linkages between green technology innovation and consumption-based carbon emissions in BRICS countries using quantile-on-quantile framework. *Technology in Society*, *66*, 101656. https://doi.org/10.1016/j.techsoc.2021.101656

Rose, D., Heller, M. C., & Roberto, C. A. (2019). Position of the society for nutrition education and behavior: The importance of including environmental sustainability in dietary guidance. *Journal of Nutrition Education and Behavior*, *51*(1), 3–15.e1. https://doi.org/10.1016/j.jneb.2018.07.006

Saint Akadiri, S., Bekun, F. V., & Sarkodie, S. A. (2019). Contemporaneous interaction between energy consumption, economic growth and environmental sustainability in South Africa: What drives what? *The Science of the Total Environment*, *686*, 468–475. https://doi.org/10.1016/j.scitotenv.2019.05.421

Salim, R., Yao, Y., & Chen, G. S. (2017). Does human capital matter for energy consumption in China? *Energy Economics*, *67*, 49–59. https://doi.org/10.1016/j.eneco.2017.05.016

Sarkis, J. (2020). Supply chain sustainability: Learning from the COVID-19 pandemic. *International Journal of Operations & Production Management*, *41*(1), 63–73. https://doi.org/10.1108/IJOPM-08-2020-0568

Shahbaz, M., Raghutla, C., Song, M., Zameer, H., & Jiao, Z. (2020). Public-private partnerships investment in energy as new determinant of CO2 emissions: The role of technological innovations in China. *Energy Economics*, *86*, 104664. https://doi.org/10.1016/j.eneco.2020.104664

Shahsavari, A., & Akbari, M. (2018). Potential of solar energy in developing countries for reducing energy-related emissions. *Renewable and Sustainable Energy Reviews*, *90*, 275–291. https://doi.org/10.1016/j.rser.2018.03.065

Sharma, R., Sinha, A., & Kautish, P. (2021). Does renewable energy consumption reduce ecological footprint? Evidence from eight developing countries of Asia. *Journal of Cleaner Production*, *285*, 124867. https://doi.org/10.1016/j.jclepro.2020.124867

Sohail, H. M., Zatullah, M., & Li, Z. (2021). Effect of foreign direct investment on bilateral trade: experience from Asian emerging economies. *SAGE Open*, *11*(4), 215824402110544. https://doi.org/10.1177/21582440211054487

Sohail, M. T., Ullah, S., & Majeed, M. T. (2022). Effect of policy uncertainty on green growth in high-polluting economies. *Journal of Cleaner Production*, *380*, 135043. https://doi.org/10.1016/j.jclepro.2022.135043
Sun, Y., Li, H., Andlib, Z., & Genie, M. G. (2022). How do renewable energy and urbanization cause carbon emissions? Evidence from advanced panel estimation techniques. *Renewable Energy*, *185*, 996–1005. https://doi.org/10.1016/j.renene.2021.12.112
Swamy, P. A. (1970). Efficient inference in a random coefficient regression model. *Econometrica*, *38*(2), 311–323. https://doi.org/10.2307/1913012
Ullah, S., Ozturk, I., Majeed, M. T., & Ahmad, W. (2021). Do technological innovations have symmetric or asymmetric effects on environmental quality? Evidence from Pakistan. *Journal of Cleaner Production*, *316*, 128239. https://doi.org/10.1016/j.jclepro.2021.128239
Usman, A., Ozturk, I., Naqvi, S. M. M. A., Ullah, S., & Javed, M. I. (2022). Revealing the nexus between nuclear energy and ecological footprint in STIRPAT model of advanced economies: Fresh evidence from novel CS-ARDL model. *Progress in Nuclear Energy*, *148*, 104220. https://doi.org/10.1016/j.pnucene.2022.104220
Usman, M., Anwar, S., Yaseen, M. R., Makhdum, M., S., A., Kousar, R., & Jahanger, A. (2021). Unveiling the dynamic relationship between agriculture value addition, energy utilization, tourism and environmental degradation in South Asia. *Journal of Public Affairs*, *22*(4), e2712.
Wang, M., Li, Y., & Liao, G. (2021). Research on the impact of green technology innovation on energy total factor productivity, based on provincial data of China. *Frontiers in Environmental Science*, *9*, 710931. https://doi.org/10.3389/fenvs.2021.710931
Westerlund, J. (2007). Testing for error correction in panel data. *Oxford Bulletin of Economics and Statistics*, *69*(6), 709–748. https://doi.org/10.1111/j.1468-0084.2007.00477.x
Westerlund, J., & Edgerton, D. L. (2008). A simple test for cointegration in dependent panels with structural breaks. *Oxford Bulletin of Economics and Statistics*, *70*(5), 665–704. https://doi.org/10.1111/j.1468-0084.2008.00513.x
World Bank. (2020). Innovative China: New drivers of growth.
Xu, X., Schönrock-Adema, J., Jaarsma, A. D. C., Duvivier, R. J., & Bos, N. A. (2022). A conducive learning environment in international higher education: A systematic review of research on students' perspectives. *Educational Research Review*, *37*, 100474. https://doi.org/10.1016/j.edurev.2022.100474
Yang, Y., Li, W., Sheldon, K. M., & Kou, Y. (2019). Chinese adolescents with higher social dominance orientation are less prosocial and less happy: A value-environment fit analysis. *International Journal of Psychology*, *54*(3), 325–332. https://doi.org/10.1002/ijop.12474
Yao, Y., Ivanovski, K., Inekwe, J., & Smyth, R. (2019). Human capital and energy consumption: Evidence from OECD countries. *Energy Economics*, *84*, 104534. https://doi.org/10.1016/j.eneco.2019.104534
Yıldırım, D. Ç., Esen, Ö., & Yıldırım, S. (2022). The nonlinear effects of environmental innovation on energy sector-based carbon dioxide emissions in OECD countries. *Technological Forecasting and Social Change*, *182*, 121800. https://doi.org/10.1016/j.techfore.2022.121800
Younis, F., & Chaudhary, M. A. (2020). Sustainable development: economic, social, and environmental sustainability in Asian economies. https://mpra.ub.uni-muenchen.de/100551/MPRAPaperNo.100551
Yuan, B., & Zhang, Y. (2020). Flexible environmental policy, technological innovation and sustainable development of China's industry: The moderating effect of environment regulatory enforcement. *Journal of Cleaner Production*, *243*, 118543. https://doi.org/10.1016/j.jclepro.2019.118543
Zafar, M. W., Shahbaz, M., Sinha, A., Sengupta, T., & Qin, Q. (2020). How does renewable energy consumption contribute to environmental quality? The role of education in OECD countries. *Journal of Cleaner Production*, *268*, 122149. https://doi.org/10.1016/j.jclepro.2020.122149
Žalėnienė, I., & Pereira, P. (2021). Higher education for sustainability: A global perspective. *Geography and Sustainability*, *2*(2), 99–106. https://doi.org/10.1016/j.geosus.2021.05.001