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Does eco-innovation and green investment limit the CO2 emissions in China?

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ABSTRACT

The continuous upsurge in worldwide economic development and human activities has intensified CO2 emissions that highlighted the significant role of eco-innovation and green investment in curbing CO2 emissions. The study aims to explore the impact of eco-innovation and green investment on CO2 emissions by using the China dataset for time period 1990–2019. The study adopts the ARDL approach. The study used two proxies to determine the impact of eco-innovation, namely environment-related technologies and patents. The empirical estimates of the ARDL approach confirm the negative impact of eco-innovation and green investment on CO2 emissions confirming that these determinants result in limiting CO2 emissions in China. Based on these findings, the study suggests strengthening environmentally friendly policies and the advancement of green investment to mitigate CO2 emissions.

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1. Introduction

According to Kyoto Protocol 1997 and Paris Agreement 2015, the oil-exporting economies pledge to increase global warming and reduce greenhouse gases (GHG) and environmental quality down. It is imperative to indicate that the largest emitters of the world are supposed to have a universal contract in place to fight against environmental pollution and climatic changes (Cohen et al., 2018). Many policymakers and researchers have tried to explore effective ways to mitigation of worldwide pollution emissions. Several studies investigated the association between energy consumption and carbon emissions (Zhang & Cheng, 2009), however, very limited research is done to explore the linkage between eco-innovation and carbon emissions. Several studies explored the validity of the EKC hypothesis and reported mixed findings regarding GDP and environmental degradation association (Apergis & Ozturk, 2015).

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In a recent study, Churchill et al. (2019) investigated the association between eco-innovation measured by research and development and carbon emissions for G-7 economies and suggested that this nexus is time-varying. Energy usage can be controlled by eco-innovations, thus carbon emissions can be reduced by the adoption of technological innovations for a cleaner environment (Dinda, 2004; Wang et al., 2020). Increasing investment in eco-innovations is likely to enhance environmental quality and reduction in CO2 emissions. The nexus between R&D and CO2 emissions has been explored by Lee and Min (2015) and Fernández et al. (2018). But these studies did not find evidence to report that eco-innovations result in reducing carbon emissions. Another strand of studies investigates the association between real GDP and eco-innovations, some other studies explored the linkage between eco-innovations and economic growth. Investment in eco-innovations can be an imperative factor that initiates advancement in innovative technologies for green production and clean environment. Grossman and Helpman (1994) denoted that eco-innovation is an engine for economic development.

However, there is still debate among researchers on the issue of eco-innovation investment in economic growth and energy sector. As a higher level of eco-innovations raises energy usage and enhances economic development, and lower levels of eco-innovations reduces economic development and increase carbon emissions. Some other studies reveal that eco-innovations simultaneously enhance clean energy usage and environmental quality (Acemoglu et al., 2012).

Besides economic development, the protection of climatic wellbeing is readily recognized as an imperative aspect of the sustainable development of worldwide economies. Resultantly, aggravating inclinations towards worldwide volumes of pollution emissions has attained attention amongst policymakers and environmentalists. Previous studies have referred to financial development (Charfeddine & Khediri, 2016), FDI and urbanization (Li et al., 2022), appropriate government policy (Ullah et al., 2021), and to green investments (Krushelnytska, 2019) as key determinants having the capacity to affect the CO2 emissions inclinations. Over the last few decades, the financial sector started paying attention to green investments for the attainment of sustained environment (Khalil & Nimmanunta, 2021). Green financial investments can support in achieving a green environment (Sachs, 2015). Financial markets and intermediaries have designed several green financial instruments like climate credit cards, express loans for small business organizations, 'go green' auto loans, climatic home equity programs, green loans for commercial building, green home mortgages, and green bonds. Green investments connect the business and financial world with eco-friendly behavior (Scholtens, 2017). However, very limited studies have linked green investment with environmental degradation.

Scholtens (2009) explored the association between the social responsibility of green financial institutions and investments. Jia et al. (2018) denoted that green financial investment is an efficient way to mitigate environmental pollution. Green finance specifically encourages investments in innovations and new technologies including renewable energy reduction (Rexhäuser & Löschel, 2015). Wang and Zhi (2016) reported that sustainability of the environment can be attained through increasing financial investment in solar energy. Previous studies did not take into consideration the association between green bonds and carbon emissions. Green bonds are long-term instrument of green financial investment that is used to finance such projects that are eco-friendly and lead to a reduction in carbon emissions. Green bonds are used to fund clean transport projects, clean water, and solar energy projects.

Sachs et al. (2019) noted that the Sustainable Development Goals (SDG) of the United Nations have also highlighted the role of green investment for a sustained environment. The agenda of SDG highlighted the applicability of investment in green projects for the collective attainment of other goals of the agenda. For example, the 12th goal of SDG aims to encourage green financial investment to ensure climate-resilient and low-carbon transitions of the worldwide economies. Consequently, the need for green investment is considered to be helpful for the mitigation of CO2 emissions and climatic adversities (Tolliver et al., 2019). Moreover, 7th goal of SDG consider the role of green investment for the development of energy infrastructure and clean energy. Thus, green financial investments can be projected to raise the transition of renewable energy all over the world (Lyeonov et al., 2019). Moreover, 11th goal of SDG aims to encourage green investments for the creation of green spaces to guarantee sustainable communities and cities (UNDP, 2020). Additionally, green investment can support in the attainment of 12th goal of SDG by confirming responsible production and consumption practices. The green investments can be directed toward the management of wastes and chemical disposals and significantly plummeting waste production involved within the production and consumption processes (UN, 2017).

Our study has identified various shortcomings in existing studies (Huang et al. 2021; Li et al., 2022; Sun et al., 2021; Shen et al., 2021; Tao et al., 2021; Ullah et al., 2021) and tries to fill the vacuum accordingly. Previous studies did not integrate the role of green investment on CO2 emissions in China at the national level. However, green investment is a core determinant that boosts the process of green growth. Previous studies have investigated the nexus between eco-innovation and CO2, and green investment and CO2 separately. To the best of the authors' knowledge, none of the studies have carried out the empirical examination by incorporating the simultaneous impact of environmental technological innovation and green investment on CO2 in a single model framework. Our study is modeling the role of eco-innovation and green investment in the carbon emissions model and reported the impact for long-term and short-term as well. China is a fast-growing economy, thus facing the issue of increasing carbon emissions. There is a dire need to explore such determinants that can significantly limit CO2 emissions. From this perspective, the current study will help in environment-related policy designing.

In order to fill this existing gap, the current study aims to examine the impact of eco-innovations and green investment on carbon emissions in China. The study makes a contribution in the pertaining stock of literature in many ways. The study considers eco-innovation and green investment as major determinants for limiting CO2 emissions, these aspects were ignored in current literature. The findings obtained from our study will help in designing policies for green financing, eco-innovation, and environmental sustainability. Another contribution of this study is that it employs the recently developed ARDL approach for exploring the short-term and long-term impact of green investment and eco-innovation on carbon emissions. Additionally, this is a first-ever study that captures the role of green investment and eco-innovation simultaneously in limiting carbon emissions in China at the national level. The role of these kinds of determinants of carbon-neutrality is required to maintain the environmental sustainability. The findings of the study will deliver key insights for the development of eco-innovation, promotion of green investment, and adoption of eco-friendly policies to combat carbon emissions.

2. Literature review

The continuous upsurge in human activities and economic development throughout the world has augmented CO2 emissions and emphasized the significance of the carbon neutrality objective around the globe (Ullah et al., 2021). Resultantly, the environmental deterioration problem becomes worsening day by day (Sohail et al., 2021). The prevailing literature highlighted several determinants that contribute to the improvement of environmental, economic, and social sustainability. Such as green technology (Wei et al., 2022), renewable energy (Sohail et al., 2021), green ideology and blockchain technology (Usman et al., 2021), and consumption of fossil fuel (Magazzino, 2016a,b; Magazzino et al., 2021). Various strategies have been adopted to control environmental pollution, among them; eco-innovation and green investment are more fundamental to combat carbon emissions (Mele & Magazzino, 2020; Wei & Ullah, 2022). In the leading economies of the world, eco-innovation and green investment are adopted as carbon neutrality strategies to improve the performance of the environment (Tao et al., 2021). Eco-innovation is considering the efficiency of the environment (Machiba, 2011). Eco-innovations are a cost-effective approach and help in the reduction of CO2 emissions. Eco-innovation augments the sustainability of the environment and economic performance (Magazzino & Falcone, 2022). Additionally, eco-innovation provokes renewable energy consumption and enhances the quality of the environment (Ji et al., 2021).

The importance of eco-innovation for combating environmental deterioration has been discussed in various studies (Ullah et al., 2021; Chien et al., 2022). The study done by Beltrán-Esteve and Picazo-Tadeo (2017) explored the association between eco-invention and low-carbon consumption and reported that eco-innovation boost environmental performance. Mensah et al. (2018) reported that eco-invention boosts the association between market effectiveness and power consumption. Conversely, Wurlod and Noailly (2018) reported a negative influence of eco-innovation on carbon emanation. However, some studies highlight the positive role of eco-innovation in the mitigation of carbon emissions through the significant reduction in consumption of non-renewable energy sources. For instance, Chen et al. (2022) reported that eco-innovation results in a reduction of non-renewable energy sources consumption which leads to less carbon emissions. Mensah et al. (2018) reported a similar association between eco-innovation and CO2 emissions in the case of OECD economies, while the same findings are also denoted by Wang et al. (2020). Wang et al. (2020) denoted that eco-innovation can be used as an important determinant to control GHG emissions. Sun et al. (2021) explained that eco-innovation moderates carbon emissions as green innovation acts as a mediating determinant for falling carbon emissions. In G7 economies, Ding et al. (2021) reported that eco-innovation significantly influences consumption-based carbon emissions. Ozturk and Ullah (2022) denoted that developing economies are highly dependent on non-renewable sources of energy and eco-innovation can lead to an upsurge in pollution emissions. However, some studies have reported a positive impact of green innovation on carbon emissions (Lee & Min, 2015).

The prevailing literature has also identified green investment as an important determinant to combat CO2 emissions. The green investment concept covers environmental, climate, and carbon financing. Most specifically, climate financing aims to mitigate climate change that tends to a low-carbon environment (Richardson, 2009). Zahan and Chuanmin (2021) study examines the contribution of green investment in determining CO2 emissions and reported a significant fall in carbon emissions due to increases in green financing. Shen et al. (2021) also examine the impact of green investment and reported that green investment helps in the improvement of a sustainable environment and environmental quality. Additionally, it is reported that green investment in the renewable energy sector can help in achieving the objective of carbon neutrality. Huang et al. (2021) investigated the impact of green investment in controlling CO2 emissions and reported that green investment can enhance environmental performance through the private-public partnership. However, Li et al. (2022) denoted the need for enhancing the contribution of private investment for the achievement of sustainable growth. It is argued that the private sector is more capable to finance environment-related heavy projects. In summary, most of the prevailing studies report a positive impact of green investment on environmental performance; however, there is disagreement on proxy measures of green investment. In terms of eco-innovation, existing studies provide a mixed outcome. One strand of literature is showing the positive impact of eco-innovation on CO2 emissions, while the other strand of literature is reporting the negative impact of eco-innovation on CO2 emissions. Thus, there is a need to further explore this area in order to achieve more clear outcomes. Hence, the present study tries to examine the role of eco-innovation and green investment in limiting carbon emissions in China.

2.1. Model and methods

In the post-industrialization stage, there is a possibility to undertake eco-friendly investment that is considered as the 'technique effect' under the proposition of EKC (Murshed et al., 2020). Based on this theoretical foundation, green investment is considered an important determinant that can solve the issue of carbon emissions throughout the globe. Green investment not only controls the emissions of pollution in the atmosphere but is also intended to trigger the renewable energy evolution that can be obtained through green technological investments and eco-innovation (Li et al., 2022). Our study also gets assistance from the study of Dietz and Rosa (1997) IPAT model that captures the determinants of CO2 emission. Undoubtedly, environmental innovation and green investment play an important role in economic development. It is noted that environmental innovation and green investment help raise productivity, reduce resource costs, and lead to positive effects on environmental quality (Wang et al., 2020; Li et al., 2022). New emerging literature showed the link between environmental innovation, green investment, and CO_2 emissions (Fethi & Rahuma, 2019; Shen et al., 2021; Wang et al., 2020; Li et al., 2022). They noted that green innovation and investment not only directly affect human development but also positively effect on the environment (Shen et al., 2021). However, this study aims to investigate the impact of environmental innovation and green investment on CO_2 emissions in China. Following the previous studies (Li et al., 2022; Shen et al., 2021; Tao et al., 2021; Ullah et al., 2021), we have developed a model to explore the nexus between eco-innovation, green investment, and CO2 emissions in China. Following the literature, we have constructed equation (1).

$$CO_{2,t} = \alpha_0 + \alpha_1 EI_t + \alpha_2 GI_t + \alpha_3 GDP_t + \alpha_4 FD_t + \mu_t \quad (1)$$

Where carbon dioxide emissions (CO2) depends on environmental innovation (EI), green innovation (GI), GDP per capita (GDP), financial development (FD), and randomly distributed error term (μ_t). In addition, increasing environmental innovation may lead to an increase in energy efficiency and renewable energy projects and as a result, improves environmental quality. We expect an estimate of α_1 to be negative, because environmental innovations boost environmental quality by reducing CO2 emissions in China. The green investment promotes green growth by lowering CO2 emissions, we expect an estimate of $\alpha 2$ to be negative. Equation (1) only provides results for the long run. We have to modify equation (1) into error correction format so that we will be able to get long-run and short-run coefficient estimates. Thus, equation (1) can be transformed as:

$$\begin{aligned}\Delta CO_{2,t} = \pi + \sum_{p=1}^{n1} \pi_{1p}\ \Delta CO_{2,t-p} + \sum_{p=0}^{n2} \pi_{2p}\ \Delta EI_{t-p} + \sum_{p=0}^{n3} \pi_{3p}\ \Delta GI_{t-p} \\ + \sum_{p=0}^{n4} \pi_{4p}\ \Delta GDP_{t-p} + \sum_{p=0}^{n5} \pi_{5p}\ \Delta FD_{t-p} + \beta_1 CO_{2,t-1} + \beta_2 EI_{t-1} + \beta_3 GI_{t-1} \\ + \beta_4 GDP_{t-1} + \beta_5 FD_{t-1} + \lambda ECM_{t-1} + \mu_t\end{aligned} \quad (2)$$

Equation (2) is the representation of the ARDL model that is developed by Pesaran et al. (2001). This model provides both short-term and long-run coefficient estimates. In equation (2), the first differenced (Δ) variables deliver short-term estimates, while the coefficient estimates associated with β_2-β_5 deliver long-run estimates. The findings of F-test confirm the cointegration association among variables in the long-run. While the (λ) coefficient provides information about the speed of adjustment towards equilibrium and the expected sign for this coefficient must be significant and negative. Another advantage of this model is that there is no need for pre-unit root testing as this approach can automatically consider the integration of variables and choose a mixture of level and first difference series. To determine the integration order of variables, unit root properties are tested with ADF and PP, and

Table 1. Data and sources.

Variables	Symbol	Definitions	Mean	Std. dev.	Sources
CO2 emissions	CO2	CO2 emissions (kt)	15.46	0.562	World bank
Environment technology	ET	Environment-related technologies	9.512	1.683	OECD
Patents	Patents	All technologies (total patents)	11.96	1.543	OECD
Green investment	GI	Nuclear, renewables, and other (quad Btu)	1.543	0.901	OECD
GDP per capita	GDP	GDP per capita (constant 2010 US$)	7.884	0.754	World bank
Financial development	FD	Domestic credit to private sector (% of GDP)	4.741	0.201	World bank

Source: Author's calculation.

to confirm the chance of ARDL. Additionally, this approach can deliver efficient coefficient estimates even in the case of small number of observations. To test the model's validity, reliability, and robustness, we employ the Lagrange Multiplier (LM) serial correlation test, Breusch–Pagan–Godfrey (BP) heteroskedasticity test, and Ramsey's RESET test functional form test (Bahmani-Oskooee et al., 2020). After examining the short and long-run relationship between concern variables, the causality between the variables will be tested by the Granger causality test (Granger, 1969).

2.2. Data

The study aims to explore the impact of eco-innovation and green investment on CO2 emissions in case of China over the period 1990–2019. Table 1 displays detailed information about abbreviations, definitions of variables, and their sources. To investigate the objective, dependent variable is CO2 emissions, independent variables are environment technology, patents, and green investment. In this study, CO2 emission is measured by carbon dioxide emissions. Eco-innovation is measured by environment-related technologies and patents in terms of all technologies (Wang et al., 2020; Hussain et al., 2021). The study also incorporates the role of GDP per capita and financial development as control variables. Where GDP per capita is measured at constant 2010 US$ and financial development is measured by domestic credit to the private sector as percent of GDP. Data for environmental technology, patents, and green investment is sourced from OECD and data for GDP per capita, financial development, and CO2 emissions is extracted from the World Bank. The mean of CO2, ET, patents, GI, GDP, and FD are 15.46 kt, 9.512%, 11.96, 1.543 quad Btu, 7.884$, 4.741%, respectively.

2.3. Empirical results

As a preliminary analysis, the study confirms the stationarity properties of data. For that purpose, the study employs ADF and PP unit root tests. Table 2 demonstrates the findings of both unit root tests. It is obvious from the outcomes of both unit root tests that there exists mix order of integration among variables. As few variables are stationary at level, means integrated at I(0); and remaining become stationary at first difference, i.e., integrated at I(1). On the basis of these properties, the study adopted the ARDL regression technique for empirical investigation. In model 1, the study first assumes that environment-related technologies exert a symmetric effect on CO2 emissions. Afterward, in order to check the robustness of the findings, in second model the study explores that patents exert a symmetric impact on CO2 emissions. Table 3

Table 2. Unit root testing.

	ADF			PP		
	I(0)	I(1)	Decision	I(0)	I(1)	Decision
CO2	−0.649	−2.714*	I(1)	−0.624	−2.849*	I(1)
ET	−1.756	−3.815***	I(1)	−1.741	−3.676**	I(1)
Patents	−2.197	−3.722***	I(1)	−1.966	−3.661**	I(1)
GI	1.023	−5.824***	I(1)	1.302	−5.897***	I(1)
GDP	−2.961*			−2.789*		
FD	−0.414	−5.226***	I(1)	−0.272	−5.257***	I(1)

Note: ***$p < 0.01$; **$p < 0.05$; and *$p < 0.1$ Unit root tests critical values are −3.68 (1%), −2.97(5%), and −2.62(10%).
Source: Author's calculation.

Table 3. CO2 emissions estimates.

	Basic model				Robust model			
Variable	Coefficient	Std. error	t-statistic	Prob.	Coefficient	Std. error	t-statistic	Prob.
Short-run								
D(ET)	−0.450**	0.214	2.100	0.060				
D(ET(-1))	0.263	0.171	1.542	0.152				
D(ET(-2))	−0.222	0.210	1.059	0.312				
D(PATENTS)					−0.407**	0.192	2.118	0.071
D(ET(-1))					−0.205	0.21	0.957	0.371
D(GI)	−0.135***	0.038	3.469	0.002	−0.025**	0.012	2.046	0.079
D(GI(-1))	0.046	0.159	0.292	0.775				
D(GI(-2))	0.198	0.128	1.552	0.149				
D(GDP)	1.891**	0.860	2.197	0.041	2.160***	0.653	3.307	0.004
D(FD)	0.002	0.154	0.010	0.992	0.129	0.162	0.799	0.434
D(FD(-1))	−0.085	0.160	0.531	0.606	0.265	0.185	1.448	0.191
D(FD(-2))	0.458***	0.159	2.880	0.015				
Long-run								
ET	−2.053**	0.991	2.071	0.063				
PATENTS					−0.336**	0.148	2.273	0.033
GI	−0.622*	0.340	1.828	0.095	−0.730***	0.183	3.980	0.000
GDP	2.741	1.799	1.523	0.156	1.209***	0.427	2.830	0.010
FD	−1.572***	0.600	2.622	0.024	−0.321	0.452	0.711	0.485
C	25.98***	7.982	3.256	0.008	7.151***	2.403	2.976	0.008
Diagnostics								
F-test	5.223***				4.888***			
ECM(-1)	−0.464***	0.169	2.745	0.019	−0.402***	0.147	2.739	0.013
LM	0.375				1.425			
BP	0.689				1.152			
RESET	0.652				0.145			
CUSUM	S				S			
CUSUM-sq	S				S			

Note: ***$p < 0.01$; **$p < 0.05$; and *$p < 0.1$.
Source: Author's calculation.

displays the short-run and long-run empirical outcomes of both ARDL models. We conduct the Granger causality test in Table 4 which is required for confirming the relationship of concern variables.

In Table 3, the long-run coefficient estimates of the basic model reveal that environmental technologies have a significant and negative impact on CO2 emissions confirming that eco-innovation contributes significantly in reducing CO2 emissions in China. The coefficient estimates reveals that due to 1 percent increase in environment technologies, CO2 emissions reduces by 2.053 percent in the long-run. On the basis of the findings of the study, it is obvious that pollution emissions can be controlled by adopting eco-friendly technologies for a clean environment and such technological

Table 4. Causality estimates.

Null hypothesis:	F-Stat	Prob.	Decision	Null hypothesis:	F-Stat	Prob.	Decision
ET →CO2	3.612	0.043	Yes	PATENTS →CO2	2.497	0.104	Yes
CO2 →ET	0.441	0.649	No	CO2 →PATENTS	0.401	0.675	No
GI →CO2	1.230	0.311	No	GI →CO2	1.230	0.311	No
CO2 →GI	2.805	0.081	Yes	CO2 →GI	2.805	0.081	Yes
GDP →CO2	3.261	0.057	Yes	GDP →CO2	3.261	0.057	Yes
CO2 →GDP	3.608	0.043	Yes	CO2 →GDP	3.608	0.043	Yes
FD →CO2	1.834	0.182	No	FD →CO2	1.834	0.182	No
CO2 →FD	6.589	0.006	Yes	CO2 →FD	6.589	0.006	Yes
GI →ET	0.157	0.856	No	GI →PATENTS	0.003	0.997	No
ET →GI	3.408	0.051	Yes	PATENTS →Cause GI	1.750	0.196	No
GDP→ET	2.762	0.084	Yes	GDP → PATENTS	2.283	0.125	No
ET →GDP	5.134	0.014	Yes	PATENTS → GDP	3.134	0.063	Yes
FD →ET	0.110	0.896	No	FD → PATENTS	0.116	0.891	No
ET →FD	2.599	0.096	Yes	PATENTS →FD	3.248	0.057	Yes
GDP →GI	5.051	0.015	Yes	GDP →GI	5.051	0.015	Yes
GI →GDP	0.063	0.939	No	GI →GDP	0.063	0.939	No
FD →GI	0.321	0.729	No	FD →GI	0.321	0.729	No
GI →FD	3.206	0.059	Yes	GI →FD	3.206	0.059	Yes
FD →GDP	0.601	0.557	No	FD →GDP	0.601	0.557	No
GDP →FD	11.60	0.000	Yes	GDP →FD	11.60	0.000	Yes

Note: ***$p < 0.01$; **$p < 0.05$; and *$p < 0.1$.
Source: Author's calculation.

innovations largely occur due to large scale investments in research and development (Alvarez-Herranz et al., 2017; Fethi & Rahuma, 2019). The findings of our study are in line with the porter hypothesis. Porter's hypothesis claimed that eco-innovation reduces environmental pollution and improves environmental quality. Mensah et al. (2018) denoted that ecological innovations are a crucial driver of economic growth. Several studies report that eco-innovations can mitigate carbon emissions without harming health outcomes (Brock & Taylor, 2010). A lot of researchers argue that environmental innovation is a key element for climatic degradation and denote that technological innovation is an efficient way to convert the economic structure of the economy and limit carbon emissions (Lin & Zhu, 2019). Technological innovation capably modifies the production process and influences the environment. However, Yii and Geetha (2017) study reported a negative association between environmental innovation and carbon emissions.

Our findings get back from Wang et al. (2020), who argued that eco-innovation promotes economic growth and reduces harmful impacts on the environment. Eco-innovation enhances the performance of the business sector as green technology reduces the negative influence of business activities on human health, natural resources, and the environment. Fernández et al. (2018) study support our findings by arguing that eco-innovation can mintage environmental pollution and help in reducing overexploitation of natural resources as the process of eco-innovation consume less resources and generate energy-effective activities. Thus, it brings beneficial impacts on environmental performance. Chien et al. (2022) study backed our findings by arguing that eco-innovation stimulates enterprises to invest more that in turn enhances the consumption of eco-friendly technologies in the process of production. Green innovations can help in attaining SDG12 by confirming responsible production and consumption practices. Green innovation stimulates the use of renewable energy sources. Innovation helps in waste management, waste processing, recycling, recycling, water sanitation, and adaptation and mitigation of climatic change.

Findings also reveal that green investment has negative impact on CO2 emissions in the long-run, confirming the improvement in environmental quality. It is obvious from coefficient estimate that due to 1 percent upsurge in green investment, CO2 emissions decline by 0.622 percent. This finding is reliable with Shen et al. (2021) and Shijie et al. (2022), who noted that green investment referred to making an investment in the industrial sector to combat environmental pollution. Investment in R&D can be an imperative determinant of innovative technology for a green environment. Our results are backed by Li et al. (2022), who denoted that green investment can stimulate low-carbon transition in energy structure that efficiently facilitates a decline in carbon emissions. Specifically, green investment reduces carbon emissions through improvement in carbon intensity and by introducing low-carbon and clean production technology. Thus, green investment brings a beneficial impact on the environment and reduces carbon emissions.

In the long-run, financial development exert a significant positive impact on CO2 emissions but GDP has an insignificant impact. Findings reveal that a 1 percent increase in financial development leads to 1.572 percent decrease in CO2 emissions. The short-run findings of environment-related technologies and green investment confirm a significant negative impact on CO2 emissions with coefficient values 0.450 and 0.135 percent, respectively. In the short-run and long-run environmental technologies and green investment have a negative impact on carbon emissions in China but environmental technologies produce a larger contribution as compared to green investment. In terms of control variables, the short-term findings reveal that GDP leads to increase CO2 emissions with a magnitude of 1.891 percent, but FDI has no impact on CO2 emissions at the current time.

The long-run coefficient estimates of the robust model expose that patents and green investments both variables produce negative impacts on CO2 emissions confirming the improvement in the environmental quality. The coefficient estimates reveal that a 1% increase in patents and green investment variables lead to 0.336% and 0.730% decline in CO2 emissions in the long-run. GDP has a positive and significant impact on CO2 emissions revealing that 1% increase in GDP leads to 1.209% increase in CO2 emissions. In contrast, financial development produces no significant impact on CO2 emissions in the long-run. In the short run, patents and green investment have a significant and negative impact on CO2 emissions confirming the significant contribution of both determinants in limiting CO2 emissions in China. GDP has a positive impact and financial development has an insignificant influence on CO2 emissions in the short-run. The findings of both models confirm that eco-innovation and green investment both play a significant role in limiting CO2 emissions in the case of China.

Table 3 displays the outcomes of diagnostic tests for basic and robust ARDL models. Long-run cointegration exists as validated through the findings of ECM statistics and F-test statistics. Autocorrelation and heteroskedasticity are not detected in the diagnostic estimates as confirmed through the results of LM and BP tests. Ramsey RESET tests confirm the overall goodness of fit of models and error terms in both models are normally distributed. Models are stable as shown by the outcomes of both CUSUM tests. Granger causality outcomes are reported in Table 4. It is found that the association between eco-innovation and CO2 emissions is unidirectional, which implies that environmental technology and patents significantly cause carbon emissions. The association between green investment and CO2 emissions is also unidirectional in China.

3. Conclusion and policy recommendations

This study aims to explore the role of eco-innovation and green investment in limiting CO2 emissions in China for time period 1990-2019. The study employed the ARDL technique for deducing empirical outcomes. The study adopted a variable-based approach for robustness. For that purpose, two proxy measures are adopted to explore the role of eco-innovation, such as environmental-related technologies and Patents in terms of all technologies. In the basic model, the study examines the impact of environment-related technologies and green investment on CO2 emissions; while in the robust model, the study explores patents and green investment impact on CO2 emissions. Long and short-run findings of the basic model infer that environmental technologies and green investment produce a significant negative impact on CO2 emissions confirming that these determinants significantly reduce CO2 emissions in China. Findings also reveal that environmental technologies contribute largely to limiting CO2 emissions as compared to green investment. Findings obtained from robust models are in accordance with the results obtained from the basic model; however, coefficient values are different in magnitude.

This study put forward some important policy recommendations. It is suggested that policymakers should immediately focus on maximizing the impact of environmental innovation for the sake of protecting and promoting the natural environment. The government of China should take serious initiatives to transform policies in favor of environment-related technologies and ecological innovation and acquire spending to promote the initiative for green investment. Such environment-friendly policies, ecological innovations, and green investments must confirm that social and environmental issues can be solved while enhancing sustainable development. With a green investment strategy, more and more designs on technology and innovation can be produced that will be capable to manage uncertainties and risks attached to technological developments and emerging innovations. It is also recommended that government should enhance fiscal spending to promote green financial growth and utilize fiscal expenditures for credit financing for green securities, green credit, and green investment purposes. The government of China should enhance its green financial setup, highlight green activities, and simplify the low-carbon, ecological, and green industrial utilization process. The Chinese government should implement green investment policies in underdeveloped areas and reduce trading thresholds and issuance for green securities and green bonds. Based on findings, this study also suggests that high-polluting economies should promote green investment to protect their environment.

The analysis is only based on China; hence, the implications of the study have limited scope. This study has examined the role of eco-innovation and green investment on carbon limiting targets in China, but it ignores impacts on green growth. The present study has so far explored the linear association among variables, in future research this analysis should be performed by using the NARDL modeling approach. A similar study is also conducted for other high-polluted economies by using a non-linear ARDL approach for better policy outcomes.

Disclosure statement

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