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RESEARCH ARTICLE

Analyzing the role of environmental technologies and environmental policy stringency on green growth in China

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Abstract
This study aims to investigate the impact of environmental technological innovations and environmental policy stringency on green economic growth in China. The empirical analysis of the study is based on the ARDL model. Findings confirm that environmental technology positively impacts green economic growth in the short and long run. In the robust model, the estimates of all technologies appeared to be significantly positive in the short and long run. Conversely, the estimated coefficients of environmental policy stringency, in the basic and robust model, have only negatively impacted the green economic growth in China in the short run. In the long run, the environmental policy stringency has not shown any significant impact on green economic growth in China in the basic and robust model. China needs to increase environmental technology and environmental policy stringency for achieving green growth and sustainability targets.

Keyword Environmental technology · Environmental policy stringency · Green growth · China

Introduction

Green growth depends on market-based technological innovations to enhance the efficiency of production, thus distinguishing the environmental effects and natural resource-based consumption from unlimited development (UNEP 2011). Green environmental technologies are effective in boosting green growth (Sohag et al. 2019), and cleaner technological innovations result in significantly reducing CO2 emissions (Ullah et al. 2021a, b, c). One strand of literature validates that for an effective and consistent reduction in carbon emissions, improvements in the efficiency of environmental technology are compulsory (Kwon et al. 2017; Du et al. 2019; Chen and Lei 2018; Mensah et al. 2018). Other strands of the literature reveal that the simultaneous role of environmental-related technologies and renewable energy technologies is required for a sustainable reduction in carbon emissions and renewable energy technologies are vital for producing clean energy (Sarkodie and Adom 2018; Gu et al. 2019). Thus, environmental technological innovation is an imperative determinant that increases energy efficiency and diminishes energy consumption (Sohag et al. 2015; Zhao et al. 2022). In the meanwhile, worldwide economic development has raised environmental issues and resource scarcity and distracted the emphasis of the economies from outdated economic development towards sustainable growth.

In this regard, opposing outdated growth theories, the new economic development literature focused on the adoption of technological innovations to attain a green revolution (Acemoglu et al. 2016; Lei et al. 2022). Aghion et al. (2020) explored the query that whether technological change combats environmental change or not. The study highlights the significance of patents and environmental stringency policies to direct environmental-related technological changes to upsurge renewable energy consumption and to reduce non-renewable energy usage for mitigation of carbon emissions. Similarly, the increasing awareness of green growth has stimulated many economies to inaugurate the green economic growth infrastructure for environmental and resources protection, especially for the transformation of energy (Herman and Xiang 2019). Consequently, renewable energy usage, non-renewable energy usage, green technological

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innovations, and environmental stringency policies contribute significantly in explaining the green growth path (Usman et al. 2021; Li et al. 2022a, b). Due to these causes, determining factors of environmental sustainability have gained the attention of policymakers and researchers. The empirical evidence reveals that trade openness (Majeed et al. 2021), governmental performance (Zhang et al. 2022), research & development (Ullah et al. 2021a, b, c), financial development (Yang et al. 2020), human capital (Jian et al. 2021; Li and Ullah 2021), green transportation (Sohail et al. 2021), FDI (Jafri et al. 2022), green economic infrastructure (Chen et al. 2022; Wei and Ullah 2022), stock markets (Ullah and Ozturk 2020), and energy consumption (Zhao et al. 2021), technology (Ullah et al. 2021a, b, c), and environmental policy stringency (Albulescu et al. 2022) are the major determining factors of CO2 emissions and green growth among others.

Zhu et al. (2014) reported that modern environmental theories highlighted that climatic issues can be solved by environmentally-related technological innovations and environment-related regulations/stringency policies. It has become imperative to investigate how to endorse environmental management practices like green growth management to combat environmental issues (Lorek and Spangenberg 2019). A vast literature supports the argument that the green growth approach has become effective for attaining sustainable development (Grover 2013; Ploeg and Withagen 2013; Liu et al. 2022). Ploeg and Withagen (2013) examine the association between green growth practices and environmental stringency policy. The findings of the study suggest that carbon tax and research and development subsidies are effective tools to attain green growth. It is well-known fact that the capital development approach is useful for the attainment of sustainable development. The findings of Nielsen et al. (2014) study reveal that incentive-based environmental stringency policies contribute to achieving green growth. Environmental technological innovation is a key determinant of green growth (Grover 2013; Alola et al. 2021).

Based on the above discussion, it is concluded that the main determinants of green growth include technological innovations, environmental policy stringency, and so on. However, the existing literature takes into consideration the association between one specific determinant and green growth, although few studies investigated the integration among technological innovation, environmental policy stringency, and green growth. Chan et al. (2015) study demonstrated that environmental dynamics have a comparatively strong impact on the association between green technological innovations and cost-effectiveness, and a slightly moderate association between green technological innovations and profitability of firms. Zhao et al. (2020) explore the impact of environmental policy stringency on corporation competitiveness and innovation.

Bel and Joseph (2018) study identified environmental stringency policy as an important determinant to enhance green growth in EU economies. It is argued that the increasing pressure of environmental regulations and environmental stringency policy directly influences green growth. For China, Zhao et al.'s (2015) study examines the influence of three measures of environmental regulations (i.e., market-based regulations, command, and control regulations, and government subsidies) on carbon emissions reduction and efficiency improvement of power plants. The findings reveal that government subsidies and market-based regulations positively improve the efficiency of power plants and reduce carbon emissions, but command and control regulations exert no significant contribution. Porter and van der Linde (1995) report that environmental stringency policy can stimulate firm innovation, hence enhancing its effectiveness on green growth. Some researchers explored the association between environmental stringency policy and technological innovations (Lanoie et al. 2011; Zhao et al. 2020; Lei et al. 2022). Castellacci and Lie (2017) examine different types of environmental innovations and reported that environmental stringency policies are more significant drivers of technological innovations and reduction in pollution emissions of firms. Furthermore, Tellis (2008) claimed that technological innovations play a significant role in viable green development in contemporary economies.

Based on the above discussion, understanding the effect of environmental-related technologies and environmental stringency policies on green growth is crucial for decision making. Previous studies have mostly focused on the influence of technological innovations and environmental stringency policies on CO2 emissions. However, the present study moves in a new direction and delivers a unique investigation on the simultaneous effect of environmental-related technologies and environmental stringency policies on green growth in the case of China. This study contributes to the current literature in the following ways. Firstly, to the best of our knowledge, this study is the first one that investigates the simultaneous impact of environmental-related technologies and environmental stringency policy on green growth in China. The study will deliver imperative policy directions that help in stimulating green growth and reducing carbon emissions in China.

Model and methods

Endogenous growth theory believes that technology innovation is the key important source of economic growth, and a bulk of empirical research has proved that technology innovation has a significant and positive effect on economic growth (Pece et al. 2015 and Lopez-Rodriguez and Martinez-Lopez 2017), while a newly emerging body of empirical studies paying attention to the influence of technology innovation on green growth (Mensah et al. 2019 and Danish and Ulucak 2020). In formulating the green growth model, we follow the most recent theoretical and empirical literature in general (Hallegatte et al. 2012 and Jacobs 2012) and assume that green technology is the main determinant of green growth in China. As such, we begin with the following long-run green growth model specification:

$$GG_t = \omega_0 + \varphi_1 GT_t + \varphi_2 EPS_t + \varphi_3 Internet_t + \varphi_4 RD_t + \varphi_5 Trade_t + \varepsilon_t \quad (1)$$

where green growth (GG) is dependent on green technology (GT), environmental policy stringency (EPS), Internet users (Internet), research and development (RD), and trade openness (trade). While green technology affects green growth in the same way as standard green variables, thus expected sign is positive. Environmental policy stringency is one of the deep causes of green growth in the modern era, thus expected coefficient estimates of φ_2 is also positive. Internet and R&D plays an effective role in green growth, while trade openness is a key pillar of green growth, thus φ_3, φ_4, and φ_5 could be positive. The basic model gives us only long-run estimates of concern variables. Next, we need to alter the Eq. (1) into error correction format for long-run as well short-run estimates as shown below:

proposed to determine the cointegration if the estimate of λ is negative and significant. This method can take integrating properties into account, and we can add combination $I(0)$ and $I(1)$ variables into our model. Lastly, this technique can provide efficient outcomes in case of small sample size (Ullah et al. 2020). This method gives us long-run and short-run estimates in one step. We have confirmed the autocorrelation problem via Lagrange MULTIPLIER (LM) test, but Breusch–Pagan (BP) test identifies the Heteroskedasticity problem. Ramsey's RESET test is employed which is used to identify model misspecification. The CUSUM and CUSUM-sq tests approve the stability of coefficients estimates in the end.

Data

The study aims to analyze the role of environmental technologies and environmental policy stringency on green growth in China. In this regard, this research utilizes time-series data for time zone 1990–2019 for the Chinese economy. Table 1 provides information about symbols, definitions, and sources of data. The data on green growth, defined as pollution-adjusted GDP growth, is collected from OECD. The data for environmental-related technologies, all technologies (total patents), and environmental policy stringency index

$$\Delta GG_t = \omega_0 + \sum_{k=1}^{n} \beta_{1k} \Delta GG_{t-k} + \sum_{k=0}^{n} \beta_{2k} \Delta GT_{t-k} + \sum_{k=1}^{n} \beta_{3k} \Delta EPS_{t-k} + \sum_{k=0}^{n} \beta_{4k} \Delta Internet_{t-k} + \sum_{k=0}^{n} \beta_{5k} \Delta RD_{t-k} + \sum_{k=0}^{n} \beta_{6k} \Delta Trade_{t-k} + \omega_1 GG_{t-1} + \omega_2 GT_{t-1} + \omega_3 EPS_{t-1} + \omega_4 Internet_{t-1} + \omega_5 RD_{t-1} + \omega_6 Trade_{t-1} + \lambda.ECM_{t-1} + \varepsilon_{it} \quad (2)$$

After rewriting Eq. (1) into error correction format, Specification (2) can now be called as time-series ARDL model of Pesaran et al. (2001). This equation can provide long- and short-run estimates at the same time. Short-run results can be deduced from the estimates connected to the first difference variables, and long-run results can be traced from the estimates of $\omega_2 - \omega_6$ normalized on ω_1. However, for the validity of long-run estimates, Pesaran et al. (2001) endorse two tests. The proposed test is F-test to determine the cointegration (Bahmani-Oskooee et al. 2020), while the t-test is

are collected from OECD. The study uses internet, research and development, and trade openness as control variables. Internet users is calculated as individuals using the Internet in percent of total population. Research and development is measured into total R&D expenditures in percent of GDP. While trade openness is taken as total trade in percent of GDP. The data on these three control variables are obtained from the World Bank.

Table 1 Variables and sources

Variables	Symbol	Definitions	Sources
Green growth	GG	Pollution-adjusted GDP growth	OECD
Environmental technology	ET	Environment-related technologies	OECD
Total technology	AT	All technologies (total patents)	OECD
Environmental Policy Stringency	EPS	Environmental Policy Stringency index	OECD
Internet users	Internet	Individuals using the Internet (% of population)	World Bank
Research and development	RD	Research and development expenditure (% of GDP)	World Bank
Trade openness	Trade	Trade (% of GDP)	World Bank

Results and discussion

Before exploring the long-run effects of environmental technologies and environmental policy stringency on green growth, the stationarity properties of variables have been checked by employing Phillips Perron (PP) test and Augmented Dickey-Fuller (ADF) test. The outcomes of these two unit root tests are displayed in Table 2. This table provides findings regarding the order of integration of variables. The results of the table reveal that a few variables are level stationary while other variables become stationary after taking the first difference. Thus, it is confirmed that the study can employ ARDL approach because this technique is beneficial in the presence of $I(0)$ and $I(1)$ variables to obtain parameters that are unbiased. Literature supports that there is no objection to using ARDL approach in the presence of mixed order of integration.

After confirming the order of integration of variables, the study employed ARDL approach in order to examine the effect of environmental technologies and environmental policy stringency on green growth. The long-run and short-run results of ARDL approach are given in Table 3. The study finds that the environmental technologies' effect on green growth is statistically significant and positive at the 10% level of significance in the long run. It is observed that a 1% increase in environmental technologies increases green growth by 4.932%. Our findings infer that promoting environmental technologies could be a fundamental policy tool to enhance green growth in China. Thus, environmental technologies in China can induce green growth, which tends to reduce environmental pollution.

Our findings are in line with Sohag et al. (2019), who reveals that environmental technology contributes significantly enhances green growth and significantly mitigates CO2 emissions. Thus, green innovation plays a vital role in explaining the path for green growth. Environmental innovation allows for technological advancement that tends to green development. Advancement in environment-related technologies boosts the clean energy share in total energy and declines the share of energy intensity. However, initially, the technological advancement in energy exerts a harmful impact on CO2 emissions but later on, it improves environmental quality in China. The advancement in equipment related to technological progress improves production efficiency, thus increasing its sustainability by improving green growth. Due to technological advancement, the combustion of fossil fuels is substituted by new sources of energy that subsequently alleviate CO2 emissions. Green technologies encourage cleaner production that tends to be sustainable to green growth.

In view of Mensah et al. (2019), green innovations are somehow dependent on intellectual and patent rights, thus dissemination could be restricted. They claim that green technologies are key determinants of green growth. It is suggested that firms should introduce cleaner production-based technologies and environmental innovation to satisfy the needs of green growth that significantly boosts production competitiveness and efficiencies. Our finding is also consistent with Yao et al.'s (2018), who infer that environmental technology addresses the emissions of both demand-based and supply-based factors and confirms that these innovations significantly encourage green growth. The study suggests that the use of biotechnology reduces the combustion of fossil fuels significantly. Moreover, transport-based technologies are capable of enhancing green growth. A study done by Danish and Ulucak (2020) reveals that transmission and generation-related technological innovations are beneficial for enhancing green growth.

The relationship between environmental policy stringency and green growth is statistically insignificant in the long run. However, the linkage between Internet use and green growth is positive and statistically significant at 1% level in the long run. We find that a 1% increase in Internet use increases green growth by 0.293% in the long run. It implies that the Chinese government focuses on digitalization products that increase Internet use, which in turn increase green growth. However, the relationship between research and development and green growth is statistically insignificant in the long run in China. However, trade openness is positively

Table 2 Unit root testing

	ADF			PP		
	$I(0)$	$I(1)$	Decision	$I(0)$	$I(1)$	Decision
GG	−2.967		$I(0)$	−2.960		$I(0)$
ET	−0.884	−3.428	$I(1)$	−0.839	−3.406	$I(1)$
AT	−0.973	−3.071	$I(1)$	−0.876	−3.079	$I(1)$
EPS	−0.340	−4.226	$I(1)$	−0.464	−4.228	$I(1)$
Internet	0. 128	−2.680	$I(1)$	0.254	−2.690	$I(1)$
RD	−2.907		$I(0)$	−2.921		$I(0)$
Trade	−1.078	−3.435	$I(1)$	−1.346	−3.426	$I(1)$

$^{***}p<0.01$, $^{**}p<0.05$, and $^{*}p<0.1$

Table 3 ARDL estimates of short and long run

	Basic model				Robust model			
	Coefficient	S.E	*t*-stat	Prob	Coefficient	S.E	*t*-stat	Prob
Short run								
D(ET)	2.015	5.338	0.378	0.715				
D(ET(-1))	4.795*	2.779	1.725	0.119				
D(AT)					4.580*	2.403	1.906	0.081
D(EPS)	−3.253**	1.493	−2.178	0.057	−2.238*	1.215	−1.842	0.090
D(EPS(-1))	−3.466**	1.765	−1.963	0.081	−3.303**	1.444	−2.288	0.041
D(INTERNET)	0.685**	0.348	1.966	0.081	0.483**	0.208	2.320	0.039
D(INTERNET(-1))	−0.528***	0.186	−2.837	0.020	−0.491***	0.177	−2.783	0.017
D(RD)	−2.663	7.193	−0.370	0.720	1.353	4.874	0.278	0.786
D(RD(-1))	5.807	6.066	0.957	0.363	7.101	5.188	1.369	0.196
D(TRADE)	0.180**	0.092	1.966	0.081	0.154***	0.048	3.195	0.008
Long run								
ET	4.923*	2.931	1.679	0.127				
AT					5.062*	2.770	1.828	0.093
EPS	−1.636	2.005	−0.816	0.436	−0.400	1.967	−0.204	0.842
INTERNET	0.293***	0.073	4.001	0.003	0.175**	0.070	2.518	0.027
RD	1.983	7.772	0.255	0.804	4.896	7.058	0.694	0.501
TRADE	0.210***	0.030	7.003	0.000	0.171***	0.036	4.748	0.001
C	39.77	19.58	2.031	0.073	53.59	26.27	2.039	0.064
Diagnostics								
F-test	5.895***				4.262***			
CointEq(-1)	−1.270**	0.517	−2.458	0.036	−0.905***	0.227	−3.981	0.002
LM	1.589				0.712			
BP	2.023				0.215			
RESET	1.023				1.536			
CUSUM	S				S			
CUSUM-sq	S				S			

***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$

associated with green growth. Other things remaining the same, a 1% increase in trade openness causes green growth to increase by 0.210% in the long run. We find that environmental policy stringency is significant negative associated with green growth in the short run at 5% level. However, Internet use and trade openness are positively and significantly attached with green growth at 5% level in the short run.

The study has used all technology variables in order to check the robustness of the findings. The results of the robust model demonstrate that all technology's effect on green growth is statistically significant and positive at the 10% level of significance in the long run. It is found that a 1% increase in all technologies increases green growth by 5.062%. The influence of environmental policy stringency on green growth is again statistically insignificant in the long run in the robust model. Internet use adds to green growth significantly and positively at 5% level in the long run. It shows that a 1% increase in Internet use increases green growth by 0.175%. In line with original model, research and development impact on green growth is again statistically insignificant. Trade openness also adds to green growth positively at 1% level of significance in the long run. It shows that a 1% rise in trade openness increases green growth by 0.171%. In the short-run, robust model findings are quite similar to the findings of the original model.

In the end, findings of diagnostic tests are given in lower panel of Table 3. The statistically significant coefficient estimates of *F*-stat confirm that long-run cointegration exists among variables in both models. The coefficient estimates of ECT are statistically significant and negative in both models. These findings confirm the long-run link among variables of interest. The findings display that any short-run deviations will ultimately achieve a stable path in the long run. There is no evidence of heteroskedasticity and autocorrelation found in both models. Both models are well specified as confirmed by findings of Ramsey RESET test. The stability of both models is also confirmed by the results of CUSUM and CUSUM SQ tests. The results from the linear causal empirical analysis are described in Table 4. The results show

Table 4 Results of symmetric causality test in China

Null hypothesis	*F*-stat	Prob	Null hypothesis	*F*-stat	Prob
ET → GG	2.949	0.075	AT → GG	3.294	0.056
GG → ET	0.879	0.431	GG → AT	0.318	0.732
EPS → GG	0.280	0.759	EPS → GG	0.280	0.759
GG → EPS	0.071	0.932	GG → EPS	0.071	0.932
INTERNET → GG	0.470	0.632	INTERNET → GG	0.470	0.632
GG → INTERNET	1.698	0.209	GG → INTERNET	1.698	0.209
RD → GG	2.270	0.129	RD → GG	2.270	0.129
GG → RD	8.037	0.003	GG → RD	8.037	0.003
TRADE → GG	1.565	0.234	TRADE → GG	1.565	0.234
GG → TRADE	2.500	0.107	GG → TRADE	2.500	0.107
EPS → ET	0.047	0.954	EPS → AT	0.602	0.558
ET → EPS	2.837	0.082	AT → EPS	3.567	0.047
INTERNET → ET	0.830	0.450	INTERNET → AT	0.517	0.604
ET → INTERNET	3.212	0.062	AT → INTERNET	3.292	0.058
RD → ET	4.178	0.031	RD → AT	6.831	0.006
ET → RD	1.451	0.258	AT → RD	0.367	0.698
TRADE → ET	0.966	0.398	TRADE → AT	0.021	0.979
ET → TRADE	0.746	0.487	AT → TRADE	1.064	0.364
INTERNET → EPS	5.298	0.014	INTERNET → EPS	5.298	0.014
EPS → INTERNET	0.750	0.485	EPS → INTERNET	0.750	0.485
RD → EPS	2.692	0.092	RD → EPS	2.692	0.092
EPS → RD	2.526	0.105	EPS → RD	2.526	0.105
TRADE → EPS	0.195	0.825	TRADE → EPS	0.195	0.825
EPS → TRADE	0.674	0.521	EPS → TRADE	0.674	0.521
RD → INTERNET	2.948	0.076	RD → INTERNET	2.948	0.076
INTERNET → RD	3.413	0.053	INTERNET → RD	3.413	0.053
TRADE → INTERNET	2.597	0.099	TRADE → INTERNET	2.597	0.099
INTERNET → TRADE	0.578	0.570	INTERNET → TRADE	0.578	0.570
TRADE → RD	0.845	0.444	TRADE → RD	0.845	0.444
RD → TRADE	2.824	0.083	RD → TRADE	2.824	0.083

***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$

no causality between EPS and GG. In contrast, unidirectional causality exists from ET to GG, and from AT to GG.

Conclusion and implications

Green economic growth has recently got popularity, representing the economic growth achieved with the help of green technological innovations energy-efficient and carbon-free production techniques. Green growth has been widely recognized as a major factor in mitigating carbon emissions and preserving energy. In recent times, policymakers and economists advocated using environmental-related rules and regulations as a crucial complementary factor in decoupling economic growth and carbon emissions. They argued that economic factors alone are not enough to attain green and sustainable economic growth, but strictness in environmental policy stringency is also very important to increase the efficacy of other mitigating measures. The literature suggests that countries with strictness in environmental policy stringency complement other mitigating measures enjoy a more clean environment. As an emerging economy, China heavily relies on energy, particularly non-renewable energy sources, for long-term economic growth. However, the pressure on China is mounting worldwide to decouple economic growth and carbon emissions. Therefore, the focus of policymakers in China has shifted to green economic growth. Hence, this study aims to investigate the impact of environmental, technological innovations, and environmental policy stringency on green economic growth in China. The empirical analysis of the study is based on the ARDL model.

The estimates from the ARDL model confirm that the estimate of environmental technology positively impacts green economic growth both in the short and long run. In the robust model, the estimates of all technologies appeared to be significantly positive in the short and long run. Conversely, the estimated coefficients of environmental policy stringency, in the basic and robust model, have only negatively impacted the green economic growth in China in the short run. In the long term, the environmental policy stringency has not shown any significant impact on green economic growth in China in the basic and robust model. The estimates of Trade and Internet also appeared to be significantly positive in the short and long run in both models.

The results are essential to draw some policy guidelines. Policymakers in China should focus on implementing environmental rules and regulations with great caution because strictness in environmental policy can correct the environment but can increase the manufacturing cost of the firms and reduce their productivity that will eventually negatively impact the economic growth. To achieve green economic growth, government should try to increase the role of environmental technologies in manufacturing and energy sectors that can decouple economic growth and carbon emissions. Environmental technologies can reduce production-driven carbon emissions, a significant factor in achieving economic growth. Therefore, policymakers should encourage investment in environmental technologies, research and development, and renewable energies.

The major limitation is that the study is done for the aggregate national level of China; however, in future studies, the analysis could be extended for provinces of China. Due to complex practices of green growth, some other factors should be considered in addition to environmental policy stringency and environmental technologies such as green credit, green investment, environmental regulations, and green fiscal spending. In future research, the same objective can be replicated for other countries and regions of the world. Future studies can adopt an asymmetric approach for detecting the positive and negative shocks of environmental stringency policy and environmental technologies on green growth.

Author contribution This idea was given by Li Chen. Li Chen and Papel Tanchangya analyzed the data and wrote the complete paper, while Li Chen read and approved the final version.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval Not applicable.

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

Consent to publish Not applicable.

Competing interests The authors declare no competing interests.

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