Technological shocks and its influence on renewable energy consumption-green growth: Do financial institutions mitigate some environmental burden?

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Abstract

Technology innovations and financial development are the tools to achieve sustainable development goals (SDGs) in the carbon neutrality process; however, such nexus has lacked evidence, particularly in top-polluting economies countries. The current study examines the effectiveness of technological innovation and financial institutions on renewable energy consumption and green growth in top-polluting economies by using the cross-sectional Autoregressive Distributive Lag (CS-ARDL) method over the period from 1991 to 2019. The findings show that in the long-run, technological progress and financial institutions are major drivers of renewable energy consumption of top-polluting economies. Moreover, the study shows that technological progress, financial institutions, education, and public spending foster green growth in top-polluting economies in long-run. Top-polluting economies need to improve energy technology innovation and financial institutions for achieving green growth and carbon neutrality targets.

Keywords: Technological shocks. Financial institutions. Renewable energy consumption. Green growth.

Introduction

Green growth has established instantaneous consideration in recent times as worldwide pursuit for development and economic growth tends to environmental degradation. Worldwide economic success demands investment in green technologies that reduce the risk of climatic change (Ullah et al., 2021). Studies denote that green growth mainly focuses on green consumption and production through the green technological shocks and use of clean energy (Luukkanen et al., 2019). The technological invention addresses both demand-based and production-based carbon emissions, hence contributing as a major determinant of industrial advancement (Yao et al., 2018). Developing, designing, and executing green technologies improve the sustainability of firms (Chen et al, 2022). Technological progress is required in supplying and generating energy for fulfilling the needs domestic, industrial, and transport sectors. Technological shocks promote supply chain and procurement activities of the industrial sector. This shows that technological shocks interconnected with strategic policies are fundamental for green growth (Wei & Ullah, 2022).

Considering the climate change and global warming issues, the economies throughout the world are adopting cleaner and newer technologies for producing that are cost-saving and eco-friendly (Horbach et al., 2012). Green technology occurred from investment in the R&D sector that shifts the economic setup towards the use of renewable energy sources (Mennicken et al. 2016; Alvarez-Herranz et al., 2017; Shuai & Fan, 2020). Development of human capital and R&D influence renewable energy consumption at both macro and micro levels. Well-developed human capital prefers to use energy-efficient products and consume clean energy sources (Li & Ullah, 2021). Moreover, well-developed human capital prefers to use advanced technologies and transform the economy to renewable and cleaner energy sources (Yin et al., 2021). Well-developed human capital influences energy consumption through the channel of technological progress and income. Human capital is strongly attached to an upsurge in output that in turn affects the consumption of energy (Ullah et al., 2019). Additionally, human capital also influences technological progress that in turn affects energy consumption (Zhang et al., 2021). Yao et al. (2019) reported that well-developed human capital reduces the consumption of dirty energy and promotes the consumption of cleaner and renewable energy.

A bulk of research has been done on green growth considering all possible determinants of green growth in the case of different economies (Popp, 2012). Researchers also assessed the nexus of green growth and CO2 emissions (Hao et al. 2021). Guo et al (2017) assessed green growth by considering the mutual impacts of technological shocks and environmental regulations. Stegemann and Ossewaarde (2018) unveiled the myth of green growth and energy transformation but isolated the impact of green technologies on the transmission and generation of energy. Studies examined the effect of technological shocks from different perspectives (Ullah et al., 2021). These studies confirmed the significance of technological shocks in the battle of environmental degradation. Mensah et al. (2019) examined the impact of technological innovation in renewable energy sources and reported that technological innovation contributes effectively to ensuring green growth. In literature, researchers mostly used research and development expenditures in the energy sector as a proxy variable for technological change. Existing studies examined the role of technological innovations on CO2 emissions and the green environment, but the effect of technological shocks on renewable energy consumption and green growth lacks attention.

Greener technology and renewable energy consumption reduce the dependence on fossil fuel sources that exert a stronger impact on energy markets. Green technological shocks prevent environmental degradation. However, the transformation from fossil fuel energy to cleaner renewable energy sources is quite challenging. The major challenge towards the adoption of green and renewable energy sources is the cost. The adoption process of renewable energy sources is attached with several financial constraints such as high operating, start-up, and infrastructure costs. Thus, it is necessary to have a strong financial institutional setup that provides effective methods of funding, price discovery, risk management, and market liquidity. Furthermore, financial institutions increase capital allocation. Well-developed financial institutions enhance investments in emergent industries, however, bad quality financial institutions reduce investments in emergent industries (He et al. 2019). Thus, in an economy, where green growth and renewable energy consumption are highly stimulated, the contribution of financial institutions can be considerable. Among the green growth literature, there is increasing interest in examining the determinants that enhance the use of renewable energy consumption. A bulk of the literature has examined the association between economic growth and renewable energy consumption, the effect of financial institutions on green growth and renewable energy consumption has not received much attention.

Besides financial institutions, environmental awareness and education are key determinants for green environmental and green growth (Zheng et al., 2021; Li et al., 2022). Akerlof (2017) denoted education as a major policy tool for sustainable green growth. Low investment in the R&D sector and technological innovation can be accredited to low educational attainment that might affect environmental performance negatively. Low level of educational attainment results in restriction of renewable energy consumption and restriction of dissemination of green environment awareness (Hess and Collins, 2018). Thus, educational attainment might affect the generation of renewable energy and green growth. Grossman and Krueger (1991) highlighted that education attainment supports policymakers in the formulation of eco-friendly policies that support in the achievement of sustainable green growth. Thus, the contribution of education in the attainment of green growth and the use of clean energy cannot be neglected.

The primary objective of this study is to explore the effect of technological shocks on green growth and renewable energy consumption. The study also explores the role of education and financial institutions in determining green growth and renewable energy consumption. The study empirically investigates the impact of technological shock, financial institutions, and education on green growth and renewable energy consumption for BRI economies over the period 1991 to 2019. The study employed a cross-sectional ARDL approach for empirical exploration. The findings of this study will help in evolving policies related to green growth and renewable energy consumption in BRI economies. The findings of this study not only expand the awareness but also highlight determinants to reinforce green growth throughout the world.

Model and methods

Technological innovations are key to fostering economic growth; therefore, it is widely recognized that they can affect environmental quality and other related factors such as renewable energy consumption and green growth. Indeed the relationship between technological innovation and economic growth is widely discussed in the circles of empirics but the mechanism through which technological innovations can affect economic growth is yet not finalized. However, theorists have highlighted a few mechanisms that can improve a firm's innovations such as the 'supply push model of innovation', 'demand-pull model of innovation', sudden advancement in scientific knowledge, and the models that can be explained in clusters (Geroski and Walters 1995). As far as, decoupling the economic growth from CO2 emissions is concerned, Grossman and Krueger (1995) suggested that technology used in the production process helps reduce carbon emissions after a technological change occurs endogenously. Modern growth theories have also pointed out the various channels such as patents and innovations through which a technological change can help to attain sustainable economic development (Wang et al. 2021) necessary to preserve the environment. Hence, we can confer that technological innovation can significantly help to decouple economic growth and CO2 emissions (Ullah et al., 2021). Therefore, to capture the impact of technology shock on green growth and renewable energy consumption we have followed Mensah et al. (2019) and constructed the following models:

$$REC_{it} = \eta_0 + \eta_1 Tech_{it} + \eta_2 FIE_{it} + \eta_3 Education_{it} + \eta_4 GS_{it} + \varepsilon_{it} \text{ ------- } (1)$$

$$GG_{it} = \eta_0 + \eta_1 Tech_{it} + \eta_2 FIE_{it} + \eta_3 Education_{it} + \eta_4 GS_{it} + \varepsilon_{it} \text{ ------- } (2)$$

Where renewable energy consumption (REC) and green growth (GG) in equations (3 & 4) are dependent on technological innovations (Tech), financial institutions' efficiency index (FIE), government spending (GS), and ε_{it} is randomly distributed error term. Estimates obtained by estimating equation (1) reflect the long-run effects of green growth. To suppose the short-run effects, we re-write equation (1) in an error-correction format. The study uses the following linear CS-ARDL regression equation.

$$\Delta REC_{it} = C_i + \lambda_i(REC_{it-1} - \beta_i X_{it-1} - \Upsilon_i GS_{it-1} - \phi_{1i}\overline{REC}_{t-1} - \delta_2 \bar{X}_{t-1} - \pi_2 \overline{GS}_{t-1}) + \sum_{j=1}^{p-1} \theta_{ij}\Delta REC_{it-j} + \sum_{j=0}^{q-1} \eta_{ij}\Delta X_{it-j} + \sum_{j=0}^{q-1} \tau_{ij}\Delta GS_{it-j} + \eta_{1i}\Delta\overline{REC}_t + \eta_{2i}\Delta\bar{X}_t + \eta_{3i}\Delta\overline{GS}_t + \varepsilon_{it} \text{ --------- } (3)$$

$$\Delta GG_{it} = C_i + \lambda_i(GG_{it-1} - \beta_i X_{it-1} - \Upsilon_i GS_{it-1} - \phi_{1i}\overline{GG}_{t-1} - \delta_2 \bar{X}_{t-1} - \pi_2 \overline{GS}_{t-1}) + \sum_{j=1}^{p-1} \theta_{ij}\Delta GG_{it-j} + \sum_{j=0}^{q-1} \eta_{ij}\Delta X_{it-j} + \sum_{j=0}^{q-1} \tau_{ij}\Delta GS_{it-j} + \eta_{1i}\Delta\overline{GG}_t + \eta_{2i}\Delta\bar{X}_t + \eta_{3i}\Delta\overline{GS}_t + \varepsilon_{it} \text{ --------- } (4)$$

Where, X_{it-1} is set of independent variable in equation (3 & 4). The first step in the empirical estimation of the model is to confirm the stationarity of the variables. To that end, we have applied two unit root tests known as the Levin–Lin–Chu (2002) and Im–Pesaran–Shin (2003). After the application of the unit root test and confirmation of the order of integration of the variables, we move to our main model.

For getting short and long-run estimates of the variables such as REC, GG, Tech, FIE, Education, and GS. We have relied on the cross-sectional augmented autoregressive distributive lag order (CS-ARDL) model proposed by Chudik and Pesaran (2013). This method has various benefits over other methods. The first-generation estimation techniques such as FMOLS, DOLS, etc can't address the issue of cross-sectional dependence and provide biased and inefficient estimates (Chen et al., 2022). Whereas, due to the inclusion of lagged dependent variable and cross-sectional averages, the CS-ARDL can deal with the most celebrated problems of the cross-sectional dependence and also deal with an additional issue of slope heterogeneity; hence, providing efficient results (Chudik and Pesaran, 2013). Another benefit of this method is that it can provide both short and long-run estimates simultaneously. Further, pre-unit root testing is not mandatory during the application of this method because it can also account for the variables that are integrated at different orders. Lastly, this method can provide efficient results even in the case of a limited number of observations across time.

To check the robustness of our results, we have applied PMG-ARDL and the quantile regression model. As compared to ordinary least square (OLS), which defines the variation in the dependent variables with the averages of the explanatory variables. Nevertheless, in the case of panel data analysis, some of the basic assumptions of OLS (zero mean, homoscedasticity, and normal distribution) are violated resulting in biased estimates. Therefore, quantile regression analysis is appropriate because in this method dependent variable is the conditional quantile of all independent variables and thereby providing regression for all quantiles. Therefore, quantile regression is better as compared to the OLS in the case of panel data due to its ability to analyze the impact of explanatory variables on the range of variation and conditional diffusion of the dependent variable.

Data

This study explores the impact of technological shocks, financial institutions, and education on green growth and renewable energy consumption. Table 1 displays the information regarding abbreviations and definitions of variables and descriptive statistics. In this research, green growth (GG) is measured through environmentally adjusted multifactor productivity while renewable energy consumption (REC) is measured in terms of the total consumption of energy in quad Btu. Technological shocks are measured through two variables. These proxies are patent applicants and eco-innovation (EI). Eco-innovation is taken as development of environment-related technologies as percentage of all technologies. Financial institutions' role is measured through financial institutions efficiency index (FIE). However, education impact is measured by average years of schooling. Government spending (GS) is used as a control variable in this study. It is measured as general government final consumption expenditures as a percent of GDP. The data for all the variables have been collected from the OECD, EIA, Barro-Lee, World Bank and the IMF.

Table 1: Definitions and descriptive

Variables	Definitions	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
GG	Environmentally adjusted multifactor productivity	4.376	4.142	13.14	-6.233	3.752	-0.045	2.780
REC	total energy consumption from nuclear, renewables, and other (quad Btu)	5.917	3.285	19.17	0.800	5.553	1.107	2.616
Patent	Patent applications, total (residents and non-residents)	11.56	12.05	14.24	8.139	1.503	-0.290	2.013
EI	Development of environment-related technologies, % all technologies	8.583	8.470	15.71	3.360	2.370	0.200	2.327
FIE	Financial institutions efficiency index	0.614	0.631	0.799	0.265	0.136	-0.604	2.554
Education	Average years of schooling	3.531	3.893	4.487	1.032	0.945	-1.012	2.868
GS	General government final consumption expenditure (% of GDP)	15.29	15.21	21.06	9.802	2.848	-0.199	2.254

Empirical results

Panel data analysis begins with the investigation of cross-sectional dependence, and for this task, the study employed Pesaran's (2004) cross-sectional dependence test. It is expected that the measures adopted by one economy influence the nearby economies due to liberalization and globalization. Thus, it is mandatory to test the cross-sectional dependence in order to avoid the biased value of cointegration and unit root analysis (Westerlund, 2007). The results of cross-sectional dependence are given in Table 2. It is reported that most of the selected variables are dependent cross-sectionally. Any variation in variables like REC, GG, Patent, FIE, education, and GS in one of the selected countries will affect other countries in the sample.

After confirming the cross-sectional dependence, the next step is to examine the order of integration of variables. For this task, the study used LLC and IPS unit root tests. Table 3 reports the findings of both unit root tests. The results of LLC test report that GG, patent, education, and GS are level stationary variables, however, REC and FIE are integrated at first difference. The findings of IPS unit root test show that GG is stationary at level and the remaining variables are stationary at first difference. The next step is to check the cointegration among variables. In this regard, Westerlund panel cointegration test is used. Table 4 displays the outcomes of panel cointegration test. The panel cointegration test results are collected from the panel group and statistics group (P_t, P_a) and (G_t, G_a). The findings display that cointegration exists among all the variables of REC model and GG model. It reveals that long-run association exists among the selected variables.

Table 2: Cross-sectional dependence tests

	REC	GG	Patent	FIE	Education	GS
Pesaran's test	0.141		3.242***	-1.774*	-0.919	-1.198
Off-diagonal	0.291		0.287	0.272	0.336	0.252
Pesaran's test		1.455	-2.390**	-1.892*	-1.821*	-1.354
Off-diagonal		0.165	0.278	0.298	0.282	0.455

Note: ***p<0.01; **p<0.05; *p<0.1

Table 3: Panel unit root tests

	LLC			IPS		
	I(0)	I(1)	Decision	I(0)	I(1)	Decision
REC	2.425	-7.007***	I(1)	0.947	-4.747***	I(1)
GG	-6.689		I(0)	-3.994***		I(0)
Patent	-1.639*		I(0)	-1.365	-4.374***	I(1)
FIE	0.441	-6.300***	I(1)	-1.971	-7.478***	I(1)
Education	-4.548***		I(0)	-1.389	-3.088***	I(1)
GS	-3.018***		I(0)	-1.980	-3.873***	I(1)

Note: ***p<0.01; **p<0.05; *p<0.1

Table 4: Panel cointegration tests

	REC			GG		
Statistic	Value	Z-value	P-value	Value	Z-value	P-value
Gt	-3.348**	2.181	0.015	-4.702***	5.129	0.000
Ga	-11.11	0.767	0.779	-10.31	1.450	0.926
Pt	-8.875***	4.168	0.000	-13.27***	8.254	0.000
Pa	-15.83**	1.770	0.038	-16.28	1.208	0.113

Note: ***p<0.01; **p<0.05; *p<0.1

After confirming the existence of long-run relationship between variables, the study evaluated the long-run and short-run relationship by employing a cross-sectional ARDL approach. The coefficient estimates of the renewable energy consumption model are given in Table 5. However, the coefficient estimates of green growth models are reported in Table 6. In the renewable energy consumption model, the positive and significant coefficient estimate of the patent variable means that an increase in technological innovation brings significant increase in renewable energy consumption in the long-run. It implies that a 1 percent upsurge in patent increases renewable energy consumption by 0.532 percent in the long-run. Financial institution's efficiency reports a significant and positive impact on renewable energy consumption in the long-run. It reveals that 1 percent improvement in financial institutions efficiency enhances renewable energy consumption by 1.210 percent in the long-run.

Education and government spending report statistically insignificant impact on renewable energy consumption in the long-run. In the short run, findings display that technology innovation reports no impact on renewable energy consumption as shown by a statistically insignificant coefficient estimate of patent variable. Financial institution's efficiency and education report statistically significant increasing effect on renewable energy consumption in the short-run. In contrast, government spending does not produce any significant effect on renewable energy consumption in the short-run. The results of technique-based and variable-based methods to measure robustness are consistent in direction and magnitude. In the end, the ECM value is negative and significant, which indicates the possibility of convergence towards equilibrium in the long-run. Likewise, in Table 7, the estimates of our concerned variables are positively significant in most quantiles, particularly, at higher quantiles.

Table 5: Short and long-run estimates of renewable energy consumption

	Basic model		Variable based-robustness		Method based-robustness	
	CS-ARDL		CS-ARDL		ARDL-PMG	
	Coefficient	Z-Stat	Coefficient	Z-Stat	Coefficient	t-Stat
Long-run						
Patent	0.532**	2.300			0.568**	2.589
EI			0.941***	8.960		
FIE	1.210*	1.860	1.300**	2.140	1.703**	2.079
Education	0.914	0.710	0.542	0.190	0.979*	1.935
GS	0.201	0.950	0.113***	3.340	0.200***	2.936
Short-run						
Patent	1.532	0.860			1.380	1.338
D(Patent(-1))					0.230	0.355
EI			0.525	0.550		
FIE	0.978*	1.710	1.052	0.500	1.161**	2.400
D(FIE(-1))					0.689	0.366
Education	0.875*	1.940	0.625	0.310	0.238**	2.099
D(Education(-1))					0.147	0.255
GS	0.142	0.460	0.107*	1.800	0.149	1.938
D(GS(-1))					0.366	0.455

C					1.803	1.203
ECM(-1)	-0.365**	2.365	-0.398**	2.012	-0.570**	2.165

Note: ***p<0.01; **p<0.05; *p<0.1

In the green growth model, long-run findings display that technological innovation tends to improve green growth in the long-run as shown by a significant and positive coefficient estimate of patent variable. It infers that a 1 percent upsurge in patent improves green growth by 1.665 percent in the long-run. Financial institutions' efficiency seems to have a significant and positive impact on green growth in the long-run. It is reported as a 1 percent improvement in financial institution's efficiency results in enhancing green growth by 1.754 percent in the long-run. Education is positively and significantly associated with green growth in the long-run. It seems that a 1 percent rise in education level brings 1.542 percent upsurge in green growth in the long-run. Government spending also reports significant and positive association with green growth in the long-run. It shows that a 1 percent expansion in government spending leads to 0.875 percent improvement in green growth in the long-run. In the short-run, findings report that the role of technology innovation and financial institution's efficiency is significant and positive in enhancing green growth. In contrast, education and government spending does not report any significant effect on green growth in the short-run. The coefficient estimates of technique-based and variable-based robustness models are also consistent as shown by their symbols and magnitude. The coefficient estimate of ECM term is negative and significant revealing the possibility of reasonable convergence in the long-run. Lastly, Table 7 revealed that technology innovation and financial institutions increase green growth in high quantiles.

Table 6: Short and long-run estimates of green growth

	Basic model		Variable based-robustness		Method based-robustness	
	CS-ARDL		CS-ARDL		ARDL-PMG	
	Coefficient	Z-Stat	Coefficient	Z-Stat	Coefficient	t-Stat
Long-run						
Patent	1.665**	2.370			1.176**	2.265
EI			0.732**	8.120		
FIE	1.754*	1.790	1.564**	2.230	1.780**	2.398
Education	1.542*	1.720	1.325*	2.470	0.992***	2.769
GS	0.875*	1.860	0.785	0.830	0.536***	2.968
Short-run						
D(Patent)	0.665**	2.150			0.497*	1.719
D(Patent(-1))					0.762	0.877
EI			0.265***	2.990		
D(FIE)	1.356**	2.340	1.154*	1.740	1.663*	1.762
D(FIE(-1))					0.899	0.428
D(Education)	0.354	0.450	0.900	0.500	1.526	0.451
D(Education(-1))					1.001	1.100
D(GS)	0.355	0.480	0.632	0.890	1.120**	2.715
D(GS(-1))					1.163	1.541
CC					6.110	2.700
ECM(-1)	-0.504*	1.875	-0.409***	3.025	-0.644***	2.823

Note: ***p<0.01; **p<0.05; *p<0.1

Results discussions

Our findings suggest that technological shocks help improve green growth and renewable energy consumption, which is also supported by some previous studies such as Chen et al. (2019) and Danish and Ulucak (2020). A positive change in technology improves the efficiency of production techniques and equipment and also helps to transform the energy structure which is crucial for decoupling economic growth and CO2 emissions. The development of innovative environmental ideas fosters the growth of environment-related technologies, in particular, and the overall technological process, in general. Similarly, the development of energy-related technologies improves the energy intensity and increases the share of renewable energy sources in the total energy mix, thereby increasing renewable energy consumption. Technological innovations are mandatory for the development of technologies, particularly to improve energy efficiency, energy conservation, and by substituting non-renewable energy sources with renewable ones. The importance of technological innovations in the development of renewable energy projects can't be ignored because more modern and sophisticated technologies can significantly improve energy efficiency and reduce energy consumption (Danish and Ulucak, 2020). These findings are also supported by the previous works (Silva et al., 2013; Sohag et al., 2015).

As far as the impact of financial institutions efficiency on green growth and renewable energy consumption are concerned it appears to be positive. According to Frankel and Romer (1999), efficient financial institutions can provide necessary funds at an affordable cost for research and development activities, necessary to boost technological innovations, which are significant for the complete separation of economic growth and CO2 emissions. Similarly, an increase in the efficiency of financial institutions provides funds for the promotion of pro-environment activities and technologies, which will ultimately be crucial for attaining green growth by reducing energy-related pollution also highlighted by Claessens and Feijen (2007), Zhang et al. (2021), and Zhou et al. (2022). Further, the transformation of the energy sector from dirty to clean energy sources require too much initial cost because the deployment of renewable energy projects is costly. To meet the high initial cost of renewable energy projects, the efficiency of financial institutions can play a crucial and significant role (Anton and Nucu, 2020).

Human capital is a by-product of education, skill, training, and experience. Therefore, it is used as a crucial input in the production function and spurs economic growth. Most of the developed economies have transformed their production process by substituting physical-capital intensive techniques with human-capital intensive techniques which have turned their production process into environmentally friendly and green (Mahalick et al. 2021). Further, the rise in the education level makes people more aware and conscious about their environment and nature; hence, their response towards the environment is more careful. Similarly, a more educated common individual and firm manager want to consume more clean energy, thus increasing literacy rate is positively linked to renewable energy consumption.

Table 7: Panel quantile regression

	0.05	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95
Renewable energy consumption											
Patent	0.445*	0.383	0.440	0.658	1.463**	3.150***	3.199***	3.037***	2.852***	2.594***	2.700***

	(1.715)	(1.181)	(1.046)	(1.330)	(2.282)	(8.198)	(9.103)	(9.867)	(7.715)	(7.359)	(6.782)
FIE	1.862*	1.347	1.561	1.195	1.540*	2.561***	2.692***	2.209***	2.507***	1.450**	1.752*
	(1.805)	(1.374)	(1.110)	(1.270)	(1.862)	(4.328)	(4.030)	(3.653)	(2.618)	(2.008)	(1.768)
Education	0.609*	0.711*	0.597	0.430	-0.187	-0.741	-0.038	0.384	1.597***	1.999***	1.702***
	(1.821)	(1.774)	(1.175)	(0.743)	(0.272)	(0.820)	(0.044)	(0.500)	(2.966)	(4.113)	(3.133)
GS	0.151*	0.140	0.135	0.161	0.346*	0.736**	1.041***	1.114***	1.397*	1.400***	1.294***
	(1.771)	(1.376)	(1.044)	(1.079)	(1.948)	(2.530)	(3.828)	(4.567)	(1.825)	(3.441)	(11.60)
Green growth											
Patent	0.981	1.255*	1.367***	1.803***	2.130***	1.856***	0.439	0.223	0.732***	0.774**	0.078
	(1.211)	(1.965)	(3.223)	(4.406)	(4.950)	(3.352)	(0.875)	(0.588)	(2.708)	(2.354)	(0.126)
FIE	0.977	-0.365	-0.128	-2.298	-4.277	-4.034	5.061*	6.025**	6.670**	4.090	3.601*
	(0.186)	(0.090)	(0.031)	(0.547)	(0.988)	(0.729)	(1.856)	(2.467)	(2.571)	(1.136)	(1.775)
Education	0.998	2.431	3.295*	4.116*	4.201**	3.836***	1.331	0.920	1.466**	2.206***	1.163
	(0.490)	(1.437)	(1.848)	(1.942)	(2.532)	(4.121)	(1.539)	(1.360)	(2.502)	(4.143)	(1.369)
GS	-0.594***	-0.326**	-0.151	-0.172	-0.284*	-0.093	-0.044	0.028	0.241*	0.319**	0.406***
	(3.255)	(2.398)	(1.088)	(1.109)	(1.662)	(0.444)	(0.236)	(0.183)	(1.766)	(2.361)	(2.860)

Note: ***p<0.01; **p<0.05; *p<0.1

Conclusion and implications

The notion of green growth implies that during the process of economic growth natural resources must be used with great caution so that extra burden on the environment should be avoided and the environment can be preserved for future generations. Therefore, the idea of green growth has got paramount importance in the issue of sustainability. Another important factor that has become popular in achieving the goal of sustainable economic development in renewable energy consumption. Renewable energy consumption is widely considered to be the most influential factor in mitigating the effects of CO2 emissions. Taking into consideration the above factors, we aim to investigate the determinants of green growth and renewable energy consumption. Among important determinants of green growth and renewable energy consumption, we have included technological shocks, financial institutions, and education. To investigate this relationship empirically we have applied the CS-ARDL model that can take into consideration the issue of cross-sectional dependence. Further, to check the robustness of our results we have applied PMG-ARDL model and quantile regression model.

From the results of the CS-ARDL model, we confer that the estimates attached to the Patent and eco-innovation are positively significant, confirming that the positive technological shock help to increase renewable energy consumption. Similarly, the estimates of the Patent and eco-innovation are positively significant in green growth models, implying that a positive technology shock is beneficial in attaining green growth. On the other side, the development of financial institutions and an increase in education also intensify renewable energy consumption and help to achieve green growth. The estimates of the robust ARDL-PMG model also follow the results of the baseline model and confirm that a positive technology shock, financial institution development, and increase in education all exert a positive impact on renewable energy consumption and green growth. Likewise, the estimates of our concerned variables are positively significant in most quantiles, particularly, at higher quantiles.

Generally, our findings imply that a positive shock in technological innovations helps to achieve green growth and increase renewable energy consumption. These results are important for policy implications in the issue of environmental sustainability. Therefore, the policymakers should focus on investing in research and development activities which are crucial for increasing the technology-related innovations in the economy. In order to boost environmental related technologies, the policymakers may entice the people and firms with the provision of easy credit facilities through financial institutions. Further, the financial and scientific policy should be integrated with environmental policy to attain the goals of environmental sustainability. Because financial institutions can provide credits and funds for the deployment of renewable energy plants which require too much initial investment. Similarly, the research and development activities also require too much investment that can be fulfilled by strengthing the financial infrastructure. Lastly, the policymakers should also focus on increasing the formal literacy rate which would be crucial for improving technological innovations and financial institution development.

The literature suggests that the activities related to technological innovation may increase during a boom and may halt during recessions; however, in this study, we have not addressed this issue empirically. Therefore, future studies should also take into account the positive as well as negative shocks in technological innovations, explicitly, and try to examine the nexus between technology, green growth, and renewable energy consumption by using asymmetric analysis.

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Consent to Participate: I am free to contact any of the people involved in the research to seek further clarification and information

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References

Álvarez-Herránz, A., Balsalobre, D., Cantos, J. M., & Shahbaz, M. (2017). Energy innovations-GHG emissions nexus: fresh empirical evidence from OECD countries. *Energy Policy*, *101*, 90-100.

Anton, S. G., & Nucu, A. E. A. (2020). The effect of financial development on renewable energy consumption. A panel data approach. *Renewable Energy*, *147*, 330-338.

Chen, J., Rojniruttikul, N., Kun, L. Y., & Ullah, S. (2022). Management of Green Economic Infrastructure and Environmental Sustainability in One Belt and Road Enitiative Economies. *Environmental Science and Pollution Research*, 1-11.

Chudik, A., & Pesaran, M. H. (2013). *Large Panel Data Models with Cross-Sectional Dependence: A Survey* (No. 4371). CESifo.

Claessens, S., & Feijen, E. (2007). *Financial sector development and the millennium development goals* (No. 89). World Bank Publications.

Frankel, J. A., & Romer, D. H. (1999). Does trade cause growth?. *American economic review*, *89*(3), 379-399.

Geroski, P. A., & Walters, C. F. (1995). Innovative activity over the business cycle. *The Economic Journal*, *105*(431), 916-928.

Grossman, G. M., & Krueger, A. B. (1991). *Environmental Impacts of a North American Free Trade Agreement* (No. 158).

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The quarterly journal of economics*, *110*(2), 353-377.

Guo, L., Qu, Y., & Tseng, M. L. (2017). The interaction effects of environmental regulation and technological innovation on regional green growth performance. *Journal of cleaner production*, *162*, 894-902.

Hao, L. N., Umar, M., Khan, Z., & Ali, W. (2021). Green growth and low carbon emission in G7 countries: how critical the network of environmental taxes, renewable energy and human capital is?. *Science of The Total Environment*, *752*, 141853.

He, L., Zhang, L., Zhong, Z., Wang, D., & Wang, F. (2019). Green credit, renewable energy investment and green economy development: Empirical analysis based on 150 listed companies of China. *Journal of cleaner production*, *208*, 363-372.

Hess, D. J., & Collins, B. M. (2018). Climate change and higher education: Assessing factors that affect curriculum requirements. *Journal of Cleaner Production*, *170*, 1451-1458.

Horbach, J., Rammer, C., & Rennings, K. (2012). Determinants of eco-innovations by type of environmental impact—The role of regulatory push/pull, technology push and market pull. *Ecological economics*, *78*, 112-122.

Li, X., & Ullah, S. (2021). Caring for the environment: how CO2 emissions respond to human capital in BRICS economies?. *Environmental Science and Pollution Research*, 1-11.

Li, X., Ozturk, I., Majeed, M. T., Hafeez, M., & Ullah, S. (2022). Considering the asymmetric effect of financial deepening on environmental quality in BRICS economies: Policy options for the green economy. *Journal of Cleaner Production*, *331*, 129909.

Luukkanen, J., Kaivo-Oja, J., Vähäkari, N., O'Mahony, T., Korkeakoski, M., Panula-Ontto, J., ... & Hogarth, N. (2019). Green economic development in Lao PDR: A sustainability window analysis of Green Growth Productivity and the Efficiency Gap. *Journal of cleaner production*, *211*, 818-829.

Mahalik, M. K., Mallick, H., & Padhan, H. (2021). Do educational levels influence the environmental quality? The role of renewable and non-renewable energy demand in selected BRICS countries with a new policy perspective. *Renewable Energy*, *164*, 419-432.

Mennicken, L., Janz, A., & Roth, S. (2016). The German R&D program for CO2 utilization—innovations for a green economy. *Environmental Science and Pollution Research*, *23*(11), 11386-11392.

Mensah, C. N., Long, X., Dauda, L., Boamah, K. B., Salman, M., Appiah-Twum, F., & Tachie, A. K. (2019). Technological innovation and green growth in the Organization for Economic Cooperation and Development economies. *Journal of Cleaner Production*, *240*, 118204.

Popp, D. (2012). The role of technological change in green growth. *Policy Research Working Paper Series*, (6239).

Shuai, S., & Fan, Z. (2020). Modeling the role of environmental regulations in regional green economy efficiency of China: Empirical evidence from super efficiency DEA-Tobit model. *Journal of environmental management*, *261*, 110227.

Stegemann, L., & Ossewaarde, M. (2018). A sustainable myth: A neo-Gramscian perspective on the populist and post-truth tendencies of the European green growth discourse. *Energy research & social science*, *43*, 25-32.

Ullah, S., Majeed, M. T., & Hafeez, M. (2019). Education, experience, social network and firm survival: the case of the electrical fittings cluster in Sargodha, Pakistan. *Decision*, *46*(3), 267-278.

Ullah, S., Ozturk, I., Majeed, M. T., & Ahmad, W. (2021). Do technological innovations have symmetric or asymmetric effects on environmental quality? Evidence from Pakistan. *Journal of Cleaner Production*, *316*, 128239.

Wang, K. H., Umar, M., Akram, R., & Caglar, E. (2021). Is technological innovation making world" Greener"? An evidence from changing growth story of China. *Technological Forecasting and Social Change*, *165*, 120516.

Wei, L., & Ullah, S. (2022). International tourism, digital infrastructure, and CO2 emissions: fresh evidence from panel quantile regression approach. *Environmental Science and Pollution Research*, 1-8.

Yao, Y., Ivanovski, K., Inekwe, J., & Smyth, R. (2019). Human capital and energy consumption: Evidence from OECD countries. *Energy Economics*, *84*, 104534.

Yin, Y., Xiong, X., Ullah, S., & Sohail, S. (2021). Examining the asymmetric socioeconomic determinants of CO2 emissions in China: challenges and policy implications. *Environmental Science and Pollution Research*, *28*(40), 57115-57125.

Zhang, D., Mohsin, M., Rasheed, A. K., Chang, Y., & Taghizadeh-Hesary, F. (2021). Public spending and green economic growth in BRI region: mediating role of green finance. *Energy Policy*, *153*, 112256.

Zhang, L., Godil, D. I., Bibi, M., Khan, M. K., Sarwat, S., & Anser, M. K. (2021). Caring for the environment: how human capital, natural resources, and economic growth interact with environmental degradation in Pakistan? A dynamic ARDL approach. *Science of The Total Environment*, *774*, 145553.

Zheng, G. W., Siddik, A. B., Masukujjaman, M., & Fatema, N. (2021). Factors Affecting the Sustainability Performance of Financial Institutions in Bangladesh: The Role of Green Finance. *Sustainability*, *13*(18), 10165.

Zhou, G., Zhu, J., & Luo, S. (2022). The impact of fintech innovation on green growth in China: Mediating effect of green finance. *Ecological Economics*, *193*, 107308.