



The role of green growth, green financing, and eco-friendly technology in achieving environmental quality: evidence from selected Asian economies

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Abstract

Many countries are trying to achieve carbon neutrality targets by using environment-friendly technology and green growth. Thus, this analysis effort to identify the key role of green growth in improving the environmental quality. This study investigates the impact of green growth, income, environmental taxes, environment-friendly technology, renewable energy, and financial development in the context of 12 Asian economies over the period of 1990 to 2018. This study used the method of cross-section – augmented autoregressive distributed lag (CS–ARDL) to find out the impact of green growth and growth (GDP) on environment quality with some plausible variables under the scheme of environmental Kuznets curve (EKC). The study employed the method of CS–ARDL and for robustness the augmented mean group (AMG) method to find out the impact of green growth and GDP growth on environment quality with some plausible variables under the scheme of EKC. The results of CS–ARDL concluded that CO₂ is significantly affected by GDP growth, green growth, and technological change in the context of Asian economies. The GDP square is inversely and the GDP growth is positively related to the CO₂, indicating the presence of inverted U-shaped EKC in this region. But the inverse relationship between green growth and green growth square and concave EKC is observed in Asian countries. The study used the Dumitrescu and Hurlin panel test to gauge the causality between the variables. This study suggested that policymakers should focus on transforming the country's energy system in ways that will reduce energy-related CO₂ emissions faster than previously expected.

Keywords Green growth · Energy · Environment · GDP growth · Technological change

Introduction

The achievement of sustainable economic growth and green growth is the critical policy of many countries worldwide, and they are trying to eliminate this environmental pollution in their countries. To develop green growth strategies for emission control, it is necessary to adopt new technologies that reduce environmental pollution (Saleem et al. 2020; Wiebe and Yamano 2016). Environmental degradation can be controlled by environment-friendly technologies, renewable energy resources, and green growth strategies (Su et al. 2020; Umar et al. 2020a). Recently, many countries have been trying to invest in energy-related technologies to protect the environment. Additionally, various factors, e.g., energy supply security, energy dependency, climate change, energy price volatility, and environmental disasters, encouraged many developed and emerging economies to divert their attention to green growth and sustainable economic growth (Sohag et al. 2019; Sandberg et al. 2019; Tawiah

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et al. 2021). However, recent shifts in global policies suggest that various policymakers are serious about transforming the country's energy system in **green growth** and low-carbon transition path that will reduce energy-related CO₂ emissions and air pollution faster than previously expected. The adoption of green growth strategies and technologies is playing an inevitable role globally, and protecting the environment and natural resources is essential for future generations because future generations must be provided with a pollution-free environment.

Sustainable economic growth and poverty reduction objectives can be achieved through green growth strategies. The economic growth and development of any economy can be threatened by the Depletion of natural resources and environmental destruction. However, the study of Schmalensee (2012) examined that the nexus between economic growth and environmental degradation is not favorable. Various studies found that developing countries are eliminating poverty through conventional growth and their policies are not clear for green growth and transition for the clean environment through a sustainable growth path (Saleem 2020; Shahbaz 2018a). However, many researchers have given less attention to renewable energy sources and green growth and their impact on CO₂ emission (Alper and Oguz 2016; Shahbaz et al. 2018a). More attention is warranted to assess the impact of technological innovation, green growth, and renewable energy sources on CO₂ emissions. Less energy is used when an economy adopts efficient technology (Sohag et al. 2015). Changing the energy structure and adopting renewable energy are highly associated with technological innovation. Renewable energy sources are the fastest-growing energy sources. The use of renewable energy sources is expected to increase from 10% (in 2010) to 14% by 2035 (E.I.A. 2012). According to recent literature, climate change and energy security are issues that renewable energy address. Renewable sources can represent environmentally friendly and low-carbon energy sources, as solar, wind, geothermal, and hydropower energy do not produce greenhouse gases (GHGs).

Various prior literature had focused on the traditional growth (GDP gross) but less work has been done on green growth under the framework of EKC. Thus, this study provides new insight to policymakers and researchers. This analysis contributes to the significance of the green growth-CO₂ emission nexus in three ways: the theoretical and empirical framework of the existing literature. First, the liaison between environmental degradation and green growth development to achieve sustainable economic growth for Asian countries is not widely discussed in the existing literature. Although the nexus between CO₂ emission-growth-environmental taxes and renewable energy is well studied in various analyses, their results are inconclusive; a more deep investigation is required to re-examine the association

between energy-growth and CO₂ emission. This current study applied the latest green growth data with the environment-based adjusted multifactor productivity growth in the most polluted selected Asian countries. Although, in recent years, various scholars such as Hao et al. (2021) and Can et al. (2021) discussed green growth in the context of OECD countries, Asian countries that are world's top emitters are not under consideration. Second, this study employed the latest data (1990 to 2018) to emphasize the role of environment-based technological change/innovations, renewable energy, green growth indicator, GDP, financial assistance for green growth, and environmental taxes on environmental degradation under the scheme of Environmental Kuznets Curve. Finally, to achieve the objectives mentioned above, the latest panel data econometric techniques are used in this analysis.

We applied those of Pesaran (2007) and Pesaran and Yamagata (2008) to identify the cross-section dependence and slope homogeneity. The model's stationery is identified by Bai and Carrion-I-Silvestre (2009) because slope heterogeneity, cross-section dependence, and structural breaks are amalgamated in this method. We also used Westerlund (2007), Banerjee and Carrion-i-Silvestre's (2017) methods to identify the long-run relationship between the variables. Then, panel augmented distributed lag (ARDL) is used along robustness of the model is checked with an augmented mean group methodology. To identify the causal association between green growth and CO₂ emission with various other variables, the Dumitrescu and Hurlin (2012) panel causality method is used in this study. Thus, this study will efficiently give suggestions for further research to various researchers, and the study provides theoretical- and empirical-based practical suggestions for environmental improvements. Therefore, to fill the vacuum of previous studies, this study investigated the GDP growth, sources of energy, and other plausible hypothetical factors on CO₂ emission under the scheme of the EKC hypothesis.

The rest of the paper covers the introduction in the first section; the second section covers literature reviews; the third section covers the methodology and theoretical background; the fourth section covers the interpretation and discussion of results, while the last section covers the conclusion and policy recommendations based on empirical findings.

Asian economies and their Potential green growth strategies

The importance and understanding of the potential of green growth is also the essence of Asian countries. In 2009, the "low-carbon-green growth" framework was passed in the Republic of Korea. The strategic 5-year plans China are based on promoting green growth in various sectors of the

economy, e.g., the transformation of the transport sector from non-renewable to renewable energy. Asian economies can now divert their growth policies to sustainable green growth with their deliberate attempts. Various high-quality green manufactured goods and services are exported by Asian countries among the world's leading production companies and are performing well internationally.

The world's largest greenhouse gas emitters are East Asia and the Pacific region. Globally, the contribution of CO₂ emission of this region is one-third, and coal consumption is more than 60%; in this regard, it is critical to achieve the global environmental sustainability agenda (World Bank 2021). Asian countries require significant green innovative technological change compared to other countries due to its stark regional disparities. The largest green manufactured goods-exporting country in the world is China while the USA ranked second. The remaining small Asian economies are the Philippines, Vietnam, Indonesia, and India and have nascent green growth activity, but we concluded that Asian countries could move towards green growth. Asian countries have already taken many thriving and substantial measures of green growth, and various famous companies are playing their role in Asian countries. Nuclear power, efficient infrastructure, road transport, and smart grids are significant opportunities for many Asian countries. The International Energy Agency predicted that by 2050 Asian countries will be the hub of green technologies. The Chinese government has put colossal capital transformation to technological innovation, especially nuclear energy. Numerous green manufactured goods and services contribute an annual \$2.9 trillion globally (World Bank 2021). Globally, carbon combat management technologies account for 22% annually from Asian economies, and exports reached 35% annually. Major trading countries of Asia are South Korea and Japan, and high-value patents in green technologies are exported by them globally, indicating that Asian countries have the potential to accelerate green technological innovation. Modern carbon dioxide mitigation innovations have been imperative place in Japan and South Korean economies.

Similarly, China, the Philippines, India, and Vietnam economies are also developing low levels of frontier innovation and low-carbon technologies. Renewable technology (e.g., wind and intelligent grid-based electricity) is flourishing in India and has a comparative advantage, while the Philippines has a comparative advantage in photovoltaic and efficient lighting. In addition, globally, China exports technological innovative goods to mitigate CO₂ emissions and contributes the highest photovoltaics share. China is also trying to reduce the cost of photovoltaic manufacture through innovations (Asia Pacific Report 2019). The Chinese and Korean economy is targeted to achieve sustainable development and green growth through innovation and green industrial policies. The strategies of these countries are related to

promoting the green growth of export-oriented technologies and the improvement of innovative capabilities.

Figures 1 and 2 illustrate the comparison of car dioxide emissions per capita and innovation in environmental technologies for selected Asian countries over the period of 2018. Figure 1 illustrates that Saudi Arabia, South Korea, Kazakhstan, Singapore, and China have the highest per capita carbon dioxide emissions and are among the top emitters of the world, e.g., China. The Philippines and India also have the lowest emissions among selected countries. In Fig. 2, it is clear that there is a significant difference between the selected Asian countries in terms of environmentally friendly technologies (number of patents). South Korea, Japan, and China are at the top compared to the other countries. The ratio of environment-technological innovation in India and Saudi Arabia is increasing. The contribution of environment-technological innovation is not significant in the rest of ASIAN economies.

Literature review

Since the last few years, the CO₂ emission-economic growth nexus (with other variables) have been discussed internationally with its importance for human wellbeing; Apergis and Payne (2009a, 2009b, 2009c) and Alam et al. (2012) have found that economic growth is the main cause of these environmental issues. Innumerable aspects of environmental degradation have been examined in numerous research studies. These determinants are related to geographic, political, and socioeconomic aspects. The findings of these studies with different dynamic relationships, methodologies, and macroeconomic variables are inconclusive and vary from region to region. However, less attention has been given to the nexus between CO₂ emission and green growth. Thus, this section will discuss the role of green growth moving towards environmental sustainability (e.g., green financing, renewable energy, environment-friendly innovation and development, and carbon taxes) and the main determinants of environmental degradation.

The pillars of environment and sustainable development in terms of environment-socioeconomic factors play a tremendous role for researchers and environmental activists in their decision-making (Saleem et al. 2020). Various factors determine environment sustainability: CO₂ emission (as in our analysis), financial development, GDP growth (Koonthar et al. 2021; Khan and Ozturk 2021; Shoaib et al. 2020; Kirikkaleli 2020), renewable energy consumption, FDI inflow (Erdogan 2014; Omri et al. 2014); technological innovation (Ahmad and Raza 2020; Khan et al. 2020a), and associations among the population, energy use, economic growth, and CO₂ emissions (Engelman 1994, 1998; Neil et al. 2001; Ohlan 2015; Rahman and Mamun 2016; Rahman et al. 2017). Similarly, other

Fig.1 CO2 Emission (metric tons per capita)

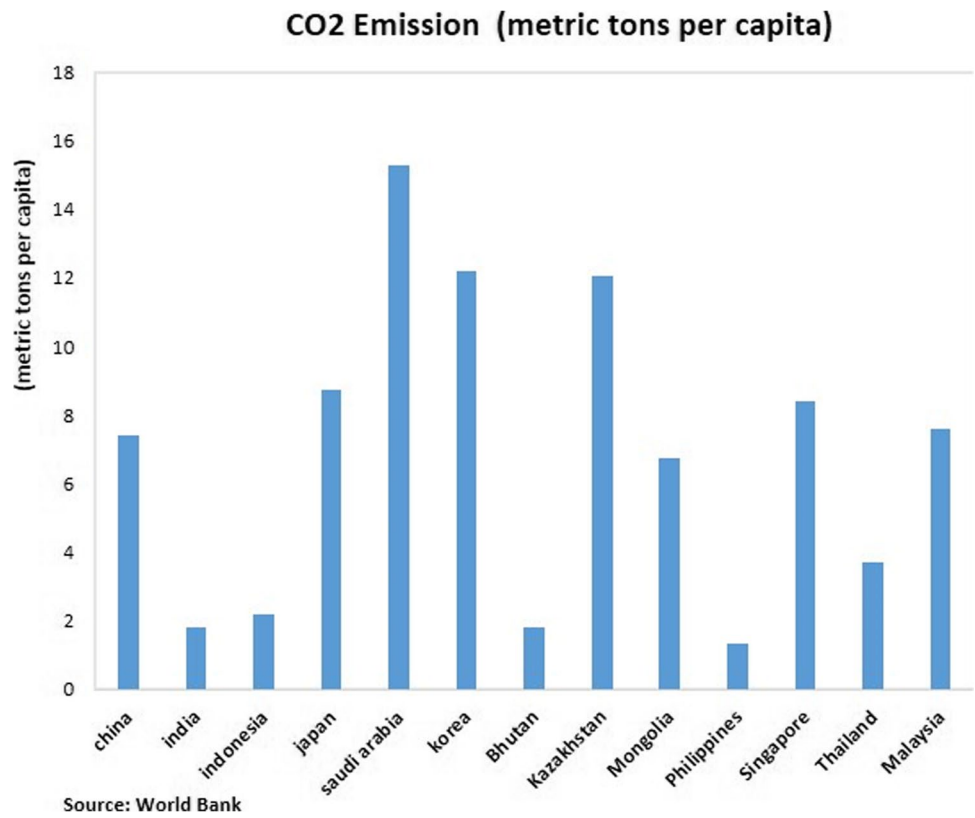
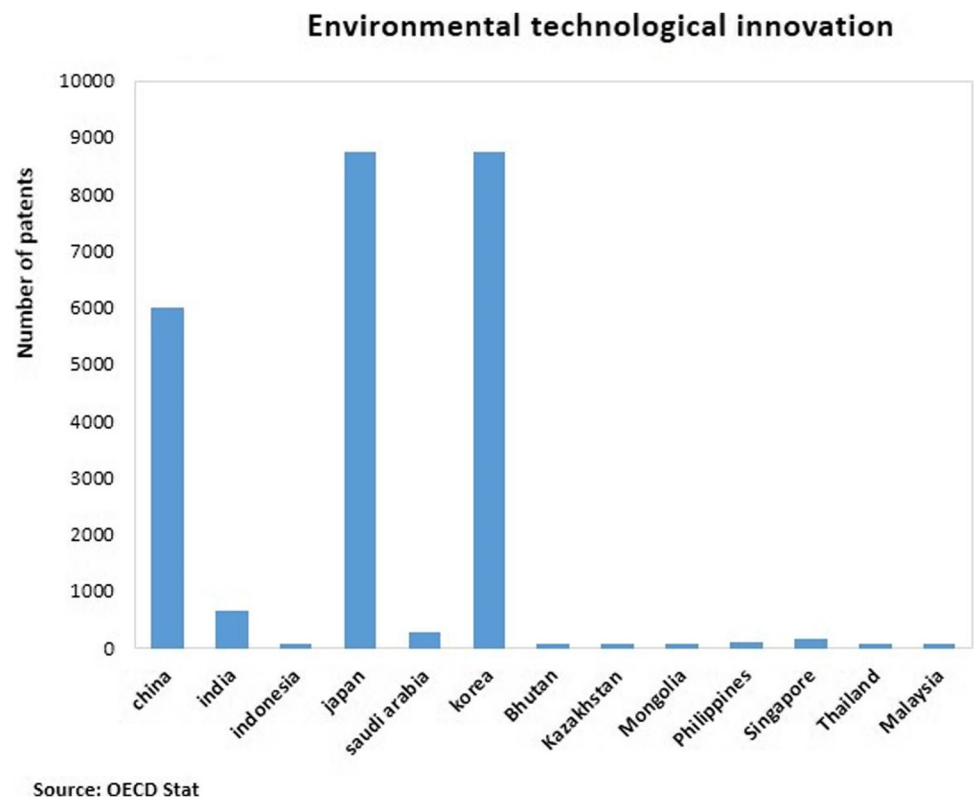


Fig.2 Environmental technological innovation



factors in addition to “scale, composition, and technical effect” contribute under the EKC framework, such as trade liberalization and environmental quality demands regarding income elasticity, regulation, and policy (Dinda 2004). Economic sustainability can be delayed or induced by all of these elements, and these elements determine the different shapes of the EKC (Bekhet and Othman 2018; Álvarez-Herránz et al. 2017).

Literature on environmental taxes and CO₂ emission nexus

Protection and encouragement of investments in clean energy and mitigation of CO₂ emission can be made possible by controlling the prices of non-renewable energy sources and imposition of taxes for non-renewable sources. Thus, various countries are trying to impose environmental taxes on their economies. Gerlagh and Van der Zwaan (2006) used the energy consumption model in their analysis and highlighted the importance of carbon taxes. Bruvold and Larsen (2004) have used a general equilibrium simulation model to investigate the contribution of carbon taxes in CO₂ mitigation in the context of Norway. Similarly, Xia et al. (2007) examined the indirect relationship between environmental taxes and CO₂ emission. The authors have also highlighted the importance of economic growth and carbon taxes and have found them essential predictors influencing environmental pollution. Nakata and Lamont (2001) described the importance of environmental protection programs regarding carbon taxes for better environmental quality in Japan. Wissema and Dellink (2007) have discussed the environmental degradation situation in the context of Ireland. According to their study, the country’s mitigating policies through carbon taxes imposition may significantly decrease carbon emissions in the future. Pigou (1920) analyzed the critical aspect of climate change and CO₂ mitigation through an “incentive-based mechanism” related to environmental taxes. Carbon taxes may also be an underrepresented factor affecting increased CO₂ emissions. A higher carbon tax rate means decreased demand for non-energy in power, industry, and transportation, resulting in decreased fossil fuel emissions. Various prior studies of Di Cosmo and Hyland (2011), Lin and Li (2011), and Hao et al. (2021) have been diverting their attention to carbon emission, growth, and carbon taxes due to their importance in economic growth and a clean environment. Therefore, these empirical studies reported similar results on the causal relationship between carbon taxes and pollution.

Literature on environmental degradation and technological change nexus

A significant contribution of technological change (innovation) is found in energy-related growth; this follows the endogenous

growth theory, especially for the energy utilization and growth process. Environmental pollution problems can be reduced by innovation externalities (Romer 1990), as technological innovations significantly improve the quality of the environment. This supposition implies that technological improvements follow the environmental correction measures based on increasing returns (in the long-term), which mitigate environmental pollution with an increasing rate of development. The nexus between energy innovation and the correction of greenhouse gases is significantly discussed within the EKC framework in many studies. The EKC scheme shows improvements in production capacity (service-oriented production) and more high technology and cleaner technologies, and these technical effects will improve environmental quality (Sarkodie and Ozturk 2020; Lorente et al. 2018; Bekhet and Othman 2018; Álvarez-Herránz et al. 2017; Lin et al. 2016).

The process of the technical effect implies that if the output composition changes, environmental quality may not inversely correlate with the economic growth rate. Simply put, the nexus between growth and air pollution shows an increasing trend until reaching a threshold level, upon which countries finally experience increases in environmental quality and demand for a cleaner environment. The technical effect under the EKC hypothesis allows for cleaner technologies in the production processes, and thus, technology and innovation are critical components in environmental quality improvement. Recently, a few studies by Inglesi-Lotz (2015), Sohag et al. (2015), Ahmad et al. (2020b), Hao et al. (2020), Hu (2021), Hussain et al. (2020), Khan et al. (2020a, 2020b), and Ahmad and Raza (2020) have discussed the associations among technological innovation, energy use, economic growth, and CO₂ emissions. According to Andreoni and Levinson (1998), the process of decontamination mostly depends on technical effects: more significant investment in innovation contributes positively and mitigates pollution. The innovation strategy with higher returns to scale facilitates improvements in energy effectiveness. Thus, the energy innovation process can accelerate environmental advancements. Researchers have explored the decrease in the use of fossil fuels when technological change takes place in Malaysia. Among empirical studies, Jones (2002) has found that CO₂ emissions are significantly decreased by technological change. Fang (2011) and Inglesi-Lotz (2015) have identified that economic growth and expenditures on research and development are positively related. Sohag et al. (2015) has found that technological change may significantly improve energy efficiency and decrease energy consumption.

Literature on renewable energy and CO₂ emission nexus

CO₂ emissions have significantly increased as a result of heavy reliance on fossil fuels, according to Oliver et al.

(2012), who have found that more than 90% of CO₂ emissions come from the burning of fossil fuel, and as reported by the European Union (E.U.) Joint Research Centre (J.R.C.). According to the report of the IEA (2014), historically, the rapid economic development in advanced nations has significantly decreased environmental quality, but recently, many emerging economies have significantly contributed to CO₂ emissions. Numerous economic studies have discussed the four core hypotheses of the energy-growth nexus (growth, conservation, feedback, and the neutrality hypothesis). These hypotheses support the theory that energy use and growth are interrelated (Shahbaz et al. 2012; Alper and Oguz 2016). GDP is directly or indirectly affected by energy consumption under the growth hypothesis. The energy-growth relationship under the conservation hypothesis indicates that environmental pollution can be reduced by managing waste and improving efficiency. The relationship between energy consumption and economic growth is mutual dependence in the feedback hypothesis.

The dependence on fossil fuels can be minimized through renewable energy generation and consumption. Thus, technological advancements in the energy sector may stimulate economic growth. Numerous past empirical analyses (i.e., Ocal and Aslan 2013; Azlina et al. 2014; and Halkos and Tzeremes 2014) for different countries have used the data of renewable energy and economic growth. Recently, the use of renewable energy and growth has been well discussed by Bhattacharya et al. (2016), Destek (2016), Amri (2017), Lu (2017), Saad and Taleb (2018), and Troster et al. (2018). The studies of Lorente and Álvarez-Herránz (2016), Álvarez-Herránz et al. (2017), Liu and Bae (2018), Saleem et al. (2020), Pata (2018), and Hao et al. (2021) have highlighted the role of renewable energy, technological change, and growth in improving environmental quality.

Literature on CO₂ emission and green growth nexus

Modern energy structures cannot be ignored to achieve the Millennium Development Goal. Economic growth, employment opportunities, transportation, and commerce are highly associated with energy (Karekezi et al. 2012). Mitigating climate change using global agreements puts pressure on economies; still a dilemma is faced by various economies, i.e., whether to adopt economic growth policies or energy reduction policies to mitigate CO₂ emissions. Therefore, more attention should be focused on the causal nexus between energy–economy–environment issues to achieve sustainable economic growth. Green growth, promoting sustainable development, using alternative energy sources, and reducing global warming are the primary goals of sustainable development set forth by the United Nations and the Paris Climate Change Conference (Renewable Global Status

Report 2017). Hence, further empirical investigations into the nexus between green growth–CO₂ emissions and other relevant variables are essential to inform the discussion on environmental protection sustainable development goals. The main objectives of sustainable development were to keep the world's temperature below from increasing by 2 °C (above the pre-industrial level) by the next coming years and focus on green growth. The relationships among energy use, CO₂ emissions, economic growth, and green growth are less discussed in the literature. In recent years, green growth has been considered an essential variable in the economic growth-driven emissions nexus research. Recently, a few studies by Qu et al. (2020), Sohag et al. (2019), Qu et al. (2020), and Hao et al. (2021) have discussed the associations among green growth, energy use, economic growth, and CO₂ emissions.

Literature on financial development towards green financing and Environmental degradation nexus

The agendas of various economies to achieve sustainability can be fulfilled through financial liberalization and policies to resolve environmental degradation. Financial development is the most influential variable that can have different impacts on environmental quality, as economic activities can flourish with a strong financial sector and cause deteriorating environmental quality. In contrast, the financial sector provides financial assistance to protect the natural environment (Nassani et al. 2017). Similarly, the financial development sector helps clean the environment via technological changes and provides the opportunity for production in an environmentally friendly environment using a clean process. Further, adopting energy efficiency policies can efficiently reduce the cost of capital (Szabó and Jäger-Waldau 2008), and the role of regulatory authorities (institutions) is also essential for improving environmental quality. Competitiveness in the power generation sector will be enhanced due to these measures.

Consequently, energy improvements are strongly associated with energy regulation procedures and financial sector development and regulations (Wüstenhagen and Menichetti 2012). Furthermore, Szabó and Jäger-Waldau (2008) also suggested that a reduction in capital costs is positively related to energy efficiency policies; thus, the energy sector can improve its competitiveness. Therefore, improvement of the energy sector can be made possible if energy regulation policies are attached to the application of financial regulations. Improvements in environmental quality can be linked with enhancing financial development if financial resources are utilized efficiently for energy-efficient firms (Shahbaz et al. 2013d; Hao et al. 2021; Saleem et al. 2020). Shahbaz et al. (2013a, 2013b) have analyzed the exact relationship between India and Indonesia. The findings of these studies

are not the same, but the casual association between CO₂ emissions and financial indicators was examined. Improved environmental quality is positively related to financial development, as Shahbaz et al. (2013e) suggested. Shahbaz et al. (2015) explained that trade openness was also related to environmental degradation via comparative advantage, composition, and technological effects of economic growth. Dogan and Turkekul (2016) have examined finance-driven pollution in the USA. The findings of their study also indicate that unidirectional causality is moving from carbon emissions to financial sector development. Aye and Edoja (2017) have examined the two-way causality between financial development and CO₂ emissions for selected developing economies.

The analysis attempts to describe the energy-green growth-led CO₂ emission in the context of 10 Asian economies (namely, China, Pakistan, India, Sri Lanka, South Korea, Japan, Singapore, Thailand, Malaysia, and the Philippines). This study incorporated green growth with the induction of carbon tax and other plausible variables such as technological change, financial development, renewable energy, and innovation. These additional factors also play a role in the environment-income relationship, but less attention has been given in prior empirical analysis; after the 2008 global recession, researchers focused their attention on green growth. Further, the role of green growth and carbon taxes are also essential for improving environmental quality. Developed nations focused on green growth strategies with conventional methodologies and criticized various researchers (Bank 2012; Development, O. for E.C 2013). Furthermore, this study tries to adopt the latest methodology (panel data econometric analysis), including the important role of green growth with technological innovation (including energy innovation) for environmental improvement, carbon taxes, and clean energy for contribution to the literature review.

Econometric model and data

Theoretical framework

The production function form consists of multiple input and output variables, and the model must have a definite mathematical relation (Yang et al. 2021). Therefore, according to the purpose of the present study, we use the neoclassical model for the production function, which is as follows:

$$Y = A * f(K, L) \quad (1)$$

where Y represents output, K represents capital input, L represents labor input, and A stands for the share of production inputs in productivity.

Production and use of inputs in various economic sectors such as industry, agriculture, and services lead to environmental pollution. The pollution emission equation (Hao et al. 2021) can be shown as follows:

$$EM_t = Y_t \sum_{i=1}^n \varphi_{i,t} QEM_{i,t} \quad (2)$$

In Eq. (2), EM_t is total emissions from different economic sectors, Y_t is the aggregate output of different economic sectors, $\varphi_{i,t}$ is the ratio of production of each sector to total production, and $QEM_{i,t}$ is the contribution of each economic sector in the emissions.

The EKC analysis describes three development stages, i.e., “scale effect, composition effect, and technique effect.” If technology and composition remain constant in a given country (in the first stage), then scale effects show the positive relationship between environmental quality and growth, where an increase in economic growth hampers environmental quality due to inefficient industries. The composition effect is related to structural changes in the economy where pollution increases due to high activity in primary energy-intensive manufacturing industries, but when light manufacturing industries and service sectors of the economy move towards the development process (Ansari and Khan 2021; Mohapatra et al. 2016). The trade openness and environmental degradation nexus can determine the composition and contributions of technical effects.

Policies focus on environmental regulations that lead to improved environmental quality. It is vital to recognize that when the EKC plans include technical effects, the “endogenous” nature of the primary hypothesis is strengthened because technological development determines the association between environmental quality and economic growth. According to Andreoni and Levinson (1998), the process of decontamination mostly depends on technical effects: more significant investment in innovation contributes positively and mitigates pollution. The innovation strategy with higher returns to scale facilitates improvements in energy effectiveness.

According to the study of Hao et al. (2021), the equation of these three effects and decomposition of the rate of change of emissions is as follows:

$$g^{EM} = g^Y + \sum_{i=1}^n \tau_i g^{QE_i} + \sum_{i=1}^n \tau_i g^{Q_i} \quad (3)$$

where g^y , g^{QE} , and g^{Q_i} are scale effect, technology effect, and composition effect, respectively. τ_i is the economic sector's share of total CO₂ emissions. According to Eq. 3, it can be said that if the increase in production is due to the use of environmentally friendly technologies, the scale effect will increase without increasing the level of pollution. Provided that the rate of reduction of pollution is greater than or equal

to the rate of increase of production. In other words, the decomposition equation is as follows:

$$g^Y = -g^{QE} + g^E \tag{4}$$

Environmental tax

According to the framework of the neoclassical production function, if the government imposes a tax, the function will be as follows:

$$Y_t = K^\alpha EM^\gamma (AL)^{1-\alpha-\gamma} \tag{5}$$

Based on the clean environment regulatory policies, assuming that the government implements two environmental regulatory policies, namely the “corporate emissions tax” and the “corporate pollution abatement subsidy” (Fan et al. 2021). The basic form of the profit maximization equation is given as follows:

$$\pi = Y_t - r_t K_t - r_t(1 - S_t)K_t - W_t L_t - \tau_t EM_t \tag{6}$$

r_t is the rate of capital return, S_t is the government subsidization rate in pollution control, and τ_t is the rate of pollution emissions tax. So, according to Eq. 7, emissions will only fall if tax grows faster than the rate of output.

$$g^E = g^Y - g^{T_E} \tag{7}$$

Green growth

Compared to traditional economic development models, green technology innovations play a key role in achieving sustainable development goals with minimal adverse environmental impacts (Shan et al. 2021). If we put green growth into the pollution emission function, it will be as follows:

$$EM_t = Y^\alpha QEM^{-b} \tag{8}$$

In Eq. 8, Y is green growth, indicating that environmentally friendly technologies reduce CO₂ emissions.

$$\frac{\partial EM}{\partial QEM} = -bY^\alpha QEM^{-b-1} < 0 \tag{9}$$

$$\frac{\partial^2 EM}{\partial QEM^2} = b(b + 1)Y^\alpha QEM^{-b-2} > 0 \tag{10}$$

Equation (9) shows that the increase in environmentally friendly technology reduces greenhouse gas emissions; in contrast, the second-order derivative (Eq. 10) shows that further increases in environmentally friendly technology may have marginal effects on greenhouse gas emissions (Hao

et al. 2021). The first- and second-order derivative equations of green growth are as follows:

$$\frac{\partial EM}{\partial Y} = (-)\alpha Y^{\alpha-1} QEM^{-b} \begin{matrix} \leq 0 \\ > 0 \end{matrix} \tag{11}$$

$$\frac{\partial^2 EM}{\partial Y^2} = \alpha(\alpha + 1)GY^{-\alpha-2} QE^{-b} \begin{matrix} \leq 0 \\ > 0 \end{matrix} \tag{12}$$

According to the value of α and b , the effect of green growth is detected. The larger the value of b represents the greener and more environment-friendly technology. Based on our theoretical premises, this study specifies the following functional form, which is to be tested empirically:

$$CO_{2t} = f(f(GDP_t, GDP_t^2, REW_t, TECN_t, ETX_t, FND_t)) \tag{13}$$

$$CO_{2t} = f(GEG_t, GEG_t^2, REW_t, TECN_t, ETX_t, FND_t) \tag{14}$$

Data and methodology

Sustainable environment and economic growth policies are well-debated topics by many scholars, and their attentions are highly focused on a clean environment with sustainable development (Hao et al. 2021; Tawiah et al 2021). According to this milieu, the well-known EKC framework is used to test the different parameters of the ecological effects. The theory of Grossman and Krueger (1991) (well known as EKC) is more attractive and advanced than traditional economic growth theories because it demonstrates the trade-off nexus environment–growth relationship. Grossman and Krueger (1991) extended the initiative of Simon Kuznets (1955) and introduced an inverted U-shaped EKC. This EKC scheme generates the argument that the environment is strongly threatened by rapid economic growth. The EKC hypothesis provided a systematic nexus linking economic incomes and environmental pollutants carbon dioxide (CO₂), sulfur dioxide (SO₂), poised particulate matter, and many others. Thus, the EKC shows the connection between GDP growth and environmental quality, where the dynamic progression of structural change is related to economic growth (Dinda 2004).

The EKC analysis describes three development stages of “scale, composition, and technique effects.” If technology and composition remain constant in a given country (in the first stage), scale effects show the positive relationship between environmental quality and growth, where an increase in economic growth hampers environmental quality due to inefficient industries. The composition effect is related to the country’s transformation of structure where pollution increases, where high activity in primary energy-intensive manufacturing industries, but when light

manufacturing industries and service sectors of the economy move towards the development process. The final stage of the EKC scheme shows improvements in production capacity (service-oriented production) and more high technology and cleaner technologies, and these technical effects will improve environmental quality (Bekhet and Othman 2018; Álvarez-Herránz et al. 2017; Lin et al. 2016). The process of the technical effect implies that if the output composition changes, environmental quality may not inversely correlate with the economic growth rate.

Simply put, the nexus between growth and air pollution shows an increasing trend until reaching a threshold level, upon which countries finally experience increases in environmental quality and demand for a cleaner environment. The technical effect under the EKC hypothesis allows for cleaner technologies in the production processes, and thus, this is the key component in environmental quality improvement. Various other factors in addition to “scale, composition, and technical effect” contribute under the EKC framework, such as trade liberalization, environmental quality demands regarding income elasticity, regulation, and policy (Dinda 2004). Economic sustainability can be delayed or induced by all of these elements, and these elements determine the different shapes of the EKC (Bekhet and Othman 2018; Álvarez-Herránz et al. 2017). Various factors are used as a key element of energy use and carbon emissions nexus-based studies (Shahbaz et al. 2013a, 2013b; Farhani et al. 2014; Saleem et al. 2020).

The above-mentioned theoretical description (Eqs. 13 and 14) and the association between CO₂ emission and GDP growth and several additional variables are used under premises of the novel EKC method following the below-mentioned equations.

$$CO_{2it} = \alpha_1 + \alpha_2 GDP_{it} + \alpha_3 (GDP_{it})^2 + \alpha_4 REW_{it} + \alpha_5 TECN_{it} + \alpha_6 ETX_{it} + \alpha_7 FND_{it} + \mu_{it} \quad (15)$$

$$CO_{2it} = \beta_1 + \beta_2 GEG_{it} + \beta_3 (GEG_{it})^2 + \beta_4 REW_{it} + \beta_5 TECN_{it} + \beta_6 ETX_{it} + \beta_7 FND_{it} + \epsilon_{it} \quad (16)$$

We used the data in log transformation form.

$$LnCO_{2it} = \alpha_1 + \alpha_2 LnGDP_{it} + \alpha_3 Ln(GDP_{it})^2 + \alpha_4 LnREW_{it} + \alpha_5 LnTECN_{it} + \alpha_6 LnETX_{it} + \alpha_7 LnFND_{it} + \mu_{it} \quad (17)$$

$$LnCO_{2it} = \beta_1 + \beta_2 LnGEG_{it} + \beta_3 Ln(GEG_{it})^2 + \beta_4 LnREW_{it} + \beta_5 LnTECN_{it} + \beta_6 LnETX_{it} + \beta_7 LnFND_{it} + \epsilon_{it} \quad (18)$$

To measure the environmental quality we employed, CO_{2t} represents the carbon emission (per capita), GDP represents the economic growth, GDP^2 indicates

the square of economic growth to evaluate the presence of EKC. Furthermore, other variables can be deconstructed into multiple critical explanatory variables, significantly impacting carbon emissions. Energy is an essential component of GDP growth (through productivity enhancement). The energy-pollution nexus is widely discussed in the EKC framework (Lorente et al. 2018). Thus, non-renewable energy sources are used as the energy factor, where energy-gear growth leads to air pollution, but renewable energy sources can mitigate environmental pollution. The EKC model incorporates renewable energy consumption as a potential factor in carbon emissions (Jebli and Yousseff 2015; Jebli and Yousseff 2016; Jebli and Belloumi 2017; Shahbaz et al. 2017). Financial development is the most influential variable that can have different impacts on environmental quality, as economic activities can flourish with a strong financial sector and cause deteriorating environmental quality. Similarly, the financial development sector helps clean the environment via technological changes and provides the opportunity for production in an environmentally friendly environment using a clean process. In addition, another facet of this analysis suggests that financial development is directly related to economic growth but inversely related to environmental quality in terms of industrial pollution. Lopez-Menendez and Moreno (2014) and Zhang (2011) described that the financial sector mitigates environmental pollution in China and emphasized environmental protection policies. Thus, finance-led growth requires more policy caution to protect environmental quality. Technological innovation is a key component to mitigate CO₂ emission (Chen and Lei 2007). Many researchers, including Fang (2011) and Inglesi-Lotz (2015), have shown that investments in research along with technological innovation have significant impacts on GDP growth, and Jones (2002) found that technological change could mitigate the level of CO₂ emission. Therefore, energy efficiency and a reduction in fossil fuel consumption can be attained through technological innovation (Sohag et al. 2015).

Description of data

This study investigates the relationship between CO₂ emission with GDP growth and green growth with other key variables over 1990 to 2018 for selected Asian countries. The descriptions of variables are given in Table 1. The GDP and FDN have been taken from the World Development Indicator (WDI 2021). To identify the EKC hypothesis, it is expected that carbon emission is positively related to an increase in GDP growth at a certain level, beyond which the shape of the EKC would flatten or reverse due to an increase in real GDP growth. The GDP and square term of GDP are positively and negatively related to CO₂ emission.

Furthermore, other variables such as REW, TECN, and ETX data have been taken from OECD (2020) statistics.

Methods

Cross-section dependence (CSD) is a critical issue in the panel data analysis; it is essential to test empirical analysis. The cause of CSD is the issue arising due to unobserved standard shock and the significantly rising interrelationship between socioeconomic factors; thus, the inconsistent results of the panel estimators will be generated. Hereafter, serious consequences can be engendered through ignorance of the issue of CSD (Sarafidis and Wansbeek 2012). The assumption of independence of CSD is the essence of the traditional unit root tests, so solving the issue of CSD is imperious for panel data analysis. Therefore, misleading results may be produced by the assumption of an independent CSD test. Thus, the issue of CSD independence (assumed in traditional unit-roots) has been resolved by Breitung and Pesaran (2008). Additionally, in panel data analysis, it is typically presumed that disturbances are cross-sectional independent in the models. The series of alternative unit root tests can be conducted from the second-generation unit root tests. However, in this analysis, a cross-sectional dependence (CSD) test is first employed to determine whether cross-sections are jointly dependent or not in a panel unit process. Invalid statistics and estimator efficiencies arise in the panel data analysis if the issue of CSD in estimation is ignored.

The following equation is given to explain CSD test.

$$CSD_{Adjusted\ one} = \sqrt{\frac{2T}{N(N-1)} \left(\sum_{i=1}^{N-1} \sum_{k=i+1}^N \hat{\Omega}_{ik} \right) \frac{(T-J)\hat{\Omega}_{ik}^2 - E(T-J)\hat{\Omega}_{ik}^2}{V(T-J)\hat{\Omega}_{ik}^2}} \tag{19}$$

Tests of slope homogeneity

This analysis used the Pesaran and Yamagata (2008) statistics to find out the homogeneity of the slope. Thus, homogeneity and heterogeneity of the panel data can be checked with this test. The role of slope homogeneity test is also crucial for empirical method, as violations of a heterogeneous

slope (assumptions) can be seen in many econometric methods.

The following equation of test is given.

$$S = \sum_{i=0}^N (\beta_i - \beta_{WFE}) \frac{x_i' M_{xx_i}}{\partial^2} (\beta_i - \beta_{WFE}) \tag{20}$$

$$\Delta = N^{\frac{1}{2}} (2k)^{\frac{1}{2}} \left(\frac{1}{N} S - k \right) \tag{21}$$

Panel unit root tests

Recently, numerous economies are interdependent and inter-related; it is difficult to count the same level of shocks and their effects in the cross-sectional panel analysis. The current study employed the Im-Pesaran-Shin (IPS) test of Im et al. (2003). The null hypothesis shows the issue of non-stationary for all these tests. In a panel data analysis, it is typically presumed that disturbances are cross-sectionally independent in the models. The series of alternative unit root tests can be conducted from the second-generation unit root tests. However, in this analysis, a cross-sectional dependence (CSD) test is first employed to determine whether cross-sections are jointly dependent or not in a panel unit process. Invalid statistics and estimator efficiencies arise in the panel data analysis if the issue of CSD in estimation is ignored. This study used significant CSD tests for robustness to address the CSD issue. The scaled and biased corrected LM test (Breusch and Pagan 1980), scaled LM test (Baltagi et al. 2012), and finally the CD test (Pesaran 2004) and Hadri test (Hadri 2000) are applied.

Cross-section augmented autoregressive distributed lags (CS-ARDL)

For the nexus between CO₂ emission and green growth with some plausible variables, we used the method of CS-ARDL. The objective of the method is to deal with the issues of CSD, endogeneity, and slope heterogeneity (Chudik and Pesaran 2013). The issue of the sensitive and inconsistent

Table 1 Statistical description of data

Variables	Description	Units	Sources
CO ₂	Carbon emissions	Metric tonnes per capita	(WDI 2021)
GEG	Green growth/production based CO ₂ emission	In percentage point %	(OECD 2020)
GDP	Gross domestic product	Constant 2010 US\$	(WDI 2021)
FDN	Domestic credit to private sector	GDP in %	(WDI 2021)
REW	Renewable energy consumption	Total final energy consumption in %	(WDI 2021)
ETX	Environment taxes	% of GDP	(OECD 2020)
TECN	Environment clean technology and innovation	% of all technologies	(OECD 2020)

small size of the sample and explanatory variables with unobserved elements can be handled by this method. So this method, with its powerful assumptions, is employed. The following equation represents the method of CS–ARDL method. AMG techniques check the robustness of the analysis. Based on the evidence, the long-run estimator’s signs of the results of AMG and CS–ARDL are the same but magnitudes are not the same. The CS–ARDL equation is given below

$$\Delta CO_{2it} = \phi_i + \sum_{m=1}^n \phi_{1i} \Delta CO_{2it,m-1} + \sum_{m=0}^n \phi_{2i} X_{it,m-1} + \sum_{m=0}^n \phi_{3i} Z_{it,m-1} + \epsilon_t \tag{22}$$

where Z_t represents the ΔCO_{2t} , X_t and X_t shows the values of all other explanatory variables such as GDP_t , GDP_t^2 , REW_t , $TECN_t$, ETX_t , FDN_t , and GEG_t .

Co-integration tests

The long-run systematic co-movement association of two or more selected variables is called cointegration (Yoo and Kwak 2010). Non-stationary variables can be accepted in the cointegration theory, but the linear combination must be stationary. Various variables can be examined for long-run stable association in this theory. The latest Westerlund (2008) panel cointegration test is used for panel data analysis to provide robust inferences. The basic tests of the Durbin-Hausman test are DH-Panel and DH-group statistics, and these tests are cointegration-based statistics. While taking CSD and common factors into account under the consideration of panel cointegration analysis, authorities implement if the level of integration is $I(0)$ and $I(1)$ for the independent variables and $I(1)$ for the dependent variable. The cointegration among different factors can be tested by the alternative hypothesis (cointegration exists) and the null hypothesis (no cointegration exists).

Panel causality test

This study used Dumitrescu and Hurlin’s (2012) test to examine the nexus between CO_2 emission and other variables such as environment-based technology, environmental degradation taxes, GDP, renewable energy, and financial development. Thus, this analysis estimates the casual associations between GDP and GDP growth square, non-renewable

energy consumption, renewable consumption, technological change, financial development, population density, and carbon emission in selected Asian economies. The Dumitrescu and Hurlin (2012) panel causality test is used in this study because of its following advantages. First, this test is applicable for the estimation in the model if $T > N$ or $T < N$ (T = time series, N = numbers of cross-section). Second, the performance efficiency of this test cannot be changed if the panel data are either balanced or unbalanced. Third, cross-section dependence is also handled by this test. Fourth, it consists of two hypotheses, including the homogenous non-causality (HNCT) test (null hypotheses) and heterogeneous non-causality (HENCT) as the alternative hypothesis. The following equation shows the null hypothesis (HNCT).

$$\text{Null hypothesis } (H_0) : \beta_i = [0], \text{ where } (i) = 1, 2, 3, \dots \cdot N_1$$

Similarly, the equation of the alternative hypothesis (HENCT) is defined below,

$$H_1 : \beta_i = [0], \text{ where } (i) = 1, 2, 3, \dots \cdot N_1 \tag{23}$$

$$\dots \cdot (H_1) : \beta_i \neq 0, \text{ where } (i) = 1, 2, 3, 4, 5 \dots \cdot N \tag{24}$$

Empirical results and discussion

Table 2 represents the statistical results of the cross-sectional dependence (CSD) test. To find out the presence of CSD in the panel data analysis among the variables, we employed four tests, namely, Pearson LM normal, Pearson CD normal, Friedman chi-square, and Breusch-Pagan chi-square test. There is cross-sectional dependence found among the variables as we rejected the null hypotheses. The results of stipulated cross-sectional statistics confirmed the cross-sectional dependency between the countries.

The slop homogeneity test is also an essential task after employing the CSD. Thus, this study used Pesaran and Yamagata (2008) technique. Therefore, Table 3 shows that we accepted the heterogeneous slope coefficients (alternative hypothesis) and rejected the null hypothesis.

Table 4 detected the unit root problem and orders of integration in the panel data analysis. The three different panel unit root tests, namely, the Hadri (2000), Im et al. (2003), and Breitung (2000) tests, are used in this study. Table 3

Table 2 Test of residual cross-section dependence

Test	Statistic	Prob	Null hypotheses	Conclusion
Breusch-Pagan chi-square	8.174	0.00	No CSD in residuals	Reject
Pearson LM normal	3.056	0.001	No CSD in residuals	Reject
Pearson CD normal	-2.51	0.02	No CSD in residuals	Reject
Friedman chi-square	25.568	0.00	No CSD in residuals	Reject

Rejection means that the null hypothesis is rejected at a 1% and 5% significance level.

reported that all of the variables are stationary in Hadri (2000) test, Im et al. (2003) tests at level but in the test of Breitung all the variables are not stationary at level. All the variables are found stationary in Hadri (2000) and Im et al (2003) tests.

The next step of this study is to identify the long-run connotation between the variables through the study of Westerlund (2008), which is based on the Durbin-H cointegration test. The current analysis used the cointegration methodology with its best performance, as it covers the heterogeneity and CSD issues—this panel analysis consists of the tests of the Durbin-H Group and Durbin-H Panel. Table 5 reported the statistical findings of both two tests (Durbin-H Group and Durbin-H Panel), and the null hypothesis was rejected and accepted the alternative hypothesis that long-run association was found among the variables.

This study used the method of CS-ARDL to find out the impact of green growth and GDP on environment quality with some plausible variables under the scheme of EKC. The results of the CS-ARDL technique are mentioned in Table 6; it is concluded that CO₂ is significantly affected by GDP, GDP², FDN, TECN, and REWN in the context of Asian economies. The inverse relationship was found between all

variables and CO₂ emission except for GDP growth. The GDP² is inversely, and GDP is positively related to the CO₂, indicating the presence of inverted U-shaped EKC in this region (Saleem et al. 2020). Achieving economic growth and development is the main objective of various economies; they have primarily concentrated on producing goods and services at the cost of environmental degradation. But after the achievement of the highest level of economic growth, they want to sustain their growth with a clean environment with spending on environment-friendly technological innovation. These findings are endorsed by Haseeb et al. (2018), Saleem et al. (2020), Mania (2020), and Shahbaz et al. (2018a, 2018b). Table 6 in model 1 and model 2 of the study verified the EKC hypothesis. As economic growth increases, it leads to increase CO₂ emissions; a 1% increase in GDP and GDP² would lead to CO₂ increases of 0.41 and –0.02%, respectively, in model 1. The results are consistent with the findings of Shahbaz et al. (2012), Can and Gozgor (2017), Lin and Raza (2019), Ahmad et al. (2020), Khan et al. (2020a), and Shahbaz et al. (2020). CO₂ emissions are decreased when an industrial sector converts to a service sector, and when technological change occurs under free trade, CO₂ emissions significantly decline. Thus, CO₂ emissions are significantly decreased by increased technological innovation. Saleem et al.'s (2020) empirical findings and those of Shahbaz et al. (2020) are consistent with our findings. The results also show that technological innovation significantly improves environmental quality; if other factors remain constant, a 1% increase in technological innovation

Table 3 The heterogeneity and homogeneity testing of slope coefficient

Model 1	
$CO_{2t} = f(GDP_t, GDP_t^2, REW_t, TECN_t, ETX_t, FDN_t)$	
Delta (<i>p</i> value)	Adjusted-delta (<i>p</i> value)
11.2346*** (0.0000)	12.8970*** (0.0000)
Model 2	
$CO_{2t} = f(GEG_t, GEG_t^2, REW_t, TECN_t, ETX_t, FDN_t)$	
Delta (<i>p</i> value)	Adjusted-delta (<i>p</i> value)
8.5946*** (0.0000)	9.9670*** (0.0000)

*** represents the level of significance at 1%

Table 5 Panel co-integration test (Westerlund 2008)

Asian countries		
Variables	<i>t</i> statistics	<i>p</i> value
Durbin-H Group stat	4.614	0.000***
Durbin-H Panel stat	3.783	0.001***

*** represents the 1% level of significance levels at 1%.

Table 4 Panel unit root test analysis

Variable names	Breitung test		Im-Pesaran-Shin (IPS) test		Hadri test	
	<i>t</i> statistics	<i>p</i> statistics	<i>t</i> statistics	<i>p</i> statistics	<i>t</i> statistics	<i>p</i> values
CO _{2t}	–0.058	0.2030	–2.991	0.0010***	–2.606	0.0040***
GDP _{it}	–18.599	0.01200***	–2.894	0.0060***	–3.037	0.0030***
(GDP _{it}) ²	–26.307	0.0000***	–2.994	0.0030***	–3.406	0.0000***
GEG _{it}	13.842	0.0010***	–3.392	0.0010***	–2.979	0.0010***
(GEG _{it}) ²	17.121	0.0000***	–5.515	0.0000***	–4.892	0.0000***
REW _{it}	13.812	0.0010***	–4.083	0.0000***	–2.979	0.0010***
TECN _{it}	–0.768	3.5010	–3.898	0.0000***	–3.62	0.0000***
ETX _{it}	–18.06	0.0080***	–2.329	0.0010***	–1.852	0.0020***
FND _{it}	18.121	0.0000***	–4.887	0.0000***	–3.992	0.0010***

**** indicates a 1% level of significance.

Table 6 Statistical findings of CS-ARDL

Model 1				
$CO_{2t} = f(GDP_t, GDP_t^2, REW_t, TECN_t, ETX_t, FND_t)$				
Variables	Short-run analysis		Long-run analysis	
	Coefficient	Standard deviation	Coefficient	Standard deviation
LGDP _{it}	0.4163***	0.0402	0.54394***	3.1845
L(GDP _{it}) ²	-0.0126***	0.0010	-0.04262***	0.0004
LREW _{it}	-0.0631**	0.0480	0.1342***	0.0456
LTECN _{it}	-0.0447**	0.0230	-0.13165**	0.0479
LETX _{it}	-0.0748***	0.0672	-0.34394***	0.0815
LFND _{it}	-0.1255**	0.0689	-0.19729***	0.0417
ECT(-1)	-0.4880***	0.0649		
Model 2				
$CO_{2t} = f(GEG_t, GEG_t^2, REW_t, TECN_t, ETX_t, FND_t)$				
Variables	Short-run analysis		Long-run analysis	
	Coefficient	Standard deviation	Coefficient	Standard deviation
LGEG _{it}	-0.0014***	0.5705	-0.0060***	0.0401
L(GEG _{it}) ²	-0.0018***	0.0475	-0.1016***	0.0199
LREW _{it}	-0.0166**	0.1023	-0.0107***	0.0012
LTECN _{it}	-0.0133***	0.0018	-0.0133***	0.0018
LETX _{it}	-0.0187	0.0119	-0.1337***	0.0172
LFND _{it}	-0.0407**	0.0204	-0.0020**	0.0213
ECT(-1)	-0.2497***	0.0328		

*** represents the 1% level of significance levels at 1.

will lead to CO₂ decreases of 0.04% in model 1 and 0.01 in model 2, respectively. Many Asian countries are trying to cut the CO₂ emissions level, and their efforts are commendable. Though the contribution of Asia to CO₂ emission increases is high, by adopting green growth strategies, Asian economies can decrease CO₂ emissions. The inverse impact of Eco-innovation is found on CO₂ emission in this analysis. Eco-friendly and efficient use of technologies by eco-innovation can significantly improve the quality of the environment. The findings are consistent with the line of (Liu et al. 2020; Umar et al. 2020b). The speed of adjustment was found significant at a 1% level of significance according to the value of ECT (-1), where results indicate that it requires 49% modification to move (in the short run from the long run) towards the equilibrium position of the analysis. Sustainable growth and development are highly associated with green growth, and environmental degradation can be solved through green growth. Therefore, the results of green growth indicate the inverse relationship with CO₂ emission, and as GEG increases, it leads to decreased CO₂ emissions; a 1% increase in GEG and GEG square would lead to CO₂ decreases of 0.001 and -0.002 percent, respectively, in model 2. The findings are consistent with the work of Jouvét and de Perthuis (2013), Lee (2011), and Hao et al. (2021). The inverse relationship between green growth and green growth square and concave EKC is observed in model 2. The statistical findings of green growth and its impact

on CO₂ emissions are reported in model 2. The impact of green growth on CO₂ emissions is negative and green growth significantly reduces CO₂ emissions in this region. Green growth can play a crucial role in achieving sustainable growth and clean environmental strategies. Green growth has the potential to attain social and economic benefits efficiently for the future of Asian economies. The GEG square and GEG coefficients found a negative and concave-shaped relationship between environmental degradation and green growth. In the preliminary stages, few CO₂ emissions were found due to the adoption of green growth techniques. In the later stages, the effects of green growth decline, and subsequently, we can see the less impact of green growth

Table 7 Robustness check analysis (AMG method)

Variables	Model 1—coef- ficient values	Variables	Model 2— coefficient values
LGDP _{it}	0.5145***	LGEG _{it}	0.0021***
L(GDP _{it}) ²	-0.0226***	L(GEG _{it}) ²	-0.0015***
LREW _{it}	0.0531***	LREW _{it}	-0.0123**
LTECN _{it}	-0.0348**	LTECN _{it}	-0.0254***
LETX _{it}	0.0512**	LETX _{it}	-0.0217**
LFND _{it}	0.065***	LFND _{it}	-0.0561**

*** and * indicates the significance at 1% and 10% levels of significance, respectively.

on environmental degradation. To achieve sustainable CO₂ emissions, the findings of this study may guide design policies efficiently for Asian countries.

Environment efficiency and environmental effectiveness can be achieved through environmental taxes, and these taxes are inversely related to CO₂ emission. The industrial sector can transform its structure from fossil fuel consumption to renewable technologies by efficiently utilizing eco-innovative technologies to combat CO₂ emissions. Similarly, the environmental tax can motivate investors to use

eco-friendly projects. Thus, environmentally friendly production can lead to abating CO₂ emissions through the imposition of environmental tax (investors will use environmentally friendly technologies). The statistical findings indicate that a 1% increase in ETX would lead to CO₂ decreases of 0.07% in model 1 and CO₂ 0.02% in model 2. The findings of our study are supported by Andersson (2019) and Criqui et al. (2019). The role of financial development on CO₂ emission is inversely related to each other if a 1% increase in financial development would lead to CO₂ decreases of 0.12%

Table 8 The statistical findings of Dumitrescu and Hurlin panel test

S. no	Hypothesis	W-stat	Z-stat	P value	Statistical results	Decision
1	CO ₂ ϕGDP	2.877	0.806	0.419	No	Unidirectional causality
	GDPϕCO ₂	3.983	2.104	0.035	Yes	
2	CO ₂ ϕGDP ²	2.847	0.77	0.441	No	Unidirectional causality
	GDP ² ϕCO ₂	3.931	2.043	0.041	Yes	
3	CO ₂ ϕREW	4.098	3.125	0	Yes	Bidirectional causality
	REWϕCO ₂	4.322	2.502	0.012	Yes	
4	CO ₂ ϕTECN	5.196	3.522	0.001	Yes	Bidirectional causality
	TECNϕCO ₂	4.789	3.045	0.002	Yes	
5	CO ₂ ϕEXT	3.612	2.669	0.01	Yes	Bidirectional causality
	EXTϕCO ₂	4.267	2.437	0.014	Yes	
6	CO ₂ ϕFDN	2.779	0.691	0.489	No	Unidirectional causality
	FDNϕCO ₂	4.825	3.092	0.00	Yes	
7	CO ₂ ϕGEG	5.494	3.877	0	Yes	Bidirectional causality
	GEGϕCO ₂	4.715	3.825	0	Yes	
8	GDPϕGDP ²	1.208	−1.152	0.249	No	Neutrality
	GDP ² ϕGDP	1.178	−1.187	0.235	No	
9	GDPϕREW	5.474	3.854	0	Yes	Unidirectional causality
	REWϕGDP	1.728	−0.542	0.587	No	
11	GDPϕGEG	7.025	6.025	0	Yes	Bidirectional causality
	GEGϕGDP	4.075	3.075	0.001	Yes	
12	GDPϕEXT	2.436	0.288	0.772	No	Unidirectional causality
	EXTϕLGDP	5.474	3.854	0	Yes	
13	GDPϕFDN	6.293	4.815	0.00	Yes	Bidirectional causality
	FDNϕGDP	4.889	3.677	0	Yes	
14	REWϕGDP ²	1.688	−0.588	0.556	No	Unidirectional causality
	GDP ² ϕREW	11.887	10.887	0	Yes	
15	REWϕTECN	7.104	6.236	0	Yes	Bidirectional causality
	TECNϕREW	3.145	2.96	0.001	Yes	
16	REWϕEXT	3.923	2.92	0.001	Yes	Unidirectional causality
	EXTϕREW	2.385	0.228	0.819	No	
17	REWϕFDN	1.775	−0.324	0.822	No	Unidirectional causality
	FDNϕREW	4.697	3.697	0.007	Yes	
18	REWϕGEG	4.682	3.643	0.001	Yes	Bidirectional causality
	GEGϕREW	7.483	6.023	0	Yes	
19	EXTϕTECN	1.967	0.967	0.333	No	Unidirectional causality
	TECNϕEXT	8.496	7	0	Yes	
20	TECNϕGEG	4.516	2.725	0.00	Yes	Bidirectional causality
	GEGϕTECN	4.657	2.891	0	Yes	

in model 1 and 0.04 in model 2 significantly. The results of our study are supported by the prior studies of Shahbaz et al. (2013c), Al-Mulali et al. (2015), Salahuddin et al. (2015), Al-Mulali et al. (2016), Uddin et al. (2017), and Saleem (2020). Renewable energy also minimizes the effects of environmental degradation as if a 1% increase in renewable energy use would lead to CO₂ decreases of 0.06% in model 1 and 0.02% in model 2. These results are supported by prior findings of Liu et al. (2020), Morawska et al. (2018), Shen et al. (2018), and Saleem (2020). The speed of adjustment was found significant at a 1% level of significance according to the value of ECT (−1), where results indicate that it requires 24% modification to move (in the short run from the long run) towards the equilibrium position of the analysis.

The robustness of the results is checked by the AMG method. The statistical finding reported in Table 7 is that all the variables minimize the level of CO₂ emission except the GDP growth rate.

This study used the Dumitrescu and Hurlin panel test to gauge the causality between the variables. The results are reported in Table 8, where causal relationship was found among GDP_t , GDP_t^2 , GEG_t , GEG_t^2 , REW_t , $TECN_t$, ETX_t , and FDN_t . The results of the Dumitrescu and Hurlin panel test showed the bidirectional causality found between $REW \phi CO_2$, $CO_2 \phi TECN$, $CO_2 \phi EXT$, $GEG \phi CO_2$, $GDP \phi FDN$, and $GEG \phi GDP$. Hence, results indicate that CO₂ emissions can be minimized through policy shock to the GEG, EXT, TECN, and REW. The finding showed that any policy shock in GDP_t , GDP_t^2 , GEG_t , GEG_t^2 , REW_t , $TECN_t$, and ETX_t will significantly have a consequence on environmental quality (CO₂ emissions). Moreover, any policy change in environmental degradation will cause a significant variation in GDP_t , GDP_t^2 , GEG_t , GEG_t^2 , REW_t , $TECN_t$, ETX_t and FDN_t . The results of green growth, technological change are consistent with the work of Hao et al (2021) and Can et al (2021). The CO₂ emission can be significantly reduced by the use of renewable energy sources, and the REW energy significantly abates environmental pollution, and thus, REW and CO₂ found the causal association. These findings are consistent with the line of Liu et al. (2020), Mehmood et al. (2017), Morawska et al. (2018), and Shen et al. (2018).

The one-way causality found between $GDP \phi CO_2$, $GDP^2 \phi CO_2$, $FDN \phi CO_2$, $REW \phi GDP$, and $GDP \phi TECN$. Thus, the consequences of GDP, GDP², and FDN policy shock on CO₂ emission will be effective. Furthermore, any policy change in environmental degradation will cause significant variation in $GDP \phi CO_2$, $GDP^2 \phi CO_2$, $FDN \phi CO_2$, $REW \phi GDP$, and $GDP \phi TECN$. The green growth, renewable energy, and technological innovation granger cause the CO₂ emissions, and these results are found in the line of Saleem et al. (2020) and Rasoulinezhad and Saboori (2018). Overall, the results indicate that the level of CO₂ emission can be significantly reduced by green growth, eco-friendly

technology, carbon tax, renewable energy, and financial development indicators. Nevertheless, GDP² significantly improves the environmental quality with the induction of eco-friendly technology and environment tax revenues.

Conclusion

The current analysis tries to investigate the contribution of green growth–CO₂ emission nexus with some plausible in the existing literature. This study investigates the impact of green growth, income, environmental taxes, environment-friendly technology, renewable energy, and financial development in Asian countries over the period of 1990 to 2018. To find out the presence of CSD, among the variables in the panel data analysis, we employed four tests, namely, Pearson LM normal, Pearson CD normal, Friedman chi-square, and Breusch-Pagan chi-square test. The results of stipulated cross-sectional statistics confirmed the cross-sectional dependency between the countries. The slop homogeneity test is also an essential task after employing the CSD test; thus, this study used Pesaran and Yamagata (2008) technique. The result was that we accepted the heterogeneous slope coefficients (alternative hypothesis) and rejected the null hypothesis. To identify the long-run connotation between the variables through the study of Westerlund (2008), which is based on the Durbin-H cointegration test. The statistical findings of both tests (Durbin-H Group and Durbin-H Panel) accepted the alternative hypothesis that the long-run association was found among the variables. This study used the method of CS–ARDL to find out the impact of green growth and GDP on environment quality with some plausible variables under the scheme of EKC. It is concluded that CO₂ is significantly affected by GDP growth, GDP², financial development, technological change, and renewable energy use in Asian economies. The inverse relationship was found between all variables and CO₂ emission except for GDP growth. The GDP² is inversely, and GDP is positively related to the CO₂, indicating the presence of inverted U-shaped EKC in this region. But the inverse relationship between green growth and green growth square and concave EKC is observed in model 2. The presence of concave EKC in our analysis indicates that green growth is a core variable that can play an important role in minimizing environmental destruction. Thus, green growth can be helpful to accomplish the target of carbon neutrality. This study used the Dumitrescu and Hurlin panel test to gauge the causality between the variables. The results of the Dumitrescu and Hurlin panel test is examined the bi-directional causality found between $REW \phi CO_2$, $CO_2 \phi TECN$, $CO_2 \phi EXT$, $GEG \phi CO_2$, and $GEG \phi GDP$. So, the consequences of policy

shock of GDP, GDP², and FDN on CO₂ emission will be effective.

Environmental sustainability and poverty reduction targets can be accomplished through the instantaneous surge in **green growth** projects. Moreover, green growth is our core variable, and these green growth projects can target carbon neutrality. However, green technologies, cleaner production, and innovations in the supply chain can minimize the impact of environmental degradation. Numerous East Asian countries are top emitter countries of the world; thus, green growth, eco-friendly technology, and environmental tax revenue are indispensable for these economies in decreasing the level of CO₂ emission. The achievement of sustainable economic growth is difficult for policymakers, owing to paradoxical and conflicting links among growth, energy use, and CO₂ emission. Policy-making in light of this conflicting relationship is crucial; for sound sustainable economic policies, the main objective of this study is to provide better solutions for policymakers. Based on comprehensive analysis, in protecting the environment in Asian countries, it is crucial to adopt the sustainable development goal by implementing environmental taxes as an institutional policy. Although, for Asian countries, economic growth will be hampered by implementing environmental taxes because the cost of production of manufacturing goods will also increase. Thus, in this regard, a two-tiered approach should be followed by these economies: where environmental taxes must complement economic strategies as it will endure the cost (economic) to help the moving towards renewable energy use. Thus, we also suggested that policymakers pay attention to sustainable and green opportunities to apply energy-efficient technologies at the manufacturing level.

Furthermore, various economic activities that cause environmental pollution can be discouraged through carbon taxes; then, the investors will start environmental-friendly production and projects. Overall, technological innovation and renewable energy sources see greater capacities due to the support of the public and environmentalists should focus on eliminating regulatory barriers for eco-friendly renewable technologies. A unidirectional causality was found between financial development and CO₂ emission, so financial assistance can be provided to technological innovation which can significantly improve the environmental quality. Financial development through green financing is also a key variable and the prerequisite for implementing policies regarding a clean environment. Thus, policymakers and the government can be encouraged to endorse renewable energy by providing loan grants to financiers in those areas. Additionally, another option is a tax holiday, to encourage investment in the sector of renewable energy. In the light of policy recommendations, the findings of this study describe valuable insights for environmentalist and policymakers. Asian countries need to give attention to eco-innovative technologies with green

growth to deal with environmental degradation. Furthermore, to achieve green growth, we required demand-based CO₂ emissions, this target can be achieved through cleaner production eco-technological innovation and green growth. These economies can shift their devotion to achieving economic growth through technological change (SDG 9), adoption of clean energy sources, and climate action programs (SDG 13). Finally, this study suggested that various Asian policymakers and researchers should focus on transforming the country's energy system to reduce energy-related CO₂ emissions and air pollution faster than previously expected.

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Declarations

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