RESEARCH ARTICLE

Role of green innovation, trade and energy to promote green economic growth: a case of South Asian Nations

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Abstract

The objective of this study is to contribute to the existing debate of green economic growth by empirically investigating the role of cleaner energy production, green innovation, and green trade in green economic growth in the context of South Asian countries. For this purpose, the study collects the data of South Asian Economies for 2000–2018 from different sources such as world development indicators (WDI), International Energy Statistics (IES), and Organization for Economic Co-operation and Development (OECD) statistics. The study applied Pesaran's (2007) second-generation unit root test to test the stationarity of the data. Wasteland's (2007) test of cointegration was applied to examine the long-run association among modeled variables. The study confirmed the long-run association among modeled variables that turn to be stationary at the first differences. Moreover, the study applied fully modified least square (FMOLS) and dynamic least square (DOLS) to estimate the empirical results of the study. Results of the study show that the production of clean energy, green innovation, and green trade positively contributes to the green economic growth of South Asian Economies

Keywords Green economic growth · Cleaner energy production · Green Innovation · Green trade · South Asian Nations

Introduction

Various studies have revealed that the present level of economic growth is not sustainable as it results serious environmental problems in the form of climate change, air pollution, contaminated water, and loss of biodiversity (IPCC, 2014). In the expanse of these environmental challenges, governments have started to search for an appropriate approach to sustainable economic progress. Furthermore, periodic failures in international policies made it necessary to explore a new paradigm of growth. Thus, the global discussion for sustained economic growth has been started. United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) indicated that environmental sustainability is

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essential to achieve the sustained economic path. Thus, a new paradigm of growth, known as "green economic growth" has been introduced. Green economic growth is an extension of the economic growth model which advances economic progress through environmental protection and social sustainability (Bagheri et al. 2018; A. A. Syed et al. 2021; Yang et al. 2019). Implementation of green economic growth in the economy can open up new sources of growth through improved productivity and macroeconomic stability. It also protects the environment, promotes social progress, and minimizes the risk to growth that arises due to a shortage of resources (Indicators 2011; A. Syed and Tripathi 2018).

Existing sustainable development goals (SDGs) shows that environmental sustainability (SDG 13), employment opportunities and economic growth (SDG 8), clean water and sanitation (SDG 6), healthiness and well-being (SDG 3), and responsible production and consumption (SDG12) are most challenging issues for developing nations (Baumeister 2018; Sinha et al. 2018) which can be solved with the implementation of green economic growth policies. Therefore, it is believed that green economic growth is critical for the achievement of sustainable development goals (SDGs). It is also a credible approach to energy efficiency and climate change mitigation (Yusof et al. 2016) and a widely recognized solution to environmental problems (Sandberg et al. 2019). Researchers identify the presence of green economic growth in history, but the disclosure of green economic growth (as another term for sustainable development) is still limited to the theoretical perspectives. Hence, there is a need for the implementation of green economic growth policies to overcome environmental disputes and for the achievement of SDGs. The present study proposes that Cleaner energy production, Green Innovation, and Green Trade are the important determinants of green economic growth as they significantly contribute to economic progress and environmental sustainability.

Green energy is one of the most important factors that significantly contribute to green economic growth. The present study claims that green energy promotes green economic growth. Numerous researchers regarded green energy as an environmentally friendly source of energy that reduces carbon emissions and argued that the production of green energy is an optimal choice of ensuring environmental protection as it reduces the dependency on inadequate resources such as gas, coal, and fuel (Alper and Oguz 2016). Most importantly, substituting the consumption of fossil fuel with renewable energy can significantly reduce the negative externalities from the production process and thus, promotes sustainable economic progress (Alper and Oguz 2016; Owusu and Asumadu-Sarkodie 2016; Sbia et al. 2014). Owusu and Asumadu-Sarkodie (2016) indicated that green energy enhances sustainable economic growth because it detaches economic growth from the deterioration of natural resources. Several empirical studies have found that green energy

positively contributes to economic progress and environmental sustainability (Pao and Fu 2013). Some official obligatory contracts such as Kyoto Agreement also encourage the production and consumption of green energy as it reduces carbon emissions.

Besides green energy, green innovation is also a key driver for promoting green economic growth. green innovation not only promotes affordable and environmentally friendly technologies but also reduces the cost of environmental sustainability (Popp 2012). Green innovation reduces environmental pollution by providing the access to modern types of machinery which ultimately promotes economic progress (Yin et al., 2015). The empirical work of Grossman and Krueger (1995) revealed the inverted U shape relation between economic growth and environmental pollution. Similarly, the Environmental Kuznets curve (EKC) indicated the positive association between environmental degradation and economic progress (Munasinghe 1999; Shahbaz et al. 2013). However, this relationship can be revisited by introducing green innovation which is inclined toward green economic growth. It advances the progress of green technologies which can observe, and reduce the patterns of carbon emissions. Green innovation can achieve the target of reducing greenhouse gas (GHG) emissions, improving energy efficiency, and environmental protection. Kaygusuz et al. (2007) indicated that green innovations result in the improvement of the energy sector which ultimately promotes economic progress. Furthermore, it is believed that real sustainable economic progress is not possible without green innovations (Abbas et al. 2020; Lorek and Spangenberg 2014). Referring to this fact, the present study incorporates green innovations in explaining long-term green economic growth.

The present study strongly argues that green trade is another important determinant of green economic growth as it provides the access to economical goods and services which accelerate the shift into the green economy. Green trade enhances green economic growth by reducing GHG emissions, improving energy efficiency, advancing industrial activities, and promoting economic progress. The literature revealed that green trade can alleviate environmental disputes, promote social sustainability, and promote economic progress by proving the assessment of environmental goods (Dahal and Pandey 2018). Thus, the author perceived green trade as an essential element that can advance the green economic growth of nations.

The aforementioned discussions motivated the researcher to examine the role of green energy, green innovation, and green trade in the green economic growth of South Asian Nations. The present study focuses on South Asian Economies due to many reasons: First, South Asia is one of the most susceptible regions with the most damaging effects of climate change which can be mitigated with the promotion of green economic growth. The region is expected to experience warming of 2–6 °C by the end of the 21st century (Ravindranath 2007). Currently, the South Asian countries

share 7% of global GHG releases, which increased gradually from 1970 to 2016. All the member nations of the region show the same pattern (Shown in Fig. 1).

Second, the region is experiencing a rapid increase in its economic growth. During the entire period of 2005–2010, regional GDP increased by the mean of 7.9% per annum and per capital Real GDP in purchasing power parity (PPP, at constant 2005 international $) increased at a compounded annual growth rate of 8.45%. However, the current approach of economic growth is not appropriate as it deteriorates the environment of the region in many ways; an incredible increase in carbon emissions is one of the most prominent. This rapid increase in economic growth results in increased demand for energy which tends to increase the region's GHG i.e., carbon emissions. Continues rise in carbon emissions increases the temperature of the earth which results in adverse environmental effects such as global warming and climate change. Figure 2 shows the average pattern of carbon emissions and economic progress across the region of South Asia, which reveals that carbon emissions are not yet separated from the annual growth rate of the region. Figure 3 shows the gradual increase in per capita carbon–emissions of each member of the state with the increase in annual growth rate. Therefore, the implementation of green economic growth policies is essential to separate the adverse environmental effects from the economic growth.
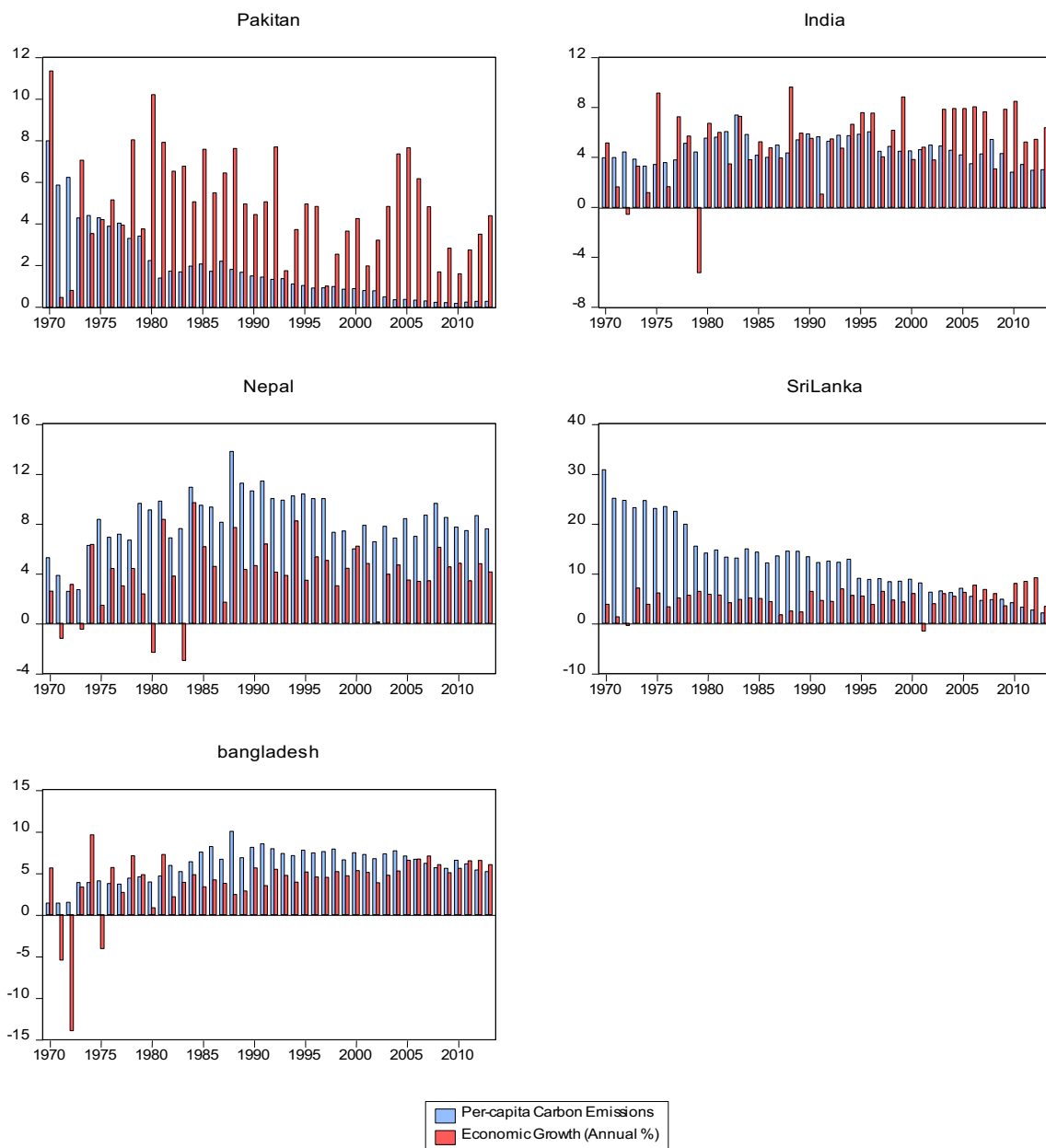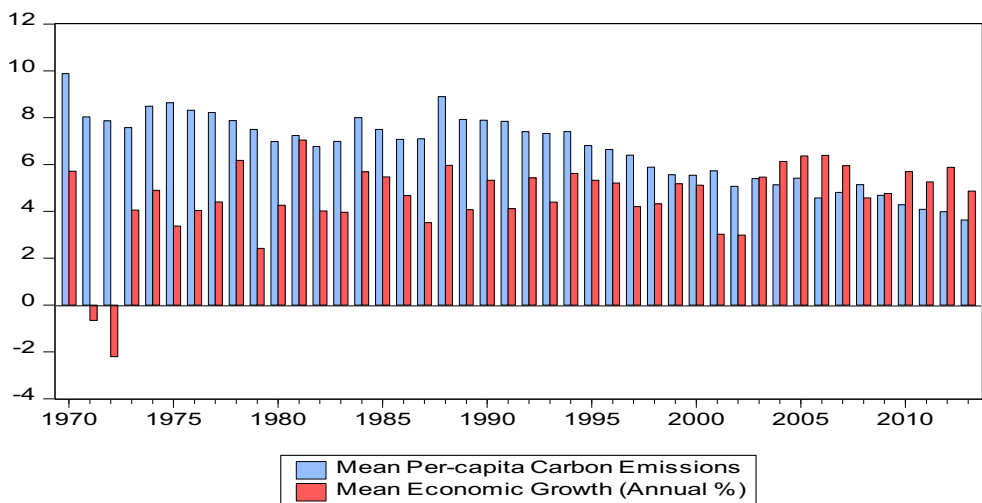

Fig. 1 A country-wise pattern of carbon emissions and economic growth

Fig. 2 Average pattern of carbon emissions and economic growth of South Asian Region

Mean Per-capita Carbon Emissions
Mean Economic Growth (Annual %)

Third, many people of South Asian Economies are living below the poverty line. Therefore, the region cannot take a chance to sacrifice its economic growth for the attainment of sustainable economic growth. Since GHG emissions are significantly related to the environmental perspective of the economy, the patterns of GHG emissions of the region could suggest valuable understandings of green economy, because Green economy does not require the reduction in economic growth for the attainment of a sustainable economic path, rather it boosts the economic growth within the limits of environmental sustainability.

Now the question of "how to achieve green economic growth" has encouraged many researchers to publish several empirical studies in various academic journals (Dai et al. 2016). Unfortunately, existing studies did not identify the factors which positively contribute to the enhancement of green economic growth, and the question of "how to achieve green economic growth" is still unexplained. However, the present study contributes to the existing debate of green economic growth in several ways. First, the study calculates the green economic growth for the selected South Asian Economies i.e.,

Nepal, Sri Lanka, India, Bangladesh, and Pakistan for 2000–2018. Secondly, to the extent of the author's best knowledge, the study for the first time explains the empirical contributions of green trade in green economic growth.

Thirdly, the study provides empirical evidence on the association between green energy, green innovations, green trade, and green economic growth in the context of South Asian Nations. At a crucial period, when South Asian Economies are struggling to tackle the environmental problems and promoting sustainable development, the results of the study do not only contribute to the literature but also illuminate the progress of green economic growth in the context of South Asian Nations. Lastly, the study suggests important policies on how to accelerate the green economic growth of South Asian economies by linking them with the achievement of SDGs. These policies are important for the sustainable development of South Asian economies. The remaining study has the following structure: "Data and methodology" section explains the review of existing literature, hypotheses development, and conceptual model of the study. The "Empirical results" section is about data and methodology. "Hypothesis

Fig. 3 Anthropogenic GHG emission by South Asian Economies

Bangladesh   India   Nepal
Pakistan   SriLanka
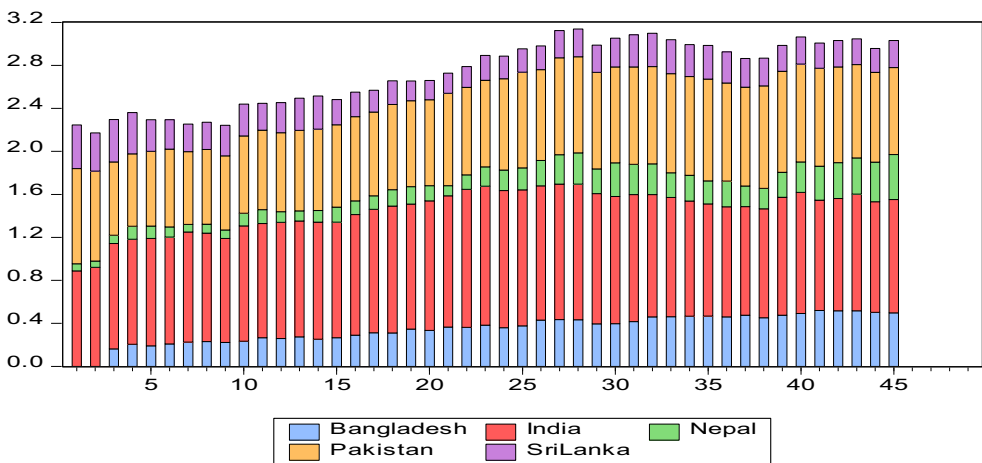
testing" section shows the empirical results of the study. "Conclusion and implications" section is about the conclusion, discussions, and policy implications.

Literature review and hypotheses development

This section represents the review of existing literature and development of hypothesis

Green Energy Production (GE) and Green Economic Growth (GG)

Several researchers examined the role of renewable energy sources on economic growth and environmental quality. Alper and Oguz (2016) examined the influence of renewable energy on economic growth by utilizing the data of European Nations from 1990 to 2009. Results of the study showed the positive affiliation between renewable energy and economic growth for Poland, Slovenia, Bulgaria, and Estonia. Several other studies such as Sbia et al. (2014) in UAE; Pao and Fu (2013) in Brazil; Yildirim et al. (2012) in the USA; and Apergis and Payne (2011) in Eurasian Nations, also revealed the positive effects of renewable energy consumption on economic growth which means that if there is an increase in the consumption of renewable energy, then on average there will be an increase in economic growth. Salim and Rafiq (2012) utilized the data of six developing nations and investigated the impact of renewable energy production on social sustainability.

The author used the provision of energy as a proxy of social progress. The study revealed the positive relationship between renewable energy and social progress. The study concluded that the production of renewable energy makes the provision of energy that enhances the quality of life of individuals which in their turn leads toward social sustainability. Fang (2011) worked on the association between renewable energy and economic progress by utilizing the data of China for 1978–2008 and showed the positive effects of renewable energy on economic progress. Apergis and Payne (2011) used the data of 13 countries of Eurasia from 1992 to 2007 for examining the impact of renewable energy sources on economic growth and revealed long term direct influence of renewable energy sources on economic growth. Sadorsky (2009) revealed similar results for developing nations and found that an almost 3.5% increase in economic growth is due to a 1% increase in renewable energy. Apergis and Payne (2011) examined the influence of renewable energy and non-renewable energy sources on economic development. The study utilized the data of 80 countries over the period of 1990–2007 and showed the positive effects of both types of energy consumption on economic growth and suggested that both of the types of energy are essential for economic progress whereas, the consumption of renewable energy lowers the carbon emissions.

Muhammad and Khan (2019) indicated that renewable energy consumption does not significantly contribute to environmental degradation. Majeed and Luni (2019), specified the positive role of renewable energy consumption in improving the environmental quality. The findings of this study were based on the panel of 166 nations for 1990–2017. Bhattacharya, Paramati, Ozturk, and Bhattacharya et al. (2016) indicated that the association between renewable energy consumption and EG is based on the stage of economic progress. Ackah and Kizys (2015) explored the drivers of renewable energy demand in the oil-producing economies of Africa. The study applied the dynamic panel model, fixed-effect model, and random effect model for examining the empirical results. Results of the study showed that per capita real income, deterioration of per capita energy resources, per capita greenhouse gas emission, and energy prices are the main drivers of GE demand in the selected sample. The author believed that renewable energy is a solution to environmental problems and energy shortage because it is produced from cleaner sources. Renewable energy refers to clean energy.

Considering the above literature, it is proposed that green energy significantly contributes to green economic growth. Few studies have investigated the influence of green energy on green economic growth. For instance, Sohag et al. (2015) examined the impact of green energy on green economic growth by using the data of turkey from 1980 through 2017. The findings of the study revealed the positive Influence of green energy on green economic growth. Dai et al. (2016) applied a dynamic computable general equilibrium model for investigating the economic effects and environmental benefits of the large-scale development of renewable energy in China. The findings of the study revealed the significant green economic growth effects of renewable energy. The study concluded that renewable energy tends to increase economic growth through environmental protection.

After reviewing the above literature, this study concluded that several researchers have focused on the relationship between green energy, economic growth, and environmental quality. However, the area of green economic growth concerning renewable or green energy is still under the discussion, especially in the case of developing nations. Therefore, the current study attempts to examine the role of green on green economic growth in the context of South Asian economies. After reviewing the above literature, it is assumed that:

H_1: "There is a significant relationship between clean energy production and green economic growth"

Green Innovation (GI) and Green Economic Growth (GG)

Numerous researchers have investigated the influence of technological innovation on environmental quality and economic

growth. Several studies have found that technical innovation plays an essential role in improving the environmental quality, or in other words, technical innovation tends to reduce Carbon emissions by enhancing the effectiveness of factor productions (Hascic et al. 2008; Liu and Liang 2013; Sohag et al. 2015). Chan et al. (2016) investigated the empirical relationship between technical innovation, environmental regulation, and firm performance by using the data of Chinese firms. The study concluded that innovations are positively influenced by environmental regulations which in turn increase the profitability of the firm.

Klewitz and Hansen (2014) indicated that technical innovations are the best way for the provision of proficient, finest, and cleanest usage of resources which improves the environment quality which ultimately enhances an individual's living standards, and promotes social sustainability. Wong et al. (2005) investigated the influence of technological innovation on economic growth by using the cross-sectional data of 37 nations that participated in GEM 2002. The findings of the study revealed the positive effect of technological innovation on economic growth. Murad et al. (2019) examined the vigorous association among technical innovation, environment quality, and economic growth by utilizing the data of Denmark, covering the period of 1970–2002. Results of the study indicated the positive association between technical innovation and economic growth. Results further showed that technical innovation tends to reduce carbon emissions and promote environmentally friendly apparatuses that having less significant contributions to carbon emissions.

Padilla-Pérez and Gaudin (2014) conducted primary research in Central American nations. The explicit aim of the study was to examine the influence of science, technology, and invention on sustainable development. The result of the study revealed the significant relationship between sustainable development and technical innovation. Du et al. (2019) collected the data of 71 nations for 1996–2012 and investigated the influence of technological innovation on the reduction of CO_2. Studies showed that technical innovation positively contributes to reducing CO_2 emissions. Carrion-Flores et al. (2006) studied the impact of environmental innovation in air pollution by utilizing the data of 127 manufacturing firms from 1989 to 2004. Results of the study showed that environmental innovation significantly contributes to reducing air pollution.

Conclusively, literature discussed the role of technical innovation in environment quality which is one dimension of green growth; so the role of technical innovation in green economic growth is a less researched area. A few studies have investigated the relationship between technical innovation and green growth. For instance; Ling Guo et al. (2017) used the data of 30 regions of China throughout 2011–2012 and showed the positive impact of technological innovation on green economic growth. Khan and Ulucak (2020) examined

the influence of environmental-related technologies, renewable energy, and nonrenewable energy on the green economic growth of BRICS economies. Results of the study showed the positive effect of environmental-related technologies and renewable energy in increasing the green economic growth of BRICS economies.

As far as we know, the literature on the relationship between green innovation and green economic growth is very limited. Most of the researchers focused on the role of technological innovation. Therefore, the present study contributes to the existing debate by empirically examining the role of green innovations in green economic growth in the context of South Asian Economies. Conclusively, after reviewing the above literature, it is assumed that:

H_2: "There is a significant relationship between green innovation and green economic growth"

Green Trade (GT) and Green Economic Growth (GG)

Numerous researchers empirically examined the relationship between trade, economic growth, and environmental quality. For instance, Yildirim et al. (2012) examined the effects of trade volume on economic growth and showed the positive association between trade, economic growth, and environmental quality. Trade stimulates economic growth through numerous channels such as technology transfer, comparative advantage, and large-scale economies. Wacziarg and Welch (2008) investigated the influence of trade liberalization on economic growth and study found the positive effects of trade liberalization on economic growth. Results further showed that the economic growth rate for the nations who liberalized their trade is higher because liberalization increased the average trade ratio to GDP. Zafar et al. (2015) utilized the data of 158 nations and examined the long-run and short-run association between trade openness and GDP.

Results of the study showed the positive association between trade openness and GDP in long run and suggested that global integration is a useful approach to enhance economic growth in the long run. The study further showed the negative association between trade openness and GDP in the short run. The study concluded that this negative short-run effect will convert into positive due to an increase in national income level. While, (Keho 2017) revealed the positive association between trade openness and economic growth in the short-run as well as in long run. Alam and Sumon (2020) showed the positive relationship between trade and economic growth by utilizing the data of 15 Asian Economies.

Therefore, the literature revealed the negative relationship between foreign trade and environmental quality. For example, Copeland and Taylor (1997) developed a static model of North-South trade for the first time and explored the association between international trade, national income, and environmental pollution. Based on the scale, technique, and

composition effects, the study revealed the positive contributions of free trade in environmental pollution. Copeland and Taylor (2001) indicated that trade would result from pollution-constrained production in nations having poor environmental regulations and limited resources. The result of the study suggested that, unlike the developed countries, developing nations shared different environmental burdens in free trade because of poor environmental regulation policies. Aklin (2016) specified that international trade shifts the pollution from one country to another. Udeagha and Ngepah (2019) worked on the relationship between trade openness and environment quality. In this regard, the study utilized the data of South African Economies and showed the positive association between trade openness and environmental quality in the short run, while negative association in long run.

Existing literature also highlighted the positive effects of international trade on environmental quality. For instance, Al-Mulali and Ozturk (2015) showed that trade reduces the environmental pollution of importing nations. However, the achievement of sustainable environmental benefits from international trade is hard for developing nations. Mensah et al. (2018) utilized the data of China for 1980–2014 and investigated the causal effect of urban population and international trade on environmental degradation. The study showed the two-way causality between urban population and imports and further highlighted the positive role of trade on environmental degradation in China. Results of the study suggested that energy consumption, urbanization, and imports are the main reason behind the environmental degradation in China. Duan and Jiang (2017) examined the progressive change of china's environmental pollution cost as compared to its economic benefits from international trade by employing the indicator of revised pollution term of trade. Results of the study indicated that the change in international trade pattern is an essential dynamic force behind the diverse changes in pollution term of trade by income groups.

After considering the significant role of international trade on environmental pollution, and in economic growth; this study comes with the role of green trade in green economic growth. For instance, Ali et al. (2020) investigated the effects of green trade and nongreen trade on GHG emissions. Results of the study showed that green trade significantly reduces GHG emissions. To the extent of the author's best knowledge, the relationship between green trade and green economic growth is still not discussed by the researchers. Therefore, the present study contributes to the existing debate of green economic growth by empirically examining the role of green trade in green economic growth. However, after reviewing the above literature it is proposed that:

H$_3$: *"There is a significant relationship between Green trade and green economic growth"*

Theoretical framework of the study

Literature on the relationship between green energy, green innovation, green trade, and green growth is very limited. Further, the relationship between green trade and green economic growth is not discussed by the researchers. This section first highlights the theoretical reasons for expecting the linkage between green energy, green innovation, green trade, and green growth, and then, it explains that "How green energy, green innovation, and green trade contributes to green economic growth. Green economic growth is identified as an efficient means of fostering economic growth by addressing environmental problems. Thus, "how to promote green economic growth is the main concern of policymakers". Core-macro economic theory concludes that factors like renewable energy are essential for sustainable economic progress. It is argued that the production and consumption of cleaner energy not only reduces the dependency on inadequate resources (i.e., fossil fuels, crude oil, and coal) but also reduces the negative externalities from the production process (Alper and Oguz 2016). It also positively contributes to the economic growth of developing economies (Shahbaz et al. 2013). Thus, based on core-macro economic theory, it is proposed that clean energy production significantly contributes to green economic growth. Besides clean energy production, green innovations also positively contribute to green economic growth. Moreover, the theory of comparative advantage highlights the importance of technical innovation in the sustainable economic progress.

Economic theory also elaborates on the significant role of technological innovations in economic growth. Ecological modernization theory suggests that environmental issues can be alleviated through advanced technologies. Advance technologies produce a certain level of output by using a lower level of energy. Such technologies are also known as green technologies that are connected with environmental policies, i.e., environmental quality and climate change mitigation. Porter's hypothesis highlights the importance of green technologies. The hypothesis suggests that green technologies, on the one hand, promote economic growth, and on the other hand, deals with environmental problems (Carrión-Flores et al. 2013). Modern growth theories also indicated the positive contributions of green technologies in sustainable economic growth (Acemoglu et al. 2016). All these theories are providing a clear theoretical basis on the relationship between green innovation and green economic growth. Finally, the extension of the H-O model by Siebert and Larrick (1992) highlights the importance of environmental endowments and competitiveness. The model specified that the production and export of pollution-intensive goods deteriorate the environment. Based on this model, the present study argues that countries should export and import environmentally friendly goods. This argument is also supported by the composition effect of the H-O model that is modified by (Grossman and Krueger 1995). The composition effect specifies that

international trade results in specialization. The nations having a comparative advantage in "dirty" products pollute more and the nations having the comparative advantage in "clean" products pollute less. These extensions of the H–O model shed the light on the association between green trade (export of clean/ environmentally friendly goods) and green economic growth.

Data and methodology

Data sources

The explicit aim of the present study is to explain the contributions of green energy, green innovation, green trade contributes in green economic growth in the context of South Asian Nations, including; Bangladesh, Sri-Lanka, Nepal, India, and Pakistan; three nations, Bhutan, Afghanistan, and the Maldives, have not been included in the study due to unavailability of data. For empirical investigation, the study utilized the data of selected South Asian Nations from 2000 to 2018. Data are collected from different sources i.e., data of green innovation and green trade are obtained from OECD statistics, data of clean energy production are obtained from International energy statistics (IES), and data of remaining variables are obtained from World development indicators (WDI). Table 1 shows a brief description of variables. The author converted all the variables in the natural logarithmic form to get more precise results.

Econometric techniques

Cross-sectional dependence

Numerous researchers have indicated that panel data generally suffers from the problem of cross-sectional dependency. This is because of the mutual shocks and unrecognized factors in cross-sections (De Hoyos and Sarafidis 2006; Pesaran 2004, 2007). Financial and economic assimilation is also a reason for cross-sectional dependence (De Hoyos and Sarafidis 2006). Hsiao and Pesaran (2008) stated that ignoring the problem of cross-sectional dependence provides biased and misleading results. Therefore, the study applies Pesaran (2007) cross-sectional dependence test for testing the likelihood of cross-sectional dependence. The test is based on pairwise correlation coefficients, which is suitable for the panels that have small N and large T. Additionally, based on the findings of cross-sectional dependence tests author can easily decide that either first-generation unit root tests (Baltagi et al. 2012) or second-generation unit root tests (Pesaran 2007) are applicable. The study used equation 1, having a null hypothesis of *"cross-sectional independence"* for testing the problem of cross-sectional dependence through (Pesaran 2015).

$$CD = \sqrt{\frac{2T}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \widehat{\delta}_{i,j}} \qquad (1)$$

where: $\widehat{\delta}$ is estimated coefficient of correlation, N is the number of cross-sections and T is period.

Panel unit root test in the presence of cross-sectional dependency

The problem of cross-section dependency is very common in panel data. Several existing studies have used first-generation unit-root tests for testing the stationarity of data (Levin et al. 2002; Maddala and Wu 1999). According to Banerjee et al. (2005), first-generation unit root tests are having a problem of influential properties and they misleadingly reject the null hypothesis of "cross-sectional dependency" and tests the stationarity of the data under the critical assumption of "cross-

Table 1 Description of variables

Variable	Notation	Measurement	Data Source	References
Dependent Variable				
Green economic growth	GG	Green economic growth = GDP + EE – NRP – NFD–CO_2 Where: "GDP is Gross domestic product growth (Annual %); EE is education expenditure (% of GDP); NRP is fossil fuel consumption (% of total), CO_2 is carbon emissions (% of fuel)"	WDI	Sohag et al. (2019)
Independent Variables				
Green Innovation	GI	"Environmental-related technologies"	OECD	Wang et al. (2019)
Green Trade	GT	"Share of export of environmental goods to total export"	OECD	GGGI Technical Report (2019)
Cleaner Energy Production	GE	"Share of electricity generated by renewable power plants in total electricity generated by all types of plants"	IES	Sohag et al. (2019)

section independence". Therefore, Pesaran (2007) and Choi (2006) developed new unit root tests, known as "second-generation unit root tests" to avoid these misleading results. Second generation unit-root tests check data's stationarity by taking into account the problem of cross-section dependency. The present study, therefore, applies CIPS unit-root test for testing the stationarity of data. CIPS is a commonly used second-generation unit root test which is proposed by Pesaran (2007). The test is based on the cross-sectional augmented dickey fuller (CADF) regression, which calculates cross-sectional lagged average of individuals y_t for monitoring the effect of common factors. CIPS is computed by using the procedure of IPS (Hossfeld 2010). Equation (2) shows the specification of CADF regression.

$$\Delta y_{it} = \alpha_i + \delta_i y_{i,t-1} + \tau_i \bar{y}_{t-1} + \sum_{j=0}^{k} \tau_{ij} \Delta \bar{y}_{i,t-j} + \sum_{j=0}^{k} \tau_{ij} \Delta y_{i,t-j} + \mu_{it} \qquad (2)$$

where: $\bar{y}_{t-1} = \left(\frac{1}{N}\right) \sum_{i=1}^{N} y_{i,t-1}$, $\Delta \bar{y}_t = \left(\frac{1}{N}\right) \sum_{i=1}^{N} y_{it}$, and t_i (N, T) is the t-statistic of the estimate of δ_i in Eq. (2), which is used for computing the individual ADF statistics. Specifically, CIPS test statistics are based on the mean of individual CADF, shown in Eq. (3)

$$CIPS = \left(\frac{1}{N}\right) \sum_{i=1}^{N} t_i \, (N, T) \qquad (3)$$

Panel cointegration tests

Cointegration techniques are used for testing the presence of long-term association among variables. Various cointegration approaches remain a target of criticism from numerous researchers (Pedroni 2000). Just like panel unit root tests, not all cointegration tests are appropriate to test the long-term association among variables under the critical assumption of CD. The present study, therefore, employs recently developed Westerlund and Edgerton (2007) bootstrap test of cointegration for testing the long-run association among green economic growth, green innovation, green trade, and clean energy production. This approach is preferable to the cointegration test of (Pedroni 2000) as it deals with the structural breaks. This approach is also robust against the problem of cross-sectional dependence and uses the bootstrapping property to deal with this problem. It also provides efficient results in the case of a small sample size. It avoids the problem of common factor constraint and tests the existence of cointegration among proposed variables under the null hypothesis of "no-error correction". This test checks the presence of error correction for the series that are integrated into order 1. Westerlund and Edgerton (2007) use four test statistics out of which two are based on "group-mean test statistics (G_t and G_a)" and two are based on "panel test statistics (P_t and Pa)". The alternative hypothesis for the group mean test assumes that "at least one element in the panel *is* cointegrated while the alternative hypothesis of panel test statistics assumes that "panel is cointegrated as a whole". Therefore, the rejection of the null hypothesis indicates the presence of long-term association/cointegration among variables. Equation (4) shows the specifications of Westerlund and Edgerton (2007) test:

$$\Delta GG_{it} = \beta_{0i} + \sum_{i=1}^{q} \beta_i \Delta GG_{i,t-i} + \sum_{i=1}^{q} \varphi_i \Delta X_{i,t-i}$$
$$+ \gamma_i ECM_{i,t-i} + e_{it} \qquad (4)$$

where: X = vector of independent variables, including green energy, green innovation, and green trade, γ_i is the value of the speed of adjustment of error-term. If $\gamma_i = 0$, then it is concluded that there is no error correction, which means that there is no cointegration among variables; $\gamma_i < 0$ specified that variables are cointegrated.

Estimation techniques

If all the variables are cointegrated, the next step is the estimation of long-run coefficients. The present study employs Fully modified least square (FMOLS) and dynamic least square (DOLS) models for estimating the coefficients of cointegrating vectors because the OLS estimator provides biased, conflicting, and inconsistent results in the presence of cointegration. FMOLS not only provides reliable estimates of parameters but also deals with the issue of cross-sectional dependency, endogeneity, and heterogeneity. Equation (5) shows the expression of the FMOLS coefficient.

$$\beta^*_{\,i} = \left(\hat{X}_i X_I\right)^{-1} \left(\hat{X}_i y^*_{\,i} - T\tau\right) \qquad (5)$$

where: Y_i^* is the transformed form of endogenous variables, y is the parameter for the adjustment of autocorrelation, and T denotes the time.

However, the problem of serial correlation, endogeneity, and heterogeneity is also addressed by using the DOLS estimator. DOLS provides unbiased and consistent estimators by using parametric modifications to the residuals along with past and future values

of the predictors that are integrated of order 1. The estimators of DOLS are obtained from Eq. (6)

$$Y_{it} = \alpha_i + X_{it}\delta + \sum_{j=-q_1}^{j=q_2} L_{ij}\Delta X_{it+j} + \mu_{it} \qquad (6)$$

where: X is the independent variables such as green innovation, green trade, and green energy, L_{ij} is the lead or lag coefficients of predictors at first difference. Equation (10) shows the expression of DOLS coefficients.

$$\widehat{\beta}_{DOLS} = \sum_{i=1}^{N} \left(\sum_{i=1}^{N} z_{it}z_{it} \right)^{-1} \left(\sum_{t=1}^{T} z_{ij}\widehat{y}_{it}^{+} \right) \qquad (7)$$

where: $z_{it} = \left[X_{it} - \overline{X}_i, \Delta X_{i,t-q}, \ldots\ldots, \Delta X_{i,t+q} \right]$ is the vector of independent variables and $\widehat{y}_{it}^{+}$ $\left(\widehat{y}_{it}^{+} = y_{it} - \overline{y}_i \right)$ is the dependent variable of the study, i.e., green economic growth Fig. 4..

Methodological flowchart

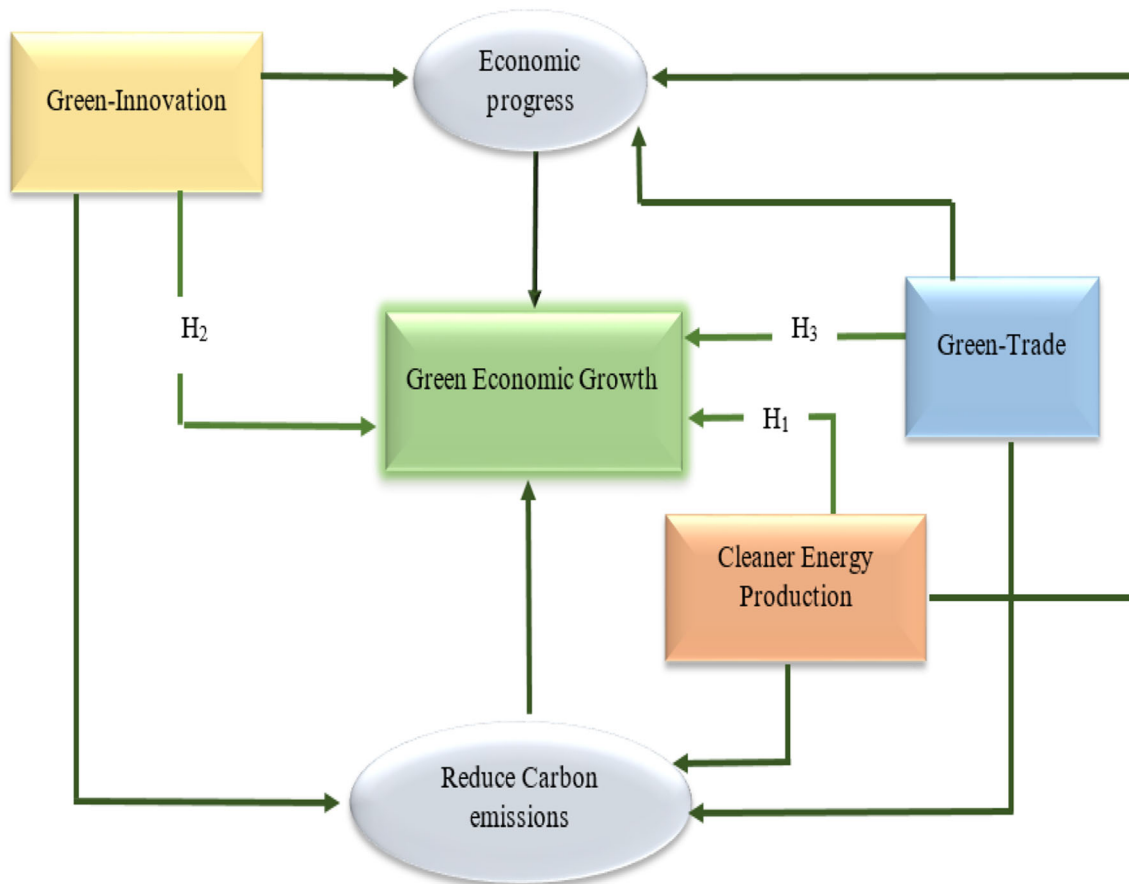The methodological flowchart of the current study is shown in Fig. 5.

Empirical results

Descriptive statistic

The analysis begins with the descriptive statistics of variables used in the sample of selected South Asian Economies (shown in Table 2). The table shows, the mean value of green economic growth (GG) is −1.7854, ranging from −2.0302 to −1.3005. Green energy (GE) is having a mean value of 3.0098 with a minimum value of −2.6757 and the maximum value of 4.6069. The mean value of green innovation (GI) is 2.2303 with the minimum and maximum values of 0.0392 and 3.8747, respectively. The mean value of green trade (GT) is 3.16E-07 ranging from −2.3748 to 2.0932. Jarque-Bera is used for testing the normality of residuals. The test has a null hypothesis of "residuals are normally distributed". The result shows that residuals are not normally distributed as the Probability values of Jarque-Bera are significant.

Cross-sectional dependence

The study employs the Pesaran CD test for detecting the issue of cross-sectional dependency in the data. Results of Table 3
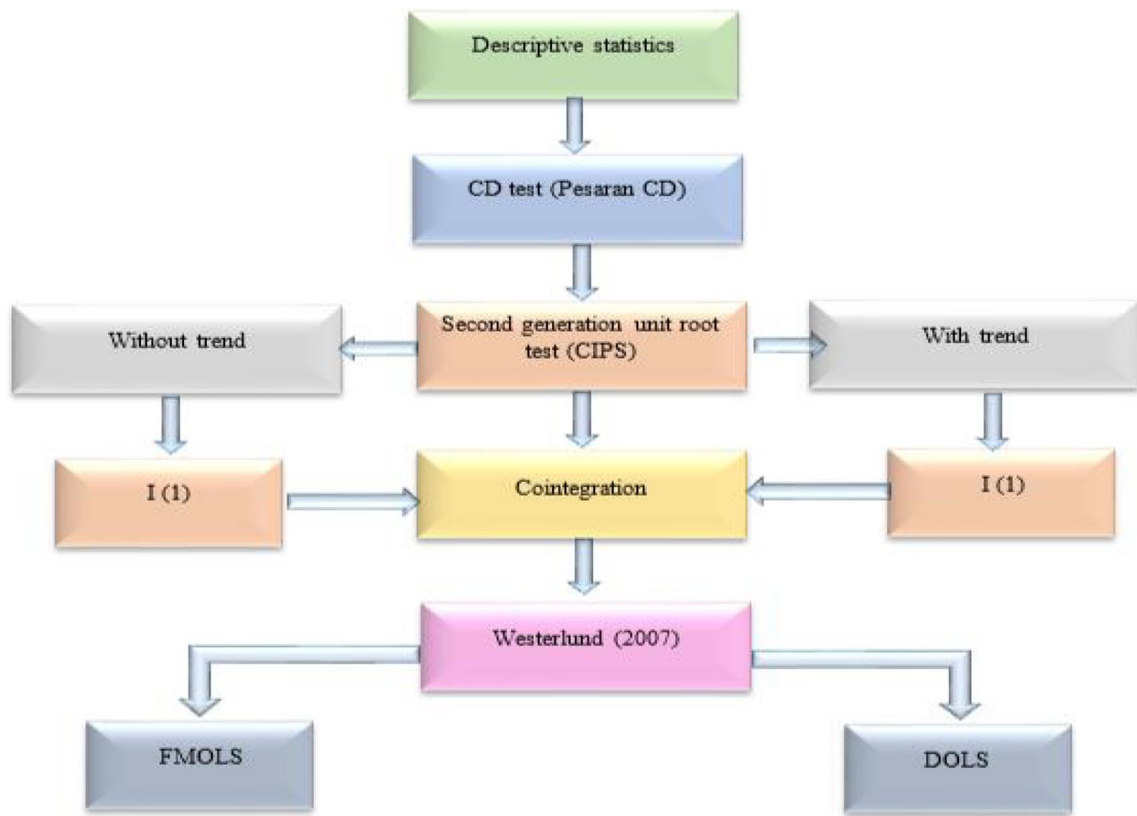

Fig. 4 Graphical Justification of the study

Fig. 5 Methodological flowchart

reveal that the null hypothesis of *"cross-sectional dependency"* is rejected at the level of 1% (*p-value<0.01*), which indicates that a shock in one of the selected nations tends to be transferred to other nations.

Panel unit root

Table 4 reports the results of the CIPS test, which is used to check the stationarity of data. The test is having a null hypothesis of *"nonstationary series"*. Results reveal that all the series are nonstationary at a level in both cases i.e., with the trend

and without trend. However, series become stationary at the first difference by rejecting the null hypothesis of *"non-stationary series"* at the level of 1% (*p-value<0.01*), which indicates that all the series are integrated of order 1 i.e., I (1)

Panel Cointegration

Table 5 reports the results of Westerlund's (2007) test of cointegration, which is used to test the existence of long-term association among variables. The result shows that the null hypothesis of *"nocointegration"* is rejected at the level of 1% as the probability value of Gt, Ga, Pt, and Pa is less than 0.01, signifying the existence of a long-term relationship among green economic growth, GE, GI, and GT.

Table 2 Descriptive statistics

	GG	GE	GI	GT
Mean	−1.7852	3.0098	2.2303	3.16E-07
Median	−1.8095	3.4341	2.1927	−0.1447
Maximum	−1.3005	4.6069	3.8747	2.0932
Minimum	−2.0302	−2.6757	0.0392	−2.3748
Std. Dev.	0.1916	1.4689	0.7643	1.0000
Skewness	0.9244	−1.3260	−0.0701	0.5816
Kurtosis	3.0164	4.7723	2.8061	3.1297
Jarque-Bera	13.533	40.273	3.8266	5.4234
P-value	0.0011	0.0000	0.0728	0.0364

Table 3 Cross-sectional dependence

Variables	CD statistics	*p*-value	Decision
GG	7.1815	0.000	*"Cross-Sectional dependence"*
GE	6.8490	0.000	*"Cross-Sectional dependence"*
GI	9.3572	0.000	*"Cross-Sectional dependence"*
GT	4.7828	0.000	*"Cross-Sectional dependence"*

Table 4 CIPS second-generation unit-root test

Variables	Level		First-Difference		Order of integration
	Without trend	With trend	Without trend	With trend	
GG	−1.1920	−1.9960	−3.7950***	−3.7750***	*I(1)*
GE	−1.3520	−1.2100	−3.7380***	−3.6830***	*I(1)*
GI	−1.6590	−1.3670	−4.4350***	−4.4500***	*I(1)*
GT	−1.4910	−1.6830	−4.9930***	−5.1150***	*I(1)*

Hypothesis testing

The study employs FMOLS and DOLS for testing the proposed hypotheses of the study. Results of FMOLS and DOLS are reported in Table 5. Results of FMOLS reveals that the coefficient of GE (0.0281) is positive and significant at the level of 5% as the *p*-value is less than 0.05 i.e., (0.0341<0.05). This implies that a 1% increase in GE tends to increase green economic growth by 2.81%. Results supported the 1st hypothesis of the study. The coefficient of green innovation (GI) (0.0132) is also positive and significant at the level of 10% as the *p*-value is less than 0.10 i.e., (0.0741<0.10). The result indicates that a 1% increase in GI tends to increase green economic growth by 1.32%. Results also supported the 2nd hypothesis of the study. The coefficient of GT (0.0504) is also positive and significant at the level of 1% as the *p*-value is less than 0.01 i.e., (0.0003<0.01), indicating that a 1% increase in GT tends to increase green economic growth by 0.504%. Thus, 3rd hypothesis of the study is also supported. The value of Adjusted R^2 shows that 93.7% variations in green economic growth are collectively explained by GE, GI, and GT Table 6.

Results of DOLS are quite similar to the results of FMOLS. Results of DOLS show that the coefficient of GE (0.0905) is significant at the level of 5% as the *p*-value is less than 0.05 i.e., (0.0312<0.05). The result indicates that GE positively contributes to green economic growth. For instance, a 1% increase in GE tends to increase green economic growth by 6.05%. Thus, 1st hypothesis of the study is accepted. The coefficient of GI (0.0083) is positive and significant at the level of 10% as the *p*-value is less than 0.10 i.e., (0.0821<0.10), indicating the positive relationship between

GI and green economic growth. This implies that a 1% increase in GT tends to increase green economic growth by 0.83%. Hence, 2nd hypothesis of the study is also accepted. The coefficient of GT (0.0112) is also positive and significant at the level of 1% as the p-value is less than 0.01 i.e., (0.0002<0.01), indicating the positive contributions of GT in green economic growth. Finding reveals that a 1% increase in GT tends to increase green economic growth by 1.12%. The value of Adjusted R^2 shows that 96.2% variations in green economic growth are explained by GE, GI, and GT collectively.

Conclusion and implications

This study analyzed the role of GE, GI, and GT in green economic growth in the context of South Asian Economies. The study found interesting findings. First, the study reveals that green energy positively contributes to green economic growth because green energy reduces the dependency on inadequate resources such as gas, coal, and fuel and thus, promotes environmental sustainability (Alper and Oguz 2016). Moreover, GDP, which produces through green energy sources is sustainable as it decouples from the deterioration of natural resources (Owusu and Asumadu-Sarkodie 2016). Results are also supported by Core-macro economic theory. Second, the findings of the study show the positive and significant role of green innovation in the green economic growth of South Asian Economies because it promotes affordable and environmentally friendly technologies which reduce environmental pollution, provide access to modern technologies and promote sustainable economic progress (Popp 2002). The findings of the study are supported by the theory of comparative advantage, ecological modernization theory, economic theory, and porter hypothesis. Last, the study shows that an increase in green trade is beneficial for the green economic growth of south Asian nations because GT enhances the green economic growth by reducing GHG emissions, improving energy efficiency, advancing industrial activities, and promoting economic progress. Results are supported by the extended H-O model by Siebert and Larrick (1992) and the composition effect of the modified H-O model by Grossman and Krueger (1995).

Table 5 Westerlund (2007) panel cointegration test

	Test statistics	Robust *p* value	Decision
Gt	−4.0490***	0.010	*Cointegration exists*
Ga	−18.0660***	0.000	*Cointegration exists*
Pt	−9.2900***	0.003	*Cointegration exists*
Pa	−16.4230***	0.000	*Cointegration exists*

Table 6 Hypothesis testing

Variables	FMOLS		DOLS		Decision
	DV: green economic growth		DV: green economic growth		
	Coefficient	p-value	Coefficient	p-Value	
GE	0.0281**	0.0341	0.0605**	0.0312	H_1 Supported
GI	0.0132*	0.0741	0.0083*	0.0821	H_2 Supported
GT	0.0504***	0.0003	0.0112***	0.0002	H_3 Supported
R^2	0.942		0.987		
Adjusted R^2	0.937		0.962		

Graphical presentation of results

Based on empirical results, the present study suggests the following policy implications. First, the study suggests that there is a need to promote the production of green energy in South Asian Economies by encouraging new projects, and investment in renewable energies. The government of South Asian Economies should encourage the private sector to increase the production of green energy by subsidizing it. To enlarge the scale of green energy production, tax credits should arrange for investors at the stages of installation and production. Carbon-tax should impose on traditional energy usage; this will shift the production of energy from traditional energy sources to renewable/cleaner sources. Second, the study suggests that there is a need to promote green innovation by modernizing the financial markets. Last, the study suggests that government should promote green trade through low-taxation policies and encourage the production of environmentally friendly goods. All the suggested policy implications not only help the government of South Asian Economies in the promotion of green economic growth but also help in the achievement of SDG7 (affordable and clean energy), SDG13 (environmental sustainability), SDG8 (decent work and economic growth), SDG12 (responsible production and consumption), SDG6 (clean water and sanitation).

Graphical justification of the study

Based on the theoretical and empirical review, Fig. 4 clearly shows that how green energy, green innovation, green trade contributes to green economic growth. These variables, on the one hand, boost up the economic growth and on the other hand, deals with environmental problems (i.e., reduce carbon emissions), which ultimately promote green economic growth. Therefore, the purpose of the present study is to empirically explain the contributions of clean energy production (H_1), green innovation (H_2), and green trade (H_3) in the green economic growth of South Asian Economies

Limitation and future directions

The present study is the first step toward a more profound understanding of green economic growth in the context of South Asian Nations. However, the present study has some limitations, which future researchers can address. First, the present study is conducted in the context of South Asian Nations, but the growth of the green economy varies from nation to nation. Future researchers, therefore, can conduct the replica of this study on the panel of different developing nations. They can also make a cross-nation comparison to get more precise and authentic results. Second, the present study explored only three factors that positively contribute to green economic growth, future researchers can explore more antecedents of green economic growth. Future researches can also consider the pandemic issue i.e., COVID-19 while further working on green economic growth.

Declarations

Consent to publish   All authors give consent to publish this paper after due process by the editorial board.

Competing interests   The authors declare no competing interests.

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