



Interrelationship among environmental policy stringency, financial globalization in OECD countries, and CO₂ emission with the role of technological innovation and financial development

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Abstract

The study examines the nexus between financial globalization (FG), environmental policy stringency (EPS), financial development (FD), and technological innovation (INV) on CO₂ emission with moderating effect of technological innovation on financial development and environmental degradation in 36 OECD countries with an updated dataset from the period of 1990 to 2020 using PMG (Pooled mean group) panel ARDL method. The results of stationarity tests; (Levin, Lin, and Chu test; ADF Fisher test) demonstrate that selected variables are stationary at level I(0) and first difference I(1); this confirms that PMG estimator can be employed. Cointegration tests indicate that cointegration exist among the variables. The empirical findings of the PMG estimator indicate that financial globalization and CO₂ are negatively associated with each other. While financial development, environmental policy stringency, and technological innovation have positive impact on environmental degradation in OECD countries. Furthermore, technological innovation strengthens the association between financial development (FD) and environmental degradation (CO₂ emission). In order to accelerate economic growth, the study recommends that policymakers should implement environmental policies to achieve low-carbon mechanisms, such as green infrastructure and renewable energy systems, which reduce energy consumption and greenhouse gas emissions. Therefore, it is crucial that the selected OECD countries should develop programs that increase awareness of the risks of carbon emissions.

Keywords CO₂ emission · Financial development · Financial globalization · Technological innovation · Environmental policy stringency · OECD

Introduction

From the last several decades, social scientists, environmental economists, and energy specialists have agreed that environmental changes have detrimental impact on life and wellbeing of human (Tahir et al. 2021). Countries are confronting major environmental issues because of the dominant role of global greenhouse gas (GHG) emissions (Yang

et al. 2021). To minimize severe environmental catastrophe, researchers, policymakers, and governments are focusing on the reduction of increasing GHG emissions which are the primary drivers of the global warming. Global environmental changes are accountable for deforestation, droughts, rising sea levels, storms, floods, and output volatility all over the world (Majeed and Mazhar 2019; Altinoz et al. 2020). Such events have great influence on human lives, infrastructure, agricultural land, and natural resources.

Environmental factors have prompted global strategies for sustainable development. Over the last 15 decades, the implications of rising global temperature (Murshed et al. 2022a, b) on life have become clear. The emission of CO₂ increased from 16 to 36 m from 1980 to 2018 (Danish et al., 2018). Energy consumption around the globe is anticipated to reach 28%, implying harmful impact on the atmosphere. Rasoulinezhad et al. (2020) reveal that 2015 was warmest year of the past four decades. In 2019, the fire in Amazon

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increased by 83% (Pham et al. 2021), which endangered millions of species.

With the industrial revolution, industrial production has expanded dramatically. As a result, energy requirements have grown significantly. Substantial increase in fossil fuel consumption have occurred as a result of global production and population growth (Ren et al. 2021; Umar et al. 2021). Considering this, many scholars considered the effect of economic growth, FD, FG, and INV in light of deteriorating environmental quality and increased awareness of importance of improving and protecting environmental quality (Apergis et al. 2021; Jahanger et al. 2022). Existing literature has highlighted several determinants of environmental degradation and suggested solution to protect global environment. Certain restrictions on the production of greenhouse gas emissions have been imposed under Kyoto Protocol agreement (1997) and implemented in 2005 (Occhipinti and Verona 2020). Therefore, according to the United Nations, one of the core goals of sustainable development growth is “Clean Energy.”

Globalization is an aspect of trade development and financial openness that increases the attractiveness of higher R&D associated with foreign direct investments (Dauvergne 2008). Thus, globalization can have an impact on sustainability. Dreher (2006) created globalization index, which comprises of social, economic, and political factors. Initially, it comprised a combination of social indices and economic and political factors; later Gygli et al. (2019) added some other indices such as financial globalization and trade globalization to check the impact of each factor on environment. As per financial globalizations index, countries are ranked on the basis of de facto and de jur components (Kılıçarslan and Dumrul 2018). De factors include international debt, FDI, portfolio investment, overseas income payment, and funds while de jur factors include investment agreements and restrictions. Thus, this index allows to differentiate which country is more financially globalized than others (Sun et al. 2022).

The increasing economic activities stimulate manufacturing level and more population. A sound financial system makes feasible for individuals to obtain funds, which elevates the quality of life and stimulates economic growth (Saud et al. 2019), it also increases energy consumption and emission of GHGs. A developed financial system and availability of financial resources contributes in updated technological production processes (Apergis and Garzón 2020; Bello et al. 2021), which are more energy efficient and ecologically responsible that ultimately lower the environmental degradation. Furthermore, FD and liberalization of capital markets stimulate interactions between businesses, technological units to transfer green technology and R&D to the host country. Similarly, Majeed and Mazhar (2019) demonstrated that FD improves environmental quality through

fostering clean and advanced technology, promoting R&D programs, and delivering technical and financial support to businesses. However, they contend that such positive environmental consequences based on the objectives of financial sector to maintain a clean and protected environment.

The increase in CO₂ emission has substantial consequences for human lives, economic growth, and environmental deterioration (Aslam et al. 2022). Irrespective of CO₂ increase or decrease, and environmental degradation due to pollutants emissions has long-term effects on human life and economy of any country (Pan and Dong 2022). Thus, to prevent the negative impact on environment and global warming, proper energy policies are required to mitigate the effect of CO₂ emissions that harm the environment. Recently, environment stringency policy is attaining attention of researchers and environmentalists for the sustainable environment and CO₂ emission reduction, for instance, Sezgin et al. (2021). Due to rising concern of environmental degradation, many governments are attempting to find, recognize, and apply the appropriate policies for CO₂ emissions while sustaining economic growth that contributes in greater social welfare. OECD calculated EPS. The EPS indices is comprised of technology, market, and non-market-based policies (Kruse et al. 2022). For the sustainable environment, EPS play vital role in combating environmental degradation and promoting energy efficiency (Eugster 2021). In general, the issue of how economic activities damage the environment has gained attention in the literature. However, scientific evidence remains inconclusive and contradictory in order to build a comprehensive list of CO₂ emission predictors. However, all countries do not contribute equally in implementing environmental rules and regulations and thus rising rules do not appear to be helpful for environmental protection. Economic growth (EG) and environmental protection are important aspects of the present global debate. Technological innovation (IT) is essential for reducing CO₂ emissions as well as improving energy efficiency (Wang et al. 2020b). Furthermore, technical innovation is vital to the optimal utilization of energy resources (i.e., renewable and traditional) Additionally, to meet the demands of energy, INV improves the capability of renewable energy by providing more energy. Many studies demonstrate that technological innovation is very effective in reducing environmental deterioration and increase economic growth (Zhao et al. 2021).

Therefore, the eminent initiatives have been taken to reduce CO₂ emission and attain emission reduction targets in OECD countries. Promoting technological innovation has evolved as a commonly recognized method in OECD countries to combat environmental issues i.e., CO₂ emissions. Furthermore, the OECD countries have experienced unprecedented growth in technical innovation (Cheng et al. 2021). Environmental statistics (OECD 2020) shows that.

in 2015, the number of patents increased more than 1.5 times. Due to rapid development of technological innovation and its related carbon mitigating effect in OECD countries, different research studies examined the relationship of INV and CO₂ emissions in OECD countries (Zhao et al. 2021). However, the direct relationship of INV and environmental degradation has been examined in many studies, but Moderating impact of INV on the association of FD and CO₂ emission is ignored.

Despite the importance of environmental concerns, many studies evaluated the impact of different environmental determinants on environmental degradation but the studies on inter-relationship among financial globalization (FG), financial development (FD), environmental policy stringency (EPS), and CO₂ emission as well as moderating influence of INV on FD and CO₂ are limited. Thus, main objective of the current study is to conform to this paradigm by investigating the moderating influence of INV between FD and environmental degradation in 36 OECD member countries. The current study has two-folded contributions in existing research. Firstly, the study evaluated the direct impact of, FG, INV, FD, and EPS on environmental degradation (CO₂ emission). Secondly, this study also employs the moderation influence of INV between FD and CO₂ emission.

Furthermore, economic growth of any country is reliant on robust financial institutions, which facilitates businesses and individuals with loan at lower interest rates. This, in turn, increases energy demand and generates environmental issues. Countries are facing environmental degradation issues due to conventional industrialization and high consumption of fossil fuels. As technological ability, resource distribution, poor financial systems, initial investment in new projects, and less governmental support sometimes endanger mutual interest of countries. As a result, different energy sources must be utilized. This significant transformation needs several policy implications. Increasing fund flow enhance the economic performance and thus boost economic growth in developed countries where environmental policies are in effect, via renewable energy sources and energy consumption efficient technologies for both individuals and businesses without damaging environment. Understanding the complexities of environmental determinants may assist the governments and policy makers in making environmental decisions.

This study offers various essential environmental policies to improve environmental quality. Three aspects are significant in terms of economics, energy, and the environment; emission (i) development of financial institutions, (ii) FG and EPS, and (iii) the role of advanced environmentally friendly technologies in FD and CO₂. These aspects reveal that development of financial sectors significantly reduce environmental degradation through innovative technology.

For the sustainable environment strong environmental policies (i.e., imposing carbon tax) and financial globalization play significant role for environmental degradation.

The subsequent section presents the studies conducted on the environmental factors and environmental degradation followed by the data description and methodology in the “[Empirical models and data](#)” section. The study results and discussion are presented in the “[Results and discussion](#)” section. And the research conclusion is summarized in the “[Conclusion](#)” section.

Literature review

The increasing research has discussed numerous potential aspects i.e., political and economic effects, in order to examine the empirical correlation between various environmental determinants such as economic growth, FD, FG, EPS, and moderating role of INV. A review of the literature is conducted in order to build a logical model in the discourse of environmental determinants and environmental deterioration. Number of studies has been considered to be useful in analyzing the current status of literature in the context of EKC hypothesis (See; Khan et al. 2021a, b; Abbasi et al. 2022). Firstly, the current study focuses on the direct association between environmental determinants i.e., INV, FG, EPS, and FD and CO₂. Secondly, current research also evaluates the moderating influence of INV between FD and CO₂ emissions. Numerous research studies have been conducted over time to explore environmental degradation determinants employing various proxies such as CO₂ emissions (Kwakwa et al. 2018; Ahmed et al. 2021; Khan et al. 2022; Islam et al. 2022; Cao et al. 2022). However, depending on the proxies selected, the results of such research investigations have yielded contradictory conclusions.

Despite the importance of environmental concerns, an increasing number of researchers are investigating the effects of INV on CO₂ emission. Studies concluded that INV contributes significantly in environmental robustness (Liu and Bae 2018; Lin and Zhu 2019a, b; Wang et al. 2020b; Adebayo et al. 2022). Hence, when INV is combined with long-term environmental measures, it becomes necessary (Rahmen et al. 2022); Han et al. (2022) to improve the environmental quality and decrease environmental degradation. Numerous studies concluded various findings by examining the association between INV and CO₂ emission. Su et al. (2021) examined the effect of INV on environmental degradation by employing second generation statistical tests in BRICS countries. Lin et al. (2022), Huang et al. (2021), and Jin et al. (2022) demonstrated that both FD and INV contributes significantly in improving environmental quality.

Technological innovation (INV) significantly influences CO₂ emissions (Ahmed and Le 2021). Lin and Ma (2022)

checked the effect of INV on environmental degradation by employing panel methodology on Chinese data from 2000 to 2018. They concluded that INV in China reduces pollution. Moreover, Fan et al. (2018) evaluated the association of INV and CO₂ emission in India. Their study used FM-OLS and D-OLS techniques on quarterly data spanning from 1992 to 2015 and concluded that INV reduces CO₂ emissions in India. On the contrary, Adebayo and Kirikkaleli (2021) employed wavelet methods on quarterly data spanning from 1990 to 2015 to examine the nexus between INV and demonstrate that in Japan, technological innovation promotes CO₂ emission and thus deteriorates the environment.

INV and CO₂ emission are negatively related to each other, but INV can predict CO₂ emission in Africa (Dauda et al. 2021). The direct association of INV and environmental degradation have been examined but the interactive role of INV is less considered in existing studies (see, Sheng et al. 2019; Bakhsh et al. 2021; Salem et al. 2021). The current study considers the INV as moderator with FD and CO₂ emission on the basis of above literature findings; the moderating effect of INV between FD and CO₂ emission is illustrated in Fig. 1

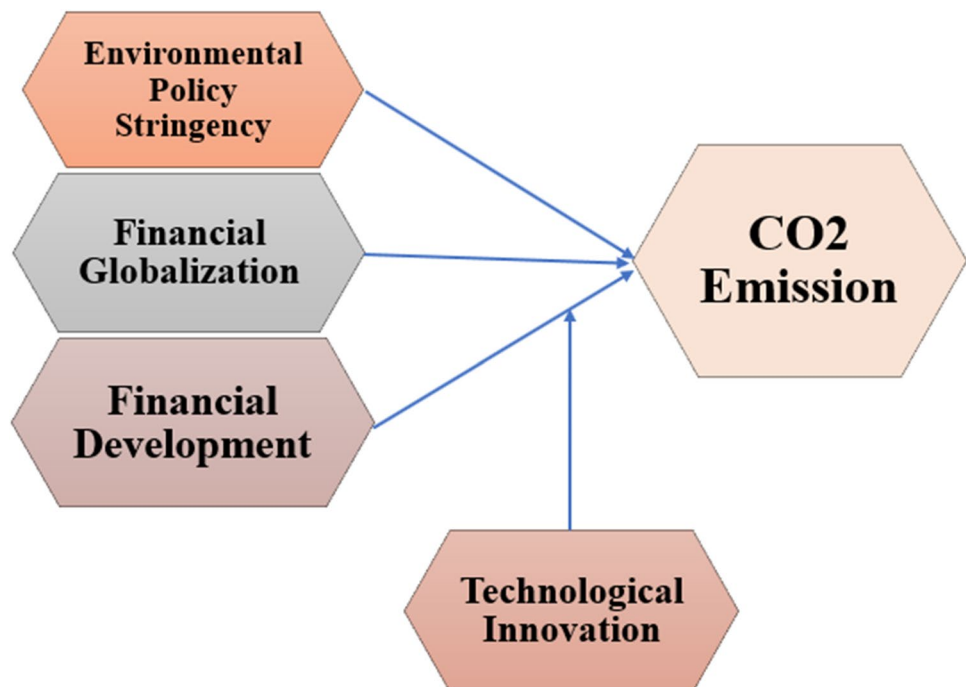
Financial globalization (FG) is the situation where global financial markets integrate into one (Stulz 2009; Yeyati and Williams 2014; Nasreen et al. 2020). FG results in the unrestricted and free movement of financial resources across countries (Gaies et al. 2022; Bibi et al. 2022). There has been contradiction in study findings on the association among FG CO₂ emission. FG contributes to increase/decrease of CO₂ emission and hence global temperature. There are two components of this association. First, more FG can provide the

required resources for investment in new energy resources, technical growth, and innovation (Ulucak et al. 2020). Second, increased FG may bring financial resources to underdeveloped economies with less strict environmental policies. Consequently, governments and investors may prioritize economic benefits over environmental degradation. Thus, FG has worsened environmental degradation.

Ahmed et al. (2021) demonstrated that the FG contributes for environment through eco-innovation in G7 countries. Similarly, Ulucak et al. (2020) demonstrated that FG helps to reduce CO₂ emission. Akadiri and Adebayo (2021) evaluated FG and FD association and they found a positive association by using annual data for India from 1970 to 2018. There are number of factors i.e., FDI, FG, and renewable energy that influences the environment in Argentina (Murshed et al. 2022a, b). Ahmed et al. (2021) found that FG has detrimental impact on environmental quality in Japan.

The growing concern about climate change and global warming turmoil caused by GHG emanations has resulted in an extensive multidimensional and multidisciplinary literature on the effects of various pollutants in various economies (Manisalidis et al. 2020; Zia et al. 2021). Concerns about how economic activities affect the environment in general attracted much interest in research. Conversely, statistics remains questionable to comprehend the predictors of CO₂ emissions. Moreover, there is limited research available on the association between EPS and CO₂ emissions. All countries emphasize equally on environmental policy and green technologies in order to enhance environmental quality. The efficacy of environmental policies is determined by

Fig. 1 Research model



their stringency (Ahmed 2020). Limited studies analyzed the impact of specific environmental policies on CO₂ emissions; for instance, Aichele and Felbermayr (2013) used dummy variable for Kyoto protocol and demonstrate that it has negative effect on environmental degradation. Similarly, Wang et al. (2020a, b) evaluated the impact of environmental policy on environmental degradation for Germany, Japan, Italy, Taiwan, and India. Their findings concluded that stringency of environmental policies contributes in reduction of environmental degradation and thus improved the environment.

Geden and Schenuit (2020) evaluated that climate policy in EU helps to reduce CO₂ emissions in post-Soviet European countries. Regardless of the consequences, although the policies for environment are frequently mentioned in the literature but empirical evidences have not yet provided concrete results. This scarcity of literature is due to lack of measurements for implementation of EPS (Galeotti et al. 2020) in different economies. Despite the challenges in measuring policy stringency and examining its effects in different economies, great concerned has been raised and related literature has prospered; for instance, De Angelis et al. (2019) used data of 32 countries spanning 1992 to 2012 and demonstrated that strict environmental policies contribute in CO₂ reduction. Wang et al. (2020a, b) evaluated the impact of EPS on CO₂ on 23 OECD countries from 1990 to 2015 and concluded that stringency of environmental policy helps to enhance air quality. Sezgin et al. (2021) used the data of BRICS countries from the time period of 1993 to 2014 and confirmed a U-shaped association of EPS and CO₂ emission, which indicates that stringent policies do not contribute to reducing CO₂ emission until a certain juncture but if policymakers continue to increase regulations, it can increase quality of environment. Similarly, De Angelis et al. (2019) used the dataset of 32 countries from 1992 to 2012 and reveal that the stringency of environmental policies has a significant impact on CO₂ emission. They concluded that effective policies help in reduction of environmental degradation.

Another important factor influencing environmental degradation and economy of country is financial development (FD). FD refers to a country's decision to stimulate the activities of financial institutions i.e., banking, FDI, and stock markets. FD increases financial activities, which in turn increase demand for energy (Sadorsky 2011; Khan et al. 2020), finance, and energy-related policies association is affected by FD and energy

demand. FD significantly and positively affect the environment in different ways, i.e., available environmentally friendly technologies and improved environmental quality. The low-cost environmental technology encourages consumers to use more efficient energy sources (Tamazian et al. 2009) and increase investment in renewable projects. While FD facilitates financial resources to stimulate investment and economic activities (Khan et al. 2020). Thus, providing financial resources can boost economic growth which ultimately affect the environmental quality negatively (Saud and Chen 2018; Khan et al. 2021a, b).

Empirical models and data

The current study is conducted to evaluate the impact of financial globalization (FG) (Sadiq et al. 2022), environmental policy stringency (EPS) (Yirong 2022), moderating role of technological innovation (IN) (Xiong et al. 2022) with financial development (FD) (Anwar et al. 2022) on carbon dioxide (CO₂) by employing pooled mean group (PMG) panel ARDL on balanced panel data of thirty-six (36) OECD countries. Following model is employed to analyze the relationship among the study selected variables.

$$CO2_{it} = \beta_0 EG_{it} + \beta_1 EG_{it} + \beta_2 FG_{it} + \beta_3 EPS_{it} + \beta_4 FD * INV_{it} \quad (1)$$

Description of the variables is illustrated in Table 1.

The study sample consists of panel data of 36 OECD countries, covering the time period of 1990 to 2020. List of sample countries is presented in Table 9. Data is obtained from OECD statistics. Notably, this study considered CO₂ emissions per capita as dependent variable, whereas, the independent variables of the study include economic growth, financial globalization, environmental policy stringency, and financial development. We also analyzed the influencing role of INV between FD and CO₂ emission. Table 1 shows the definitions of these variables. The panel ARDL model (P,Q,Q,Q,...,Q1) is estimated by employing a panel data set of countries $i = 1, 2, 3, 4, \dots, N$ with time period of $t = 1, 2, 3, 4, \dots, T$.

$$COemission_{2it} = \sum_{j=1}^p \lambda_{ik} COemission_{2it-k} + \sum_{j=0}^q \delta'_{ik} X_{it-j} + \mu_i + \varepsilon_{it} \quad (2)$$

Table 1 Variable description

Sr. #	Variables	Description	Proxies	Source
1	CO ₂	Environmental Degradation	CO ₂ emissions (metric tons per capita)	OECD Statistics
2	EPS	Environmental Policy Stringency	Index	OECD Statistics
3	FG	Financial Globalization	KOFFiGIdj	OECD Statistics
4	INV	Technological Innovation	Patent applications, residents	OECD Statistics
5	FD	Financial Development	Monetary Sector credit to private sector (% GDP)	OECD Statistics

Vector of regressor group i ; μ_i is represented by X_{it} which shows fixed effect. Coefficients of lagged regressands CO_2 , λ_{ik} demonstrate scalars in equation, whereas δ_{ik} shows vector's coefficient. If there is cointegration among regressors and regressands, it indicates that error correction term is applied in all countries. This property of the regressor and regressand implies that divergence from equilibrium has an effect on the error correction model, which shows the short-term dynamics of the regressors and regressand in the system. On the basis of this panel ARDL equation, error correction model is specified as:

$$\Delta CO\ emission_{2it} = \phi_i (CO\ emission_{2it-1} - \theta'_i X_{it-1}) + \sum_{j=1}^{P-1} \lambda^*_{ik} \Delta CO\ emission_{2it-j} + \sum_{j=0}^{Q-1} \delta'^*_{ik} \Delta X_{it-k} + \mu_i + \varepsilon_{it} \quad (3)$$

Above equation $\phi_i = -(1 - \sum_{k=1}^P \lambda_{ik})$, $\theta_i = \sum_{k=0}^Q \frac{\delta_{ik}}{(1 - \sum_{k=1}^P \lambda_{ik})}$, $\lambda^*_{ij} = -\sum_{m=k+1}^P \lambda_{im}$, $k = 1, 2, 3, \dots, P-1$, and $\delta'^*_{ik} = -\sum_{m=k+1}^Q \delta_{im}$, $k = 1, 2, 3, \dots, Q-1$. ϕ_i in model indicates the speed with which modifications to equilibrium are implemented is referred as error correction speed. If the speed of adjustment is equal to zero in evaluated error correction ($\phi_i = 0$) then there is no long-run association. The error correction term is negative and large on the basis of return of selected variables in long-term relationship, while θ'_i indicates that between regressors and regressand there is long-term relationship. On the basis of model 3, illustrated below equation is evaluated.

$$\Delta CO\ emission_{2it} = \beta_0 + \phi_{1,i} [CO\ emission_{2it-1} - \theta'_{2,i} (FD_{it}, FG_{it}, EPS_{it}, FD * INV_{it})'] + \sum_{j=1}^{P-1} \lambda^*_{ik} \Delta CO\ emission_{it-j} + \sum_{k=0}^{Q-1} \delta'^*_{ik} \Delta ED_{it-k} + \sum_{k=0}^{Q-1} \delta'^*_{ik} \Delta FGD_{it-k} + \sum_{k=0}^{Q-1} \delta'^*_{ik} \Delta EPS_{it-k} + \sum_{k=0}^{Q-1} \delta'^*_{ik} \Delta FD * INV_{it-k} + \mu_i + \varepsilon_{it} \quad (4)$$

Methodology

The primary concern of current research study is to evaluate the direct effect of FD, INV, EPS, FG on CO_2 emission, and the moderating influence of INV between FD and CO_2 emission by employing PMG panel ARDL method developed by Pesaran et al. (1997, 1999) from the period of 1990 to 2020. The first step is to check the stationarity of the data by employing stationary tests i.e.; Pedroni (1999, 2004), Kao (1999), and Westerlund and Edgerton (2007). The study results indicate that variables are stationary at $I(0)$ and $I(1)$ which confirm that PMG panel ARDL can be employed. The second step of analysis is to test cross-sectional dependence (CD) in the dataset. Estimation of CD test is important before moving to subsequent analysis. Pesaran (2004) developed CD test to investigate the panel dependence. The current study also used Pesaran (2004) CD test. The study results indicate that there is no cross correlation and study variables are intertwined.

Panel data MG (mean group) proposed by Pesaran and Smith (1995) describe that error variation and all intercepts and slopes of confidents are different across the different economies. Later, Pesaran et al. (1997, 1999) introduced PMG (pooled mean group) estimator for panel data by linking pooled and average properties. PMG technique allows the coefficients of short run of variables, intercepts, and error variations are dissimilar around the group of countries. However, coefficients of regressors in long run are similar in different group of countries. Unit root is examined with Levin, Lin, and Chu test (Harris and Tzavalis, 1999; Levin et al, 2002) and ADF Fisher test developed by Pesaran (2007). To strengthen this investigation, this study also employed Pedroni (1999, 2004) and Kao (1999) tests to evaluate the cointegration between the selected factors. The results of these tests confirm the strong cointegration among study variables.

Results and discussion

Descriptive statistics

Table 2 illustrates the findings of descriptive statistics. The findings indicate that in terms of coefficient of variation, mean value of CO_2 is 8.656 with minimum and maximum values are 2.171 and 30.362 respectively. The average value of FD is 81.888 with minimum and maximum value of 1.798 and 304.575, respectively. The mean value of INV 21,720.09 with the minimum value of 12.0 and maximum value of 387,364. The mean value of EPS is 1.807 and the minimum value of 0.208 and maximum value of 4.133, while the average value of FG is 75.867 and the minimum and maximum values are 29.688 and 97.942, respectively. This shows that minimum and maximum values are within three standard deviations, demonstrating that there are no outliers for any variables.

Correlation matrix

Table 3 indicates the results of pairwise correlation among the study variables; the regressor, i.e. CO_2 emissions and the regressands, i.e., FD, INV, EPS, and FG respectively.

Table 2 Descriptive statistics

Variable	Obs	Mean	Std. dev	Min	Max
CO_2	1080	8.656	4.312	2.171	30.362
FD	1080	81.888	43.267	1.798	304.575
INV	1080	21,720.09	66,106.076	12.00	387,364
EPS	1080	1.807	.925	0.208	4.133
FG	1080	75.867	12.612	29.688	97.942

The results of pairwise correlation demonstrate that there is significant and positive relationship between CO₂, financial development, and financial globalization, while negative and significant relationship with technological innovation (INV) and environmental policy stringency (EPS). FG and EPS are negatively related with technological innovation while positive relation with FD.

Unit root test

Results of unit root tests are depicted in Table 4. Before employing panel ARDL method, unit root test is necessary for the selected variables to confirm that variables are stationary at level I(0) and first difference I(1).

The results of Levin, Lin, and Chu test shows that environmental degradation (CO₂), technological innovation (INV), and financial globalization (FG) are stationary at level. FD and EPS have unit root at level I (0), while these are stationary at first difference I(1). The findings of ADF unit root test also demonstrate that CO₂, INV, and FG have no unit root at level I (0). FD and INV are stationary at I(1). According to the Levin, Lin, and Chu; ADF Fisher tests, the series of carbon dioxide emissions, technological innovation, and financial globalization are stationary at the level and first difference. Moreover, the results of both unit root tests show that the variables of FD and EPS are not stationary at the level, but they become stationary at the first difference.

Table 3 Matrix of correlations

Variables	(1)	(2)	(3)	(4)	(5)
(1) CO ₂	1.000				
(2) FD	0.632	1.000			
(3) INV	−0.486	0.198	1.000		
(4) EPS	−0.714	0.507	−0.001	1.000	
(5) FG	0.135	0.333	−0.123	0.332	1.000

Table 4 Unit root tests

Variables	Levin, Lin, and Chu test		ADF Fisher test	
	At level	First diff	At level	First diff
CO ₂	−10.9035 ***	−11.3964***	94.7864***	360.1170***
FD	−1.0949	−5.1982***	61.6932	206.251***
INV	−1.5080***	−14.0026***	96.9615***	357.245***
EPS	0.7871	−10.6056***	13.4074	226.113***
FG	−5.9276***	−13.0254***	138.165***	361.050***

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Cross-sectional dependency test (CD test)

Table 5 summarises the CD test results. At the 5% level, the CD statistics for CO₂, FD, EPS, and FG are significant. The findings strongly contradict the null hypothesis that variable innovations are cross-sectionally independent. These findings are consistent with our prior prediction of a high degree of CD across OECD countries (36 countries), reflecting several commonalities within a regional economic group.

The analysis results shows that the selected variables of the study have cross-sectional dependency among all the sample countries.

Cointegration tests

Cointegration tests are analyzed to evaluate the long-run relationship between selected variables. Long-run cointegration relationships between variables are required before determining long-run elasticities using appropriate regression techniques.

Table 6 demonstrates the results of cointegration tests, i.e., Pedroni (1999, 2004) and Kao (1999) tests. The study results confirm the existence of cointegration among regressand CO₂ and regressands i.e., FD, INV, FG, and EPS across panel of selected OECD countries. The study result shows that the values of both tests Pedroni (1999, 2004) and Kao (1999) are significant and confirm the existence of cointegration among selected variables.

Table 5 Average correlation coefficients and Pesaran (2004) CD test

Variable	CD-test	p -value	Corr	Abs. (Corr)
CO ₂	21.99	0.000	0.359	0.618
FD	25.56	0.000	0.363	0.694
INV	0.12	0.905	0.003	0.547
EPS	55.37	0.000	0.799	0.786
FG	25.07	0.000	0.380	0.563

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

According to these results, it can be held that regressors and regressand have long-run association. These results confirms that PMG ARDL panel model can be applied to evaluate the long-run correlation. Cointegration tests are compulsory to determine the long-run association between specified variables. To determine the long-run association of study variables, it necessary to check cointegration among them. If the presence of cross-sectional dependence is confirmed in the selected variables, cointegration tests i.e., Pedroni (2004) and Kao (1999) test feature various biases that might leads to inaccurate conclusions. To resolve such issues, we employed Westerlund (2007) cointegration test because it can minimize cross-sectional dependency effects among variables using the bootstrap approach. Results in Table 6 demonstrate that cointegration exists which confirms the long-run association amid study variables. The significant p -value shows that H_0 is rejected. This signifies cointegration which reveals that there a relationship among study variables in long run.

Pooled mean group panel ARDL

In order to evaluate the relationship between CO₂ with FD, INV, EPS, FG, FD*INV, we employed PMG panel ARDL approach. Results of PMG panel ARDL for short and long run for 36 OECD selected countries are demonstrated in Table 7. To select between MG estimation and PMG estimation, Hausman test is employed. The examined results of Hausman Chi² p -value indicates that PMG estimation is more suitable than MG estimation. The results demonstrate that FD, INV, EPS, and the moderating effect of INV are negatively significant with CO₂ emission in long run. The results indicate that 1% increase in FD, INV, EPS, and FD*INV in selected countries helps to reduce

CO₂ emissions by 0.04842, 0.3210, 0.4440, and 1.9530, respectively. These findings indicate that development of financial sector promotes the use of environmentally friendly advanced and green technologies that helps in reduction of CO₂ emission. These findings are consistent with the study findings of (Khan et al. 2020, 2022). They demonstrated that financial development and CO₂ are significantly related to each other. Developed financial markets offer businesses the necessary financial resources to acquire advanced technologies that eventually contributes to improve environmental quality.

These results recommend more essential policies for implication. It is also recommended that OECD countries should promote the FD, technological innovation, and stringency of environmental policies that invites individuals and companies to invest in renewable energy projects and contributes in the decrease of environmental pollution. These results are similar with the study of (Qayyum et al. 2021; Oryani et al. 2022). They determined that financial development contributes in the reduction of CO₂ emission.

These findings of PMG panel ARDL indicates that with the increase of financial globalization (FG), CO₂ emission will also increase in panel of selected countries. The results depict that 1% increase in FG, there is an also increase in environmental degradation by 0.0196 in the long run. Easy access to capital promotes the production and manufacturing sector thus contributes in increase of CO₂ emission. These are aligned with the conclusion of Bayar et al. (2020). They demonstrated that there is significant increase in CO₂ emission due to rising global production and population as well as financing provision, while in short-run, FD, FG, and FD*INV are negatively and significantly related to CO₂ which indicates that 1% increase in selected variables decrease CO₂ emissions by 0.1231, 0.8448, and 0.8931, respectively in short run, whereas EPS and INV are positively and significant associated with environmental degradation, which indicate that stringent environmental policies contribute in decrease of CO₂ emission. The study findings are comparable with the research of Yirong (2022), who examined the environmental policy stringency in China, the USA, Japan, Russia, and India. He concluded that EPS has positive role in CO₂ reduction; it helps to improve the quality of environment. Results of INV demonstrate that development of technological innovation also contributes to effectively reduce CO₂ emission in OECD countries. Results of current study are similar with findings of Cheng et al. (2021). They examined the direct and moderating role of INV on environmental degradation in OECD member countries and argued that with the environmentally friendly technologies are produced and thus application of these technologies can help in reducing CO₂ and hence improves the environmental quality. The study results demonstrate

Table 6 Panel cointegration test

	Statistics	p -value
Pedroni cointegration test		
MPPt	4.2305	0.0000
PPt	1.4878	0.0684
ADFt	2.0307	0.0211
Kao cointegration test		
MDFt	−3.2849	0.0005
DFt	−4.0492	0.0000
ADFt	0.8481	0.1982
UMDFt	−2.9420	0.0016
UDFt	−3.8941	0.0000
Wester Lund test		
Variance ratio	3.4763	0.0003

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 7 Results of PMG estimator

Variables	Coef	Std. err	Z	p-value
Long-run PMG results				
FD	−0.4842**	0.2540	−1.9060	0.0570
INV	−0.3210**	0.0962	−3.3368	0.0010
EPI	−0.4440***	0.0630	−7.0435	0.0000
FG	0.0196**	0.0070	2.8047	0.0050
FD*INV	−1.9530***	0.4382	−4.4569	0.0001
Short-run PMG results				
ECT	−0.1071***	0.0159	−6.7300	0.0000
Δ FD	−0.1231**	0.0545	−2.2573	0.0314
Δ INV	0.3358***	0.0386	8.6995	0.0000
Δ EPS	0.1233**	0.0625	1.9720	0.0579
Δ FG	−0.8448***	0.0509	−16.5925	0.0000
Δ FD*INV	−0.8931**	0.381	−2.3441	0.0259
_cons	0.7985	0.1456	5.4840	0.0000

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

that environmental degradation (CO₂ emission) can be reduced if the FD specifies more sustainable consumption of energy by adopting environmentally friendly advanced technologies and if more financial resources improve the rules and policies concerning environmental degradation.

Current research also evaluated the moderating effect of INV on the empirical relationship of FD and CO₂. Findings represent that INV strengthen the association of FD and CO₂ emission.

The study findings are consistent with the study of Salem et al. (2021). They concluded that INV has significant moderating effect between determinants of environment i.e., FD, FDI, and CO₂ emission. These results have high significance for policy makers in making policies for the protection of environmental quality.

Moreover, results indicate that FG and CO₂ are positively related to each other. The findings are similar as of study of Khan et al. (2019). They revealed that financial globalization is significantly and positively related with the CO₂ emissions in Pakistan. Another study of Xu et al. (2018) evaluated the effect of FD with the role of globalization. They concluded that FG contributes in CO₂ emission. In the study of Twerefou et al. (2017), FG and CO₂ emission are positively correlated with each other. The coefficient of ECT is negatively significant which indicates a long-term equilibrium association among study variables. The ECT coefficient is 0.1071 which demonstrate that when disequilibrium arises, the convergence speed is 10.70%, returning to equilibrium every year.

To check the robustness of the study results, the current study examines whether and how CO₂ determinants of environment are related with environmental quality. The current study employed PQR (Panel quantile regression) to check the robustness. Table 8 demonstrates the results of quantile

regression estimation on the effect of FD, INV, EPS, and FG on environmental degradation. The results are provided for each quantile (25th to 95th) of predictive variable. Overall, the statistics indicate that the impact of different components of the environmental degradation is significantly different. According to the results, there is a substantial inverse association between FD, INV, EPS, and CO₂ emission. The results demonstrate that 1% increase in financial globalization causes 0.0460%, 0.0474%, 0.0780%, and 0.1845% increase in environmental degradation from 25 to 95th quantile, respectively, in selected OECD countries. FD, INV, and EPS are inversely related to CO₂ emission which indicates that with increase of 1% in FD, EPS, and INV, there is a substantial decrease in CO₂ emission. Findings demonstrate that with 1% increase in FD causes to reduce CO₂ by −0.005067% and −0.0093466% in 50th to 75th quantile, while 0.0003338% and 0.001389% increase in 25th and 95th quantile. The results of INV show that with 1% increase in environmentally friendly technologies, there is a positive trend of 0.0000191%, 0.0000341%, and 0.0000527% in CO₂ emission in 25th, 50th, and 75th quantile, respectively, while there is negative trend of 0.0000272% in CO₂ emission in 95th quantile. While the statistics of EPS shows mix results shows that there is negative trend of 0.1141139%, 0.1067336%, and 0.0060091% from 25 to 75th quantile while in quantile 95th, there is increase in CO₂ by 0.6544613%. The statistics of interactive role of INV between FD and CO₂ demonstrate that with 1% increase in environmentally friendly technologies and better financial system, it reduces the CO₂ by −5.3E-08%, −1.55E-07%, −0.000000274%, and −2.48E-07% from 25 to 95th quantile. This indicates that when financial institutions provide financial assistance to the industries so that they can buy environmentally friendly

Table 8 Robustness check with quantile regression

	Simultaneous quantile regression			
	Q25	Q50	Q75	Q95
Financial development	0.0003338*** (−0.17)	−0.005067*** (−1.85)	−0.0093466*** (−3.06)	0.0013892*** (−0.26)
Technological innovation	0.0000191*** (−2.88)	0.0000341*** (−8.27)	0.0000527*** (−5.78)	0.0000272*** (3.68)
Environmental policy stringency	0.1141139*** (3.66)	0.1067336* (1.38)	0.0060091** (0.06)	0.6544613 (5.3)
Financial globalization	0.0460232*** (4.48)	0.047448** (4.45)	0.0780406* (10.95)	0.1844653 (11.64)
FD*INV	−5.3E-08*** (−0.89)	−1.55E-07*** (−6.32)	−0.000000274*** (−5.61)	−2.48E-07*** (−5.57)
_cons	1.701404 (2.04)	4.328323 (5.41)	4.403378 (8.61)	1.324956 (1.46)
Pseudo R^2	0.86	0.734	0.5124	0.596
N	1116			

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

technologies for manufacturing and production purposes, then there is decrease in CO₂ emission thus improve the environmental quality. Thus, it can be argued that INV strengthen the relationship of FD and CO₂. These results are consistent with study of (Dagar et al., 2022; Weimin et al., 2022).

Quantile regression are graphically represented in in Fig. 2. Quantile regression graph demonstrate that FD trend is negative trend in environmental degradation from quantile 25th to 75th. After that, the trend changes towards positive. The graph of technological innovation represents the negative trend in environmental degradation from 75 to 95th quantile, while there is positive trend in environmental degradation from 25 to 75th quantiles. The quantile regression EPS represents that there is negative trend from 25 to 75th quantile, while there is positive trend from 75 to 95th quantile in environmental degradation. The graph of FG shows the positive trend in environmental degradation from quantile 25th to 95th. The graph of interaction term of FD and INV indicates negative trend in environmental degradation from 25 to 95th quantile.

Conclusion

The significant environmental deterioration and depleting fossil fuel sources have prompted policy makers and academics to explore possible alternatives for long-run economic growth and environmental protection. In this instance, the current study is conducted to investigate the correlation among FD, INV, FG, EPS, and the moderating effect of INV on FD and CO₂ emission on data from 1990 to 2020 for the 36 OECD member countries. Pooled mean

group (PMG) estimator is employed to examine the positive /negative association among selected study variables. The results of Levin, Lin, and Chu test and ADF Fisher test demonstrate that the selected series of variables are stationary at level I(0) and at first difference I(1) respectively that conform to the panel ARDL method. The results of cointegration tests i.e., Kao (1999), Pedroni (2004), and Westerlund (2007) demonstrate the existence of cointegration among study variables. Hausman test is employed to select between MG estimator and PMG estimator. The test findings supported the selection of PMG estimator. The results of PMG estimator indicate that CO₂ emission in the selected countries is influenced positively by FG and negatively by FD, INV, EPS in long run which indicates the inverse relationship. While INV moderates the relationship between FD and CO₂ emission. FD transfer advance environmentally friendly technologies to host countries, and thus, it has positive effect on businesses. It may contribute in reduction of CO₂ emissions which ultimately leads to improve environmental quality. The study of Khachoo and Sharma (2016) and Du et al. (2019) concluded that INV is beneficial to reduce CO₂ emissions. With financial globalization capital inflow increases hence there are more industries in the countries which ultimately increase the deterioration of the environment. This follows that financial system in the selected countries is weak (Ajide and Ojeyinka 2022; Qamri et al. 2022). This indicate that resources allocation is inefficient and monitoring of the production machines is ineffective. Therefore, this contributes to the use of outdated and emitted machines which causes an increase in CO₂ emissions. Similarly, all p -values are significant which shows that selected variables have impact on CO₂ emission. The negative

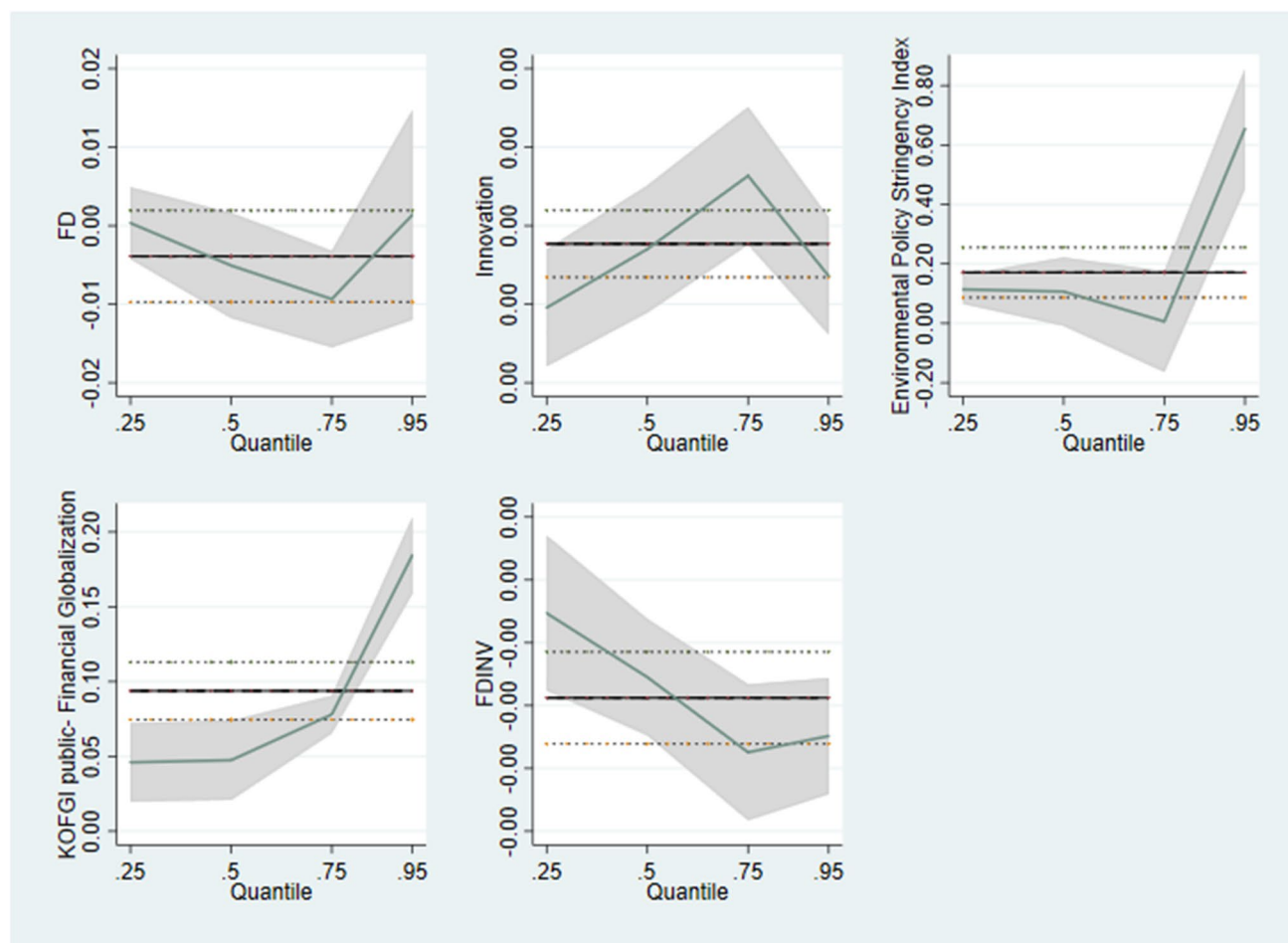


Fig. 2 Graphical representation of quantile regression

coefficient signs of the FD, INV, EPS, and FD*INV reveals an inverse relationship with environmental quality. This demonstrates that with more FD, increased environmentally friendly technologies, more stringent policies for environment contribute in reduction of CO₂ emission and thus improve quality of environment.

Based on the study findings it can be argued that uncertainty about the global economy may motivate investors to invest in economic activities that produce emission free goods by using advance environmentally friendly technologies. Financial institutions should prioritize provision of credit for investment in the production and use of green technologies by offering lower interest rates on environmental agreements. More policies should be implemented to encourage efficient economic activities in services and financial sectors in the selected OECD countries because these countries diversify their economies with increased production that ultimately contributes in higher CO₂ emission. The findings of the study recommend that, in order to accelerate economic growth and improve environmental quality,

policymakers should implement low-carbon mechanisms, such as green infrastructure and renewable energy, which reduce energy consumption and GHG emissions. Consequently, it is essential that the selected OECD governments should develop programs to elevate awareness of the risks of CO₂ emissions. In general, green financing is an environmentally friendly approach that contributes in achieving economic as well as environmental sustainability. It has been determined that promoting renewable energy has climatic advantages. Science and technological improvements are also essential for the development of sustainable energy sources and accompanying infrastructure.

Therefore, governments should concentrate on efficient allocation of resources to foster technological development in the industrial sectors such as provision of loans at lower interest rate for the investments that produce low emitting goods and promote green financing projects. Such strategies contribute in improvement of energy efficiency, subsequently reduce CO₂ emission. Other steps that governments can initiate include provision of support for development of energy

generation from renewable resources i.e., solar, wind, and hydro technologies. The government should also concentrate on the policies that boost the economic activities and reduce the CO₂ emissions. Collaboration among numerous public and private entities, such as government ministries, research institutions, universities, and businesses, would be required for successful mitigation policy implementation. Some of the more effective measures might include imposing a tax on carbon as well as trading carbon quotas.

This research is useful to policymakers in OECD countries. Regulators and other stakeholders are encouraged to prioritize FD while also considering clean and eco-friendly technologies to achieve long-term economic goals. For these reasons, renewable energy consumption refers to the process by which OECD countries can achieve zero-carbon emission goals and thus protect the environment. However, several important aspects of this study point to certain limitations. This study analyzed the data from 1990 to 2020 for 36 OECD countries. Future research should focus on other economies to investigate environmental associations with economic and noneconomic factors. Other variables that might have an effect on the correlation between the study variables should also be considered.

Appendix 1

Table 9 List of sample countries

Austria	Spain	Ireland	Greece
Hungary	Estonia	Poland	Mexico
New Zealand	Lithuania	Czech Republic	United States
Australia	Switzerland	Israel	Germany
Italy	France	Sweden	Norway
Netherland	Luxembourg	Canada	United Kingdom
Belgium	Slovenia	Japan	Denmark
Iceland	Finland	Slovak Republic	Korea
Portugal	Latvia	Chile	Turkey

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Data availability The datasets generated and analyzed during 1990 to 2020 the current study are available in the OECD Statistics <https://stats.oecd.org/>.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare no competing interests.

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