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RESEARCH ARTICLE

The nexus of financial development, technological innovation, institutional quality, and environmental quality: evidence from OECD economies

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Abstract

The present study investigates the effect of institution quality, technological innovation, and financial development on environment quality using 37 OECD nations from 1998 to 2018. The cross-sectional dependence (CD) and Lagrange multiplier (LM) techniques are used to measure the cross-sectional dependence. The second-generation panel unit root tests and panel cointegration tests are applied to examine the unit-root properties and long-run association existence between variables. Finally, we employed the two-step (SYS-GMM) methodology to estimate the coefficient values. The findings showed that financial development has a positive effect on selected carbon (CO2) emission dimensions. When the moderating term is introduced, it was identified that institutional quality and technology innovation conditioning effects are crucial between financial development and CO2 emission. Our evidence-based study provides significant results for technology innovation and institutional quality moderating role in reducing CO2 emissions in OECD economies. Our findings are also robust to alternative measures, which could be useful for policymakers to formulate long-term and short-term strategies and policies for a better sustainable environment.

Keywords Technological innovation · Institutional quality · Financial development · CO_2 emissions · SYS-GMM · OECD

Introduction

After the signature of the Paris Agreement in November 2016, major-emitting countries agreed to mitigate the harmful effects of rising carbon emissions. This agreement is an attempt to solve the challenge of global warming and climate change and to maintain greenhouse gas (GHG) emissions to a degree that prevents environmental issues by adopting advanced structures. Thus, global warming gained full consideration as many countries worldwide have noticed environmental problems (Hughes et al. 2017). Then, new technologies, production methods, and consumption are needed to achieve eco-innovations and mitigate the GHG

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effects (Durán-Romero et al. 2020). Since 1970, the OECD and developing economies have contributed to about 85% of the world's carbon emissions, revealed by the Global Atmospheric Research (EDGAR) database. In 2007, the carbon emission of OECD economies was very high. After the global financial crisis of 2008, the emissions have been declined due to slow industrialization and economic activities and strengthened environmental policies. However, it is expected that in the years after the COVID-19 pandemic, GHG emissions are set to increase again due to recent rises in emissions, production, and energy usages. In order to achieve sustainable economic growth, several countries around the world are implementing financial, institutional, and innovation measure to mitigate the GHG emission and to improve environmental quality (Godil et al. 2021a, b, c; Ullah et al. 2021a, b; Luo et al. 2021). Financial sector development can directly enhance their expenditure on goods and services, which might rise in the demand for energy in both personal and business setups which ultimately effect the environment quality in a country (Godil et al. 2021a, b, c). Similarly, Luo et al. (2021) explained that innovation activities derive energy efficiency and promote sustainable production, leads to reduce carbon emission. Institutional quality is also seen to have a significant role in promoting. Efficient institutions offer governance mechanisms that reduce risk and transaction costs. They advocate for effective production and financing in technical innovation and energy-efficient developments that all improve the environment conditions (Kassi et al. 2021). Hence, the present study is conducted with comprehensive objective to examine the influence of institutional quality, financial development, and technology innovation on environmental quality of OECD economies.

The OECD economies were selected for the analysis since these countries have the greatest contribution to the emissions. According to OECD (2021), OECD economies emit 35% of global CO_2 Ems. A slower pace of industrialization, human and economic activity, and stronger environmental policies have helped reduce emissions. CO_2 emissions decrease in OECD economies during the COVID-19 epidemic, especially in 2020. From 2017 to 2020, the overall OECD economies' environmental quality will improve, reducing CO_2 emissions (tons/capita) from 8.69 to 7.64%. Canada and Australia emitted 15.3%, USA 15%, and Luxembourg 14.7% are the top-releasing CO_2_Emiss (tons/per capita) OECD economies, while Colombia 1.5%, Sweden 3.4%, and Mexico 3.6% are the low-releasing CO_2_Emiss countries. Thus, an increase in energy consumption for industrialization and production is demanded from countries in process of industrialization and economic development. It can also be argued as larger economic development implies consuming higher energy resulting in more environmental degradation if not using renewable energy sources. To the best of our knowledge, no empirical research has been existing so far, to examine the effects of FDV, INSTQ, TINNOV, and environmental quality indicators on 37 OECD economies. Recent studies related to OECD members, such as Martínez-Zarzoso et al. (2019), Paramati et al. (2020), Ozcan et al. (2020), Cheng et al. (2021), Petrović and Lobanov (2020), Saidi and Omri (2020), and Teng et al. (2020). From these selected studies, the aim of the research conducted by Teng et al (2020) was to investigate the effects of TINNOV, INSTQ, and FDV on CO_2_Emiss indicators in OECD countries from the period 1998–2018 (Figs. 1 and 2).

Several scholars identified that financial development could enhance energy efficiency or environmentally friendly technologies. According to Pata (2018), carbon emissions including environmental pollution will be decreased. This strong assumption is mainly due to the perception that the development of financial intermediaries and financial openness would draw more FDI, which could increase the level of research and development (R&D) and support the enhancement of the climate issues (Frankel and Romer 1999; Mahalik et al. 2017). Several research studies assessed the effect of different factors influencing carbon emission, e.g., globalization (Xu et al. 2018), renewable energy (Sharif

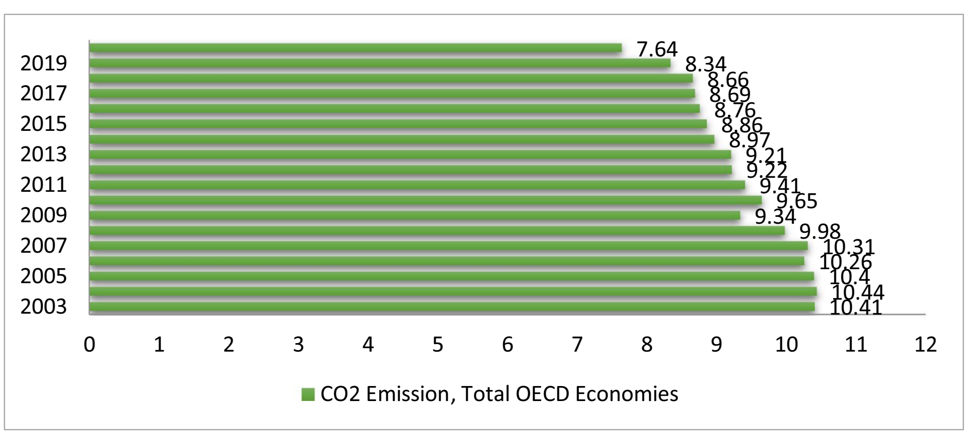
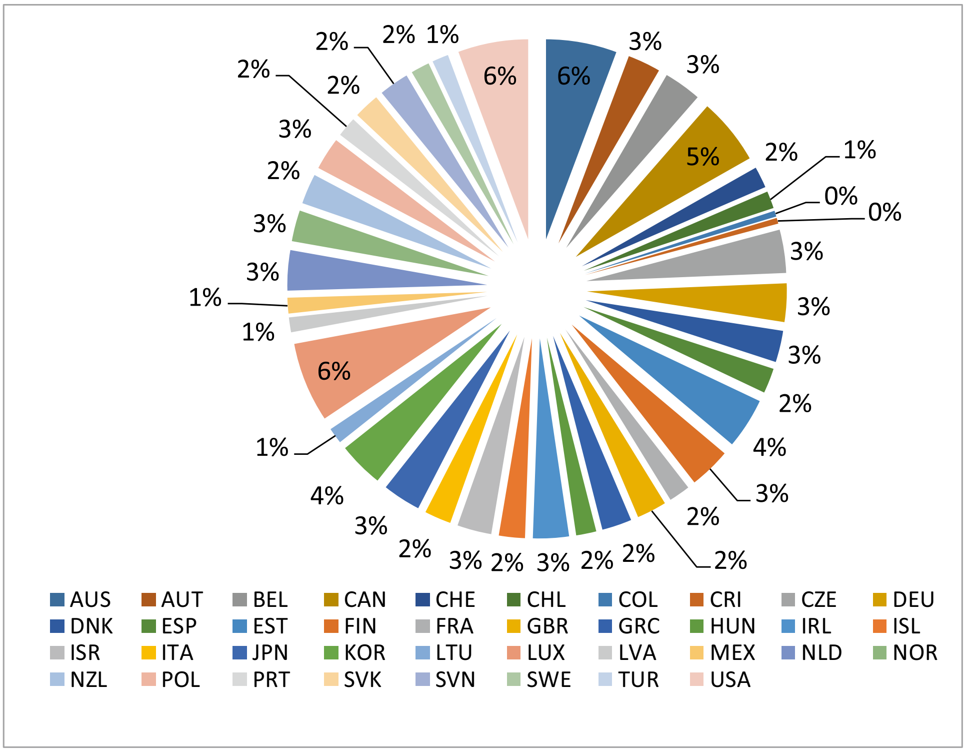


Fig. 1 Share of the total OECD economies in their total CO_2_Ems. Source: Authors' own calculations based on OECD database (2020)

Fig. 2 The OECD nations' share of total carbon dioxide emission (CO_2_EMS). Source: Authors' own calculation (OECD database, 2020)



et al. 2019), urbanization (R. Ali et al. 2019a, b), tourism (Jebli et al. 2019), financial development (FDV) (K. Ali et al. 2020), institutional quality (INSTQ) (Salman et al. 2019), information and communication technology (ICT) (Godil et al. 2020), and technological innovation (TINNOV) (Erdoğan et al. 2020; Bakhsh et al. 2021).

Despite all these efforts, a study addressing the financial, technological, and institutional aspects of environmental sustainability is still needed for OECD economies. Our study provides new insights into important role of these key elements for achieving sustainable development. These elements were selected due they are considered as the leading environment degradation influence, which is appropriate for the conditions of OECD economies, and thus helpful indicators for structuring environmental policies in those countries.

The justifications behind studying FDV when analyzing the relations between INSTQ, TINNOV, and CO_2_Emiss indicators are (i) FDV can encourage foreign direct investment (FDI) and increasing the degrees of R&D investments, which can boost the economy's expansion and raise CO_2_Emiss (Frankel and Romer 1999); (ii) according to Dasgupta et al. (2001), stock market development helps listed companies to minimize funding costs, expand financing sources, distribute operating risks, optimize the asset/responsibility system, and invest in new ventures, leading to an increase in carbon emissions and energy consumptions; (iii) FDV encouraging to consumer lending practices, making it easier for customers to buy more expensive products, such as houses, automobiles, washing machines, air conditioners, refrigerators, and kitchen appliances, and then generate more CO_2_Emiss (Sadorsky 2011); (iv) Birdsall and Wheeler (1993) underlined that FDV offers the incentive and potential for developed countries to use modern technologies, to assist them with sustainable, environmentally-friendly production and, ultimately, to boost the global environment and enhance the sustainability at regional development; and (v) FDV may contribute to more industrial emissions and environmental deterioration (Fig. 3).

The contributions of this research to the literature are numerous. (i) Our research explores the impact of FDV on environmental quality along with the moderating role of INSTQ and TINNOV. The study expands to the region, i.e., to the 37 OECD countries, which received relatively little interest in previous studies. (ii) We used four environmental quality indicators CO_{2pc}, emissions (per capita); CO_{2IS} (intensity); CO_{2HE} (heat and electricity generation); and CO_{2FL} (fuel and liquid consumption), independently considering the environmental quality proxies for the related policy implications not considered in earlier studies for OECD economies. (iii) The current research explores the effects of FDV, INSTQ, and TINNOV on CO_2_Emiss, as well as other different control dimensions, such as GDPG, FDI, ENU, and TOP as control indicators, for the 37 OECD economies from 1998 to 2018. We used the cross-section dependency approach (CADF) and IPS (CIPS) panel unit root methods. Also, we employed a generalized method of moment two-step (system-GMM) econometric technique.

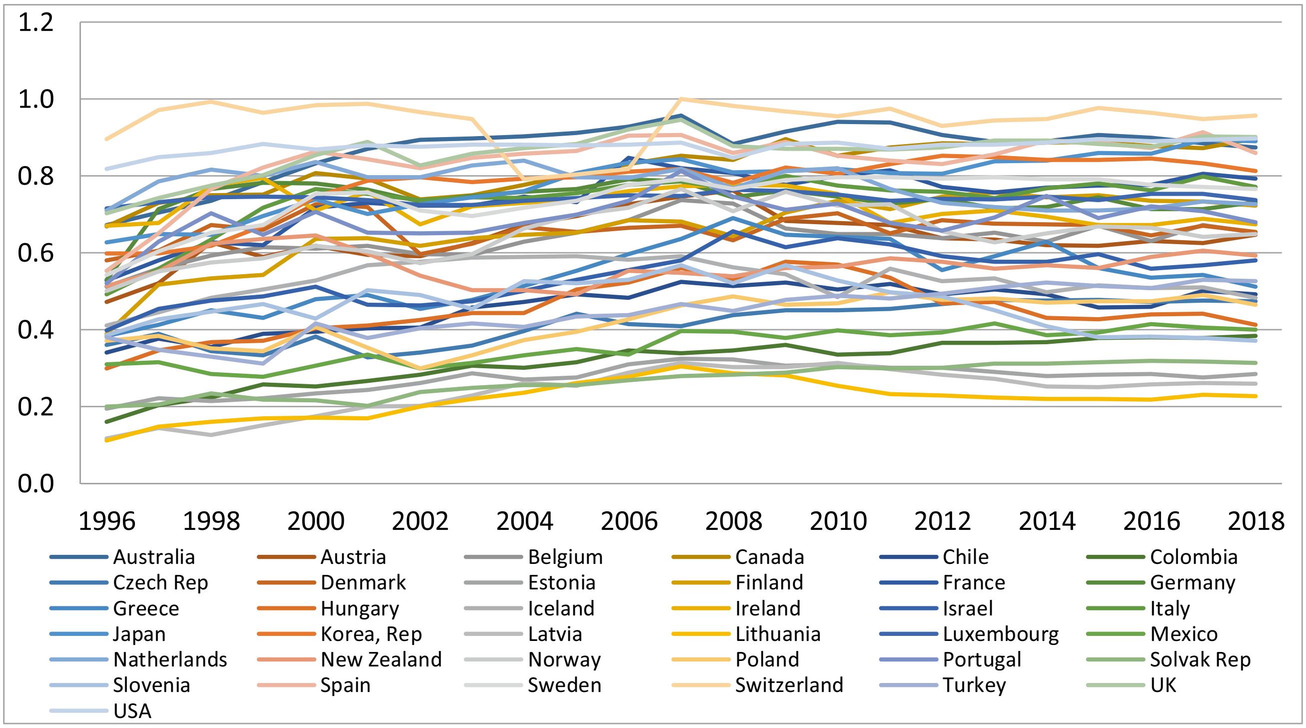


Fig. 3 Source: IMF and authors' own calculations (financial development)

This empirical approach enables us to elaborate model descriptions to address the potential endogeneity and heterogeneity issues and to check the findings' robustness. The findings demonstrate that FDV, GDPG, ENU, and TOP mitigate environmental quality by increasing CO_2_Emiss, while TINNOV and INSTQ increase environmental quality by decreasing CO_2_Emiss.

This study is structured as follows. Following the "Introduction" section, (2) the literature review explores the determinants selected for our study (FDV, TINNOV, INSTQ, and CO_2_Emiss). (3) Research design is then presented, where the data collection and analysis procedures are described. (4) The main findings and a summary of the estimation and policy implications are explained in the section of results and discussion. The paper ends with major conclusion and policy suggestions.

Literature review

This section consists on the empirical studies regarding the influence of financial development, institutional quality, and technology innovation on environmental quality. For the better understanding of the influence of these variables, we divided the literature review into three sub-sections.

Financial development and CO_2 emissions

The role of FDV on environmental quality has recently gained attention in the literature (Tamazian and Rao 2010); however, prior study's conclusions showed conflicting results. Few studies reported positive relation between FDV and the CO_2_Emiss release, since a well-organized financial sector might provide financial support to finance projects that enhance the environment. The outcomes indicated positive relation between FDV and energy consumption. Further, Boutabba (2014) examined the effect of income and FDV on CO_2_Emiss, emphasizing that the Indian economy has a positive relation between FDV and CO_2_Emiss release. We can identify various studies suggesting that FDV has a positive impact on CO_2_Emiss (Ali et al. 2019a, b; Nasreen and Anwar 2020; Shahbaz et al. 2016; Khan and Ozturk 2021). Extensive attention has been drawn to promoting sustainable development and addressing global climate change. According to Zhang (2011), emissions in a country are dependent on their income level and FDV. In a recent study, Godil et al. (2020) also observed the influence of ICT, institutional efficiency, and financial development on environment quality in Pakistan. The study found an adverse impact of financial development and ICT on CO2 emission, whereas institutional quality found to have augmenting impact on CO2 emission. Anser et al. (2021) also explained that financing in low-carbon energy improves the clean production by using data of ASEAN states. The empirical study by Ullah et al. (2022) also found the finical development as a key factor to abate CO2 emission in case of OECD economies.

Otherwise, some studies demonstrated a negative relation between FDV and CO_2_Emiss. The findings showed a negative indicator of the coefficient of financial development. Shahbaz et al. (2016) indicated that FDV hampers the environment quality in Pakistan. Xu et al. (2018) stated the nexuses between FDV and emission in Saudi Arabia. Other negative influences on CO_2_Emiss were studied by other relevant studies (Dar and Asif 2018; Shahbaz et al. 2020).

Empirically, several findings have been performed to investigate the FDV effects on the environment, CO_2_Emiss in different regions worldwide (Pan and Yang 2019; A. Khan et al. 2019; Z. Khan et al. 2020; Yang et al. 2020). Earlier studies generally concentrated on investigating and exploring the key determents of CO_2 emission, energy usage, institutional quality, trade openness, FDI, economic growth, technological innovation, and financial development (Xu et al. 2018; Shahbaz et al. 2020; Zakaria and Bibi 2019; Bayar and Maxim 2020; Godil et al. 2020; Neog and Yadava 2020; Öztürk and Le 2020; Zhao and Yang 2020; Erdoğan et al. 2020; Qin and Ozturk 2021).

From the perspective of cross-country studies, few empirical findings have revealed the impact of FDV on energy usages and CO_2_Emiss. Among these studies, there are De Vries and Withagen (2005) indicating that TINNOV mitigates emissions in 13 OECD economies and Omri and Hadj (2020) focusing on 12 North Africa and the Middle East (MENA) countries, indicating a neutral relationship between FDV and CO_2_Emiss. Additionally, Ziaei (2015) examined the associations in 12 East Asia, Oceania, and 13 European countries. Abbasi and Riaz (2016) found that in small, emerging economies, FDV plays an essential role in reducing CO_2_Emiss. Other studies applied FDV in different countries, Kais and Sami (2016) for North African countries and Bekhet et al. (2017) in all Gulf Cooperation Council (GCC) countries. The studies of Baloch et al. (2019), Khattak et al. (2020), Rafique et al. (2020), and Ulucak (2020) examined the relations between the BRICS economies' FDV, energy usages, TINNOV, and CO_2_Emiss and suggested that FDV is an essential factor for environmental quality. Bayar and Maxim (2020) addressed the effect of FDV, economic growth, and energy usage in 11 post-transition European economies on CO_2_Emiss, and Gök (2020) used the results of 72 studies and found that changes in the magnitude and direction of the effects of FDV on CO_2_Emiss focus on the measures of FDV. Erdoğan et al. (2020) examined the impact of technology innovation on emissions for 14 G20 countries and investigated that while an increase in TINNOV in the industrial sector leads to a decrease in CO_2_Emiss, an increase in TINNOV in the construction sector increases CO_2_Emiss.

Thus, the aforementioned studies presented several proofs of long-term relations between financial development and CO_2 emissions; however, the more recent empirical relationship between financial development and CO2 emission is missing. Moreover, the combine effect of financial development and institutions on CO2 emission is also missing in the empirical literature.

Technological innovation and CO_2 emissions

Financial sector development boosts investments in technologies that are energy-efficient and thus reduces emissions. Several empirical research findings have already shown that the financial sector can significantly reduce CO_2_Emiss by promoting technological enhancement in the energy industry. According to Aghion and Howitt (1990) and Romer (1990), a panel data model was used to define the environmental problems from a global context. They discuss the heterogeneity of the TINNOV of CO_2_Emiss. The country's FDV attracts more FDI and induces a higher level of R&D investments that results in better climate conditions (Frankel and Romer 1999). Tamazian and Rao (2010) found that FDV has enabled the listed companies to improve energy efficiency by implementing new technologies. Moyer and Hughes (2012) and Al-Mulali et al. (2015) have also shown that technological progress reduces environmental emissions due to the technology spillover impact. According to Fei et al. (2016), the relation among CO_2_Emiss and TINNOV was investigated, and the results showed that R&D investments enable the use of renewable energy. Sohag et al. (2015) found that technological development declines energy consumptions and decreases CO_2 emissions. In the study of Asongu et al. (2018), the effect of ICT on CO_2_Emiss is positively related; however, more advanced ICT use reduces CO_2_Emiss and leads to an improved environment in Sub-Saharan African countries. Henriques and Borowiecki (2017) studied the carbon emission determination measured in Japan, Northern America, and European Union. The outcome showed that technological transformation mainly affects CO_2_Emiss in the long term. According to Ibrahim (2020), the role of CO_2_Emiss, TINNOV, renewable energy resources, economic growth, and FDV in Egypt (1971–2014) showed that while TINNOV and renewable energy enhance the quality of environment, FDV reduces the economic growth in country. Rafique et al. (2020) argued that the impact of FDI, TINNOV, and FDV on CO_2_Emiss in BRICS economies indicated long-term significant and negative correlations with CO_2_Emiss. Many studies suggested that TINNOV helps reduce CO_2_Emiss and increase the quality of the environment (Tan et al. 2019; Lin and Zhu 2019; Chen and Lee 2020; Shahbaz et al. 2020). Murad et al. (2019) investigated the dynamic connection between innovations, energy, energy price consumption, and economic growth by using the Denmark data. The cointegration results confirmed the existence of long-run relationship among the considered variables. Moreover, innovations in energy sector improve the energy efficiency and energy consumption. Koondhar et al. (2021) argued that modern technologies usage is also increasing along with CO2 emission as consequence of large fossil fuels. The study further explained that an enlargement in use of fossil fuels to operate modern technology is the key reason behind CO2 emission increase.

TINNOV is of considerable interest to environmental quality. TINNOV not only has a significant effect on production development but also decreases energy usage and emission indicators. The most significant contribution of TINNOV is to reduce GHG emissions without affecting economic and social development. Weitzman (2017) and Frankel and Romer (1999) examined that FDV allows companies to accumulate resources and minimize costs by using environmentally friendly technologies. This justification is supported by Yuxiang and Chen (2011) when promoting FDV measures as a major issue in developing technological spillovers, reducing CO_2_Emiss, and boosting domestic consumption. According to Yeh and Rubin (2012), the most critical theoretical hypotheses in the investigation of global warming, relating to energy and the atmosphere, discuss the existence and pace of technological change. Ahmed et al. (2016) examined that TINNOV mitigates emissions by enhancing energy consumption over the long term. Simultaneously, technological innovation was found to raise energy efficiency and decrease energy usages, then ultimately leading to a decline in carbon emissions. Erdoğan et al. (2020), studying the impact of TINNOV on emissions on an industrial and construction basis, found that an enhancement in technology in the construction sector increases emissions, and a boost in TINNOV in the industrial sector leads to a decline in emissions. Rafique et al. (2020) examined that the effect of FDI, TINNOV, and FDV has significant and adverse on CO_2_Emiss indicator. Godil et al. (2021a, b, c) explained that technology innovations have adverse impact on CO2 emission in by using data from 1990 to 2018 in case of China. They illustrates that an increase in innovation, the carbon emission from the transportation sector tends to reduce. By using the data of selected Asian countries, Luo et al. (2021) also explained that technology innovation can significantly reduce the CO2 emission and promote sustainability.

The previous literature has largely ignored the technology innovation to influence the environment quality, or primarily consist on environment innovations such as R&D in energy sector, which is narrow prospective of overall all innovation quality of a country. We filled this gap by using a broader proxy of innovation, i.e., total number of patents that was also missing in empirical literature especially in case of OECD economies.

Institution quality and CO_2 emission

The importance of INSTQ and the increase in CO_2_Emiss has not been addressed in the current literature. The majority of papers that considered institutions merely focused on one or two indicators only. Kaufmann et al. (1999) presented six separate indicators related to INSTQ, political stability, the effectiveness of government, regulation quality, voice and accountability, corruption control, and the rule of law. Kaufmann et al. (2010) observed that various governance dimensions are concentrated on single dimension of institutions. Halkos and Tzeremes (2013) stated that different aspects of governance quality might have varying effects on CO_2 emissions. Ozturk and Al-Mulali (2015) noted that an effective governance system encourages environmentally sustainable policies and enhances the quality of the environment. Abid (2016, 2017), analyzed the impact of various INSTQ dimensions on environmental quality, suggests that their influence is quite strong. Additionally, effective governance plays a significant role in reducing CO_2_Emiss, and INSTQ determines CO_2_Emiss in equally ways.

das Neves Almeida et al. (2017) also stated that political dimensions are related to the environment, and democratic institutions improve the environment since successful legislation and regulations improve the environment. Wang et al. (2018) reported that the control of corruption helps reduce carbon emissions directly and indirectly. Ali et al. (2020) stressed that institutional quality imposes an environmentally sustainable approach. According to Teng et al. (2020), renewable energy usage has been shown to help minimize environmental degradation. Foreign direct investments, energy usage, economic development, and institutional quality have positively affected environmental degradation. Bakhsh et al. (2021) suggest that the amount of CO_2_Emiss is substantially reduced between INSTQ dimensions and FDI inflows.

Some empirical research found a significant positive relationship between INSTQ and emissions (Batool et al. 2020; Godil et al. 2020; Le and Ozturk 2020; Salman et al. 2019), although some findings confirmed that institutional efficiency is important to decrease in CO_2 emission (Lau et al. 2018; Zakaria and Bibi 2019; Batool et al. 2020).

Institutional quality is a significant but somewhat neglected factor that also affects environmental sustainability (Ibrahim and Law 2016; Lau et al. 2018). Prior studies have also neglected the impact of INSTQ on emissions. During the economic growth process, neutral and efficient domestic institutions play an essential role in reducing emissions (Mehmood et al. 2021). Hosseini and Kaneko (2013) stated that institutional quality influences countries' environmental quality and can also spread the environment quality of the countries to their neighboring countries through a spatial institutional spillover channel at the same time.

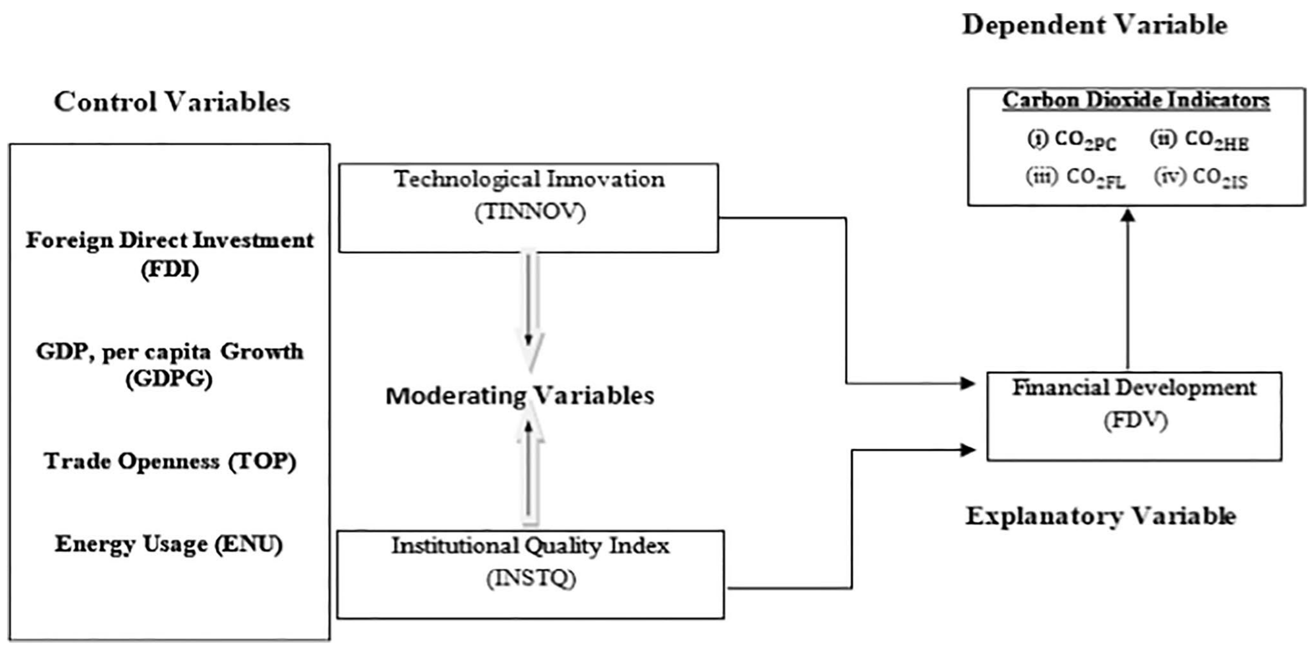


Fig. 4 The conceptual framework. Source: Authors' own elaboration

Low institutional quality is the main determining factor of a low-income trap in a country (Kar et al. 2019). According to Zakaria and Bibi (2019), institutions are sufficiently effective to enforce environmental regulations and improve the quality of the environment. Similarly, many other recent studies found institutional quality as a main factor to promote sustainable development (Bakhsh et al. 2021; Batool et al. 2020; Omri and Hadj 2020).

The previous studies only included one or two dimensions of institution quality and examine their impact on the environment quality. In contrast, we used six institutional indicators to estimate more efficient results, which is not analyzed before in the empirical literature.

The conceptual framework of our research

Figure 4 represents the conceptual structure of presented research. The financial development and effects have been measured upon CO_2_Emiss indicators. Moreover, the moderating effects of institutional quality and technology innovation are also assessed on the financial development regarding its impact on CO_2_Emiss. Control variables are also involved in the study, which comprises FDI, GDPG, TOP, and ENU. The control variables are also assessed for evaluating the effects of FDV on CO_2_Emiss.

Research design

The present study examined the influence of financial development on the CO2 emission by incorporating institutional quality and technology innovations as moderating variables for the sample of 37 OECD economies. The study performs following methods to examine the influence of considered variables.

Cross-sectional dependency test

To initiate the empirical research, the paper used the cross-sectional dependence (CD) test Pesaran (2021) to establish if the countries under consideration are cross-sectional dependent or independent. For instance, regions are linked via border sharing, culture, social, economic, and trade agreements. Thus, the CD test is required to establish the best panel unit root and panel cointegration technique for dealing with CD. To test cross-sectional dependence in time series panel data, we employed the CD test proposed by Pesaran (2021) and the LM test introduced by Breusch and Pagan (1980). Based on the results in Table 3, the null of cross-section independence is rejected and the alternative of cross-section dependence is accepted. This indicates there is a cross-section of economies. We used following equations:

$$Y_{it} = \alpha_i + \beta_i x_{it} + \varepsilon_{it} \tag{1}$$

where i denotes the dimension of cross-sections, whereas t is indicating the time period in Eq. 1.

$$CD = \sqrt{\frac{2T}{N(N-1)}(\Sigma_{t=0}^{N-1}\Sigma_{j=i+t}^{N}\rho_{ij})} \quad (2)$$

In Eq. 2, the term N showing the sample size and T shows the time period whereas p_{ij} shows the estimates cross-sectional error correlation of the country i and j.

Unit root test

After determining cross-sectional dependence, the determinants' integration order is checked. The panel unit root test should be used to determine the order of integration for each variable because the cointegration tests require all factors to be integrated into orders one (Al-mulali et al. 2015). The present study used the second generation of unit root tests, including the Pesaran cross-sectionally (CADF) and the Pesaran cross-sectionally (CIPS) (Pesaran 2007) because the first-generation unit root testing methods are inappropriate when there is cross-sectional dependency present in the model (Luo et al. 2021; Ullah et al. 2022). The econometrics specification is below:

$$Y_{it} = \alpha_{it} + \beta_i x_{it-1} + \rho_i T + \sum_{j=0}^{n} \theta_{it} \Delta x_{it-j} + \varepsilon_{it} \quad (3)$$

where term Δ denotes the difference operator and x_{it} indicates the examined variable. The term α signifies the intercept, T shows the time tendency, and ε indicates the error term.

The Westerlund (2007) panel cointegration results

After the unit root analysis, the panel cointegration analysis is used to assess if the indicators have long-run correlations. The adoption of first-generation panel cointegration methods is not acceptable, as it was in the case of unit root analysis. In our study, we used the Westerlund (2007) panel cointegration test; this technique is preferable over traditional cointegration tests and is widely used in CD. The Westerlund panel cointegration method findings are shown in Table 6.

$$\Delta Y_{it} = \alpha_i d_t + \rho_i y_{it-1} + \gamma_1 \chi_{it-1} + \sum_{j=1}^{\tau i} \rho_{ij} \Delta Y_{it-j} + \sum_{j=-\alpha i}^{\tau i} Y_{ij} \Delta \chi_{it-j} + \epsilon_{it} \quad (4)$$

where in Eq. 4 d_t denoted as residual of the model, i denotes the cross-sections, and t represents the time, null hypothesis signifying no cointegration among the variables.

Two-step system generalized method of moments (SYS-GMM)

Our research utilized the generalized method of moments (GMM), specifically the system-GMM data analysis method. Various explanations served as inspirations to use this methodology. For instance, the total period in years $T=21$, from 1998 to 2018, is smaller than cross-section $N=37$ (number of countries). Secondly, the existence of a relation between unobserved country-specific impacts and the lagged value of dependent variables and the possible endogeneity of the variables used in the model in solving these issues. Previous studies already suggested the system-GMM for such kind of study (Arellano and Bover 1995; Blundell and Bond 1998). Compared to the first-difference GMM, the GMM system incorporates possible level relation information and the association between levels and the first differences (Ahn and Schmidt 1995). Thus, by manipulating stationary constraints, the GMM system method produces a more robust performance. In addition, when the instruments are weak, the GMM system can minimize possible biases and inaccuracy correlated with first-differenced GMM estimation techniques. In the context of these econometrics problems, the SYS-GMM method is used in this study. The Sargan test was conducted to over-identify the constraints on the validation of the instruments. The Sys-GMM estimator method's effectiveness is further validated by analyzing the autocorrelation of the error conditions. The absence of autocorrelation in Eqs. (6) and (7) is supported if the errors in the first-differenced equation show autocorrelation in order 1 and the absence of autocorrelation in order 2.

Data collection and analysis

The goal of this research is to investigate whether technology innovations (TINNOV) and the institution quality (INSTQ) have a mediating effect in FDV decline CO_2 emission. The study used yearly data over time period 1998 to 2018 focusing on the OECD countries, and data[1] are collected from various sources.

The proxy indicator for analyzing environmental pollution is CO_2_Emiss. There are several carbon emission dimensions, but four of them are going to be used in this research: (i) CO_2, carbon emission (per capita metric ton); (ii) CO_2 generated from electricity and heat production; (iii) CO_2, from fuel liquids consumption; and (iv) CO_2, intensity.

Financial development (FDV) index is an important independent variable, in this study; we used the index of financial development developed by the "International Monetary Fund (IMF)." Current researches have already highlighted the importance of using FDV on CO_2_Emiss proxies and preferred the IMF's FDV index (Bayar and Maxim, 2020; Rafique et al. 2020).

[1] Data were extracted from the World Bank Development Indicators (published by WDI-2020), International Monetary Fund (IMF) database, World Governance Indicator, British Petroleum database (BP Statistical Review, 2020), and OECD database.

This research used technological innovation (TINNOV) as the number of total patent applications. Several empirical research used patents as a proxy for technology innovation (Saudi 2019; Alam and Murad 2020; Rafique et al. 2020; Bakhsh et al. 2021) because patent shows the range of R&D activities and sources of technology in an economy. Study expects a positive relationship among the TINNOV and CO_2_Emiss indicators of the sample countries, and the results of this research are aligned with the current study (Bakhsh et al. 2021).

Regarding institutional quality index, this research considers six dimensions as a proxy for INSTQ: political stability, effectiveness of government, the rule of law, regulation quality, and corruption control. Study expects a positive link among INSTQ and CO_2_Emiss as estimated by Bakhsh et al. (2021) and Batool et al. (2020).

As per previous empirical studies, several control variables are also included in our study such as FDI is taken (percentage of GDP), GDP per capita growth, and openness to trade is total measure trade (exportations plus importations) percentage of GDP and energy intensity, defined as an energy consumption to GDP ratio is used to measure energy efficiency, are used as a indicators of CO_2 emissions (Baloch et al. 2019; Mardani et al. 2019; Bakhsh et al. 2021).

Econometric model specification

We applied the following dynamic panel regression model in this study, which connects CO_2 emissions to FDV, TINNOV, and INSTQ with control variables:

$$\begin{aligned} CO_2\_Emiss_{i,t} &= a_i + \lambda_t + \beta_1 FDV_{it} + \beta_2 TINNOV_{it} \\ &+ \beta_3 INSTQ_{it} + \beta_4 ROL_{it} + \beta_5 COR_{it} \\ &+ \beta_6 GOE_{it} + \beta_7 POS_{it} + \beta_8 ROQ_{it} + \beta_9 FDI_{it} \\ &+ \beta_{10} GDPG_{it} + \beta_{11} TOPS_{it} + \beta_{12} ENU_{it} + \varepsilon_{it} \end{aligned} \tag{5}$$

where CO_2_Emiss represents the four indicators of carbon dioxide emissions, i shows countries, t shows a time of the study conducted, and α, β, δ are considered as the coefficient, νt specifies country-specific impact, and ε is the residual term. The coefficients $\beta_1, \beta_2 \dots \beta_{11}$ represent the estimates of CO_2_Emiss for mediating, explanatory, and control variables. FDV = financial development, TINNOV = technological Innovation, INSTQ = institutional quality, and ROL, COR, GOE, POS, ROQ are the six indicators of institution quality. While control variables FDI = foreign direct investment, GDPG = GDP growth, TOPS = trade openness, and ENU = energy usage.

$$\begin{aligned} CO_2\_Emiss_{i,t} &= a_i + \lambda_t + \beta_1 FDV_{it} + \beta_2 TINNOV_{it} \\ &+ \beta_3 FDV_{it} * TINNOV_{it} + \sum_{j=1}^{k} \delta_j Z_{jit} + \varepsilon_{it} \end{aligned} \tag{6}$$

$$\begin{aligned} CO_2\_Emiss_{i,t} &= \alpha_i + \lambda_t + \beta_1 FDV_{it} + \beta_2 INSTQ_{it} \\ &+ \beta_3 FDV_{it} * INSQ_{it} + \sum_{j=1}^{k} \delta_j Z_{jit} + \varepsilon_{it} \end{aligned} \tag{7}$$

In Eqs. 6 and 7, we checked the interaction effect of FDV*TINNOV on CO_2_Emiss and FDV*INSTQ on CO_2_Emiss between technological innovation, institutional quality, and financial development where $\delta_j Z_{it}$ represents control variables.

Two-step Sys-GMM generates more accurate results than one-step GMM estimator. The Sargan and Hansen tests (Hansen and Singleton 1982; Sargan 1958) have to be used for instrumental validity tests. Even though Sargan test is sufficiently appropriate (Bakhsh et al. 2021; Iqbal and Daly 2014), we extend the Sargan test to over-identify conditions on the validation of the instruments.

$$\begin{aligned} CO_2\_Emiss_{i,t} &= \alpha + \beta_1 CO_2\_Emiss_{2it-1} + \beta_2 FDV_{it} + \beta_3 TINNOV_{it} \\ &+ \beta_4 FDV_{it} * TINNOV_{it} + \sum_{j=1}^{k} \delta_j Z_{jit} + \lambda_t + \varepsilon_{i,t} \end{aligned} \tag{8}$$

$$\begin{aligned} CO_2\_Emiss_{i,t} &= \alpha + \beta_1 CO_2\_Emiss_{2it-1} + \beta_2 FDV_{it} + \beta_3 INSTQ_{it} \\ &+ \beta_4 FDV_{it} * INSTQ_{it} + \sum_{j=1}^{k} \delta_j Z_{jit} + \lambda_t + \varepsilon_{i,t} \end{aligned} \tag{9}$$

Robustness test

Principal component's analysis (PCA), FDV*QOGI, and QOGI_INSTQ

PCA minimizes the dimension of data and combines them into a single index. Simultaneously, multicollinearity's potential problem by including more than one proxy in a given model can be mitigating (Lenka 2015). Table 9 in Appendix reports PCA results that are used to develop the index institutional quality and quality of governance.

$$\begin{aligned} CO_2\_Emiss_{i,t} &= \alpha + \beta_1 CO_2\_Emiss_{it-1} + \beta_2 FDV_{it} \\ &+ \beta_3 TINNOV_{it} + \beta_4 FDV_{it} * INSTQ_{it} \\ &+ \beta_5 INSTQ_{it}\_QOGI_{it} + \sum_{j=1}^{k} \delta_j Z_{jit} + \lambda_t + \varepsilon_{i,t} \end{aligned} \tag{10}$$

Equation 10 shows the lag value of carbon emission indicators, t for time, for country i, and QOGI quality of governance index; the dependent variable's lagged is linked to the residual. Our study suggested employing the lagged value of dependent and independent variable as instrument. Blundell and Bond (1998) condemned the difference GMM estimates because the difference level gives very small evidence regarding future dynamics and shows that Sys-GMM can resolve this issue and is more consistent than difference GMM.

Results and discussions

Table 1 displays the descriptive stats and the association of FDV, TINNOV, INSTQ, and CO_2_Emiss. The average value of CO_2_Emiss, carbon per capita, emissions from electricity and heat production, CO_2_Emiss from the liquid fuel consumption, and carbon emission intensity are 9.784, 56.740, 12,652.02, and 4.805, respectively. The average value of FDV index and TINNOV patent per thousand are 13.458 and 1152.08, respectively; the INSQ dimension mean values varied from − 0.879 to − 0.604. For the value of dispersion, the emissions from the standard deviation's intensity indicate less variance than the other CO_2_Emiss measures in the study. Although TINNOV is highly volatile than FDV, there is less volatility in the INSTQ; thus, during 1998–2018, institutional dimensions have been stable.

Table 1 shows the correlation among variables used in this study, and the result indicates a low association between variables. It is essential to say that some independent variables show a strong correlation but evaluated independently in econometric model. As result, it is verified that there is non-existence of multicollinearity in our outcomes.

The coefficient value of all dependent variables is less than 0.85, indicating no multicollinearity. Table 2 estimates the variance inflation factors (VIF) for the indicators to rule out the possibility of multicollinearity, which can lead to skewed results. The findings show that the VIF values for each variable are less than 5, indicating that there is no multicollinearity in our model.

Table 3 shows substantial evidence of CD in our OECD panel dataset from Breusch-Pagan and Pesaran tests (LM and scaled LM). The statistics demonstrate the rejection of cross-sectional independence and the presence of CD. Based on panel data analysis, it appears that CD is currently the focus of scholarly study in environmental economics. This work examined the CD among selected indicators. The OECD countries have several contracts and trade with each other. Thus, these economies are interconnected.

Table 4 exhibits, after revealing the CD findings, this research used the second-generation IPS (CADF) and CIPS unit root test to check the stationarity. Regarding CIPS, CO_{2PC}, CO_{2H}E, CO_{2FL}, CO_{2IS}, TINNOV, VOS, POS, ROQ, GOV, ROL, COC, GDPG, ENU, FDI, and TOP are stationary at level; however, FDV is stationary at first difference. The CADF test show a mixed order of integrations as CO_{2PC}, CO_{2HE}, CO_{2FL}, CO_{2IS}, TINNOV, VOS, POS, ROQ, GOV, ROL, COC, GDPG, ENU, and TOP are stationary at level; however, FDV and FDI are stationary at first difference.

Table 5 shows the Westerlund panel cointegration test results. The results confirm the model's cointegrating equations. Thus, there are long-run relationships between environmental quality indicators and the explanatory variables obtained in this study. Our result shows that one group (Gt) and one panel (Pt) test provide significant statistics. Based on these findings, our model's variables are cointegrated.

After confirming the existence of long-run relationship among variables through Westerlund panel cointegration test, long-run coefficients of the explanatory variables are estimated by Sys-GMM. Table 6, Table 7, and Table 8 indicate the results of the Sys-GMM related to the statistical relation between FDV, INSQ, TINNOV, and the applied CO_2_Emiss indicators. The results show the relation between INSTQ, FDV, and CO_2_Emiss indicator. Concerning the impact of FDV on CO_2_Emiss proxies, FDV showed a significant and positive impact on CO_2_Emiss, ranging from 0.103 to 0.547 percentage term. The positive relation between FDV and CO_2_Emiss is supported by existing literature (Ahmad et al. 2018; Salahuddin et al. 2018; Esmaeilpour Moghadam and Dehbashi 2018; Zakaria and Bibi 2019; Neog and Yadava 2020; Bayar and Maxim 2020). This positive linkage between FDV and environmental quality can be explained by the fact that FDV degrades the environment in developing countries; FDV is used for capitalization in these countries, i.e., to motivate the development of industries from small scale. The small industries have some advantages of economies of scale in resources usage and the pollution reduction. For that reason, pollution has enlarged in such countries after FDV.

Secondly, the INSTQ variables have a significant and negative influence on the environment, ranging from the 0.090 to a value of 0.983. These results indicate that a stronger institution climate could efficiently and conveniently decline the country's CO_2_Emiss and thereby protect the environment from degradation. This negative impact of INSTQ and environmental quality is consistent with North (1990) and Omri and Hadj (2020), when suggesting that efficient institutions will contribute to environmental sustainability, thereby reducing CO_2_Emiss (Zhang et al. 2020; Zugravu et al. 2009) that the environment is harmed by more corruption and that INSTQ enhances the environment.

Our analysis focuses on another weakness in the current literature, the composite impact of the FDV indicators of INSTQ on the four CO_2_Emiss dimensions. Tables 6 and 7 present that the finding of the moderating role between INSTQ variables and FDV on CO_2_Emiss indicators has significant negative effects on all CO_2_Emiss dimensions. The negative coefficients of the mediating role FDV and INSTQ suggest that, when institutions are strong, FDV will reduce CO_2_Emiss. In turn, if INSTQ is statistically

Table 1 Descriptive stats and the correlation matrix

	CO2pc	$CO2_{HE}$	$CO2_{FL}$	$CO2_{IS}$	FDV	TINNOV	VOA	POS	ROQ	GOE	ROL	COC	GDPG	ENU	FDI	TOP
Mean	9.784	56.740	2652.02	4.805	13.458	1152.08	−0.879	−0.852	−0.510	−0.992	−0.659	−0.604	8.907	2095.05	68.413	102.364
Std.dev	15.698	21.126	8593.52	8.918	38.012	8547.41	0.961	2.310	2.678	1.987	0.998	2.409	12.502	1169.98	52.674	72.549
Min	0.129	0.018	552.02	−1.587	−19.903	−2.250	−4.189	−7.253	−1.536	−4.821	−2.059	−2.729	−23.341	−3.652	2.049	0.082
Max	85.489	97.304	29,870.9	15.236	548.149	22,547.9	3.901	3.583	6.209	5.367	4.009	7.259	66.716	7965.51	346.259	510.209
CO_{2pc}	1.000															
$CO2_{HE}$	0.759**	1.000														
$CO2_{FL}$	−0.118	0.340*	1.000													
$CO2_{IS}$	0.608*	0.708**	0.450*	1.000												
FDV	−0.207*	0.108**	−0.241*	0.478**	1.000											
TINNOV	−0.743*	0.914**	0.985**	−0.359*	−0.189*	1.000										
VOA	−0.114*	0.427*	0.190**	0.114	0.245	0.193*	1.000									
POS	0.741**	0.421*	0.680*	0.754**	0.189*	0.210**	0.405	1.000								
ROQ	0.701	0.509*	0.298**	0.315	0.210	0.189*	0.705*	0.629*	1.000							
GOE	0.293*	0.516**	0.351*	0.340**	0.287**	0.362**	0.810*	0.608**	0.782	1.000						
ROL	0.582**	0.687*	0.201**	0.152*	0.359**	0.485**	0.544**	0.470*	0.890*	0.844*	1.000					
COC	0.297*	0.208*	0.172*	0.488**	0.250*	0.201**	0.320*	0.623*	0.791*	0.796*	0.756*	1.000				
GDPG	−0.098*	0.283**	0.098**	0.974*	−0.109	0.146**	−0.289*	−0.344*	−0.458	−0.408*	0.687**	−0.482*	1.000			
ENU	0.682*	0.379*	−0.108*	0.471**	0.153**	0.501**	−0.188	0.410	0.550**	0.689*	0.703	0.246*	0.743**	1.000		
FDI	−0.273*	−0.370*	0.470**	0.369**	−0.509*	−0.483	0.263**	0.478**	−0.783*	−0.294*	0.791**	−0.647*	0.645**	−0.092*	1.000	
TOP	0.076*	−0.416*	0.390**	−0.209*	0.088*	−0.254*	0.590**	0.582*	0.584*	0.783**	0.583*	0.763*	0.279**	0.228*	−0.510*	1.000

*, **,and *** indicate that the coefficient is significant at 10%, 5%, and 1% respectively; *t*-statistics are reported in the parentheses

Table 2 Test of multicollinearity

Indicators	VIF	Tolerance
CO_{2PC}	1.48	0.675
CO_{2HE}	1.54	0.649
CO_{2FL}	1.68	0.595
CO_{2IS}	1.86	0.537
FDV	2.14	0.467
TINNOV	1.21	0.826
VOS	1.57	0.636
POS	1.67	0.598
ROQ	1.21	0.826
GOV	1.18	0.847
ROL	1.47	0.680
COC	1.24	0.806
GDPG	2.14	0.467
ENU	1.89	0.529
FDI	2.85	0.350
TOP	1.24	0.806
Mean VIF	1.58	

DV are the environmental quality variables. The tolerance values are all greater than 0.2, and the VIF values are all less than 5, indicating that there is no multicollinearity

weak, CO_2_Emiss would increase as a result of FDV. These assumptions validate the regulatory impact of the hypothesis that FDV is good for the economy in the presence of (climate change) regulations. The institutions are that the financial industry would provide loans to environmentally sustainable projects in the presence of strong institutions. Thus, the moderation nexuses' negative and significant effect suggests the complementary influence of FDV and INSTQ on CO_2_Emiss (Zakaria & Bibi, 2019). Al-Mulali et al. (2015) suggested that a well-functioning institutional framework promotes environmental policy decisions that decrease CO_2_Emiss. Omri and Hadj (2020) also endorse the negative correlation between FDV and governance variables with CO_2_Emiss. However, the positive effect of INSTQ is supported by previous studies (Godil et al., 2020; Ibrahim, 2020). The key findings are that a significant and positive interaction variable between CO_2_Emiss and INSTQ suggests that efficient and impartial domestic institutional framework is significant for improving FDV and decreasing the carbon emission. The findings regarding the effect of control variables such as GDP, energy usage (ENU), foreign direct investment (FDI), and trade openness (TOP) on CO2 emissions are also in line with previous empirical studies (see, for example, Ullah et al., 2022; Luo et al., 2021; Ullah et al., 2021a, b; Ali and Kirikkaleli 2021; Shabir et al., 2021).

Table 8 outcome indicates the nexuses between TINNOV, FDV, and CO_2_Emiss dimensions. Concerning the correlations among FDV on different dimensions of CO_2_Emiss (per capita, heat and electricity production, liquid fuel, intensive) showed a positive effect on FDV on CO_2_Emiss indicators, which range from 0.185 to 0.852. The outcomes revealed that all coefficients of TINNOV have significantly negative on CO_2_Emiss indicator, as revealed

Table 3 Cross-sectional dependency tests

Variables	Breusch-Pagan LM		Pesaran scaled LM		Bias-corrected scaled LM		Pesaran CD	
	Statistic	Prob	Statistic	Prob	Statistic	Prob	Statistic	Prob
CO_{2PC}	1962.658***	0.000	121.521	0.000	119.623	0.000	28.147	0.000
CO_{2HE}	2247.265***	0.000	145.236	0.000	141.142	0.000	18.251***	0.000
CO_{2FL}	1836.721***	0.000	115.520	0.000	113.574	0.000	12.413***	0.000
CO_{2IS}	2157.068***	0.000	125.058	0.000	123.637	0.000	9.547***	0.000
FDV	994.423***	0.000	119.544	0.000	117.746	0.000	38.829***	0.000
TINNOV	886.348***	0.000	96.647	0.000	94.509	0.000	11.489***	0.000
VOS	678.147***	0.000	75.354	0.000	73.879	0.000	14.538***	0.000
POS	789.257***	0.000	55.984	0.000	52.967	0.000	9.478***	0.000
ROQ	593.896***	0.000	35.478	0.000	33.426	0.000	4.217***	0.000
GOV	791.527***	0.000	87.634	0.000	85.943	0.000	7.487***	0.000
ROL	917.834***	0.000	91.578	0.000	89.328	0.000	13.578***	0.000
COC	867.647***	0.000	98.657	0.000	95.713	0.000	17.547***	0.000
GDPG	5472.571***	0.000	156.331	0.000	153.175	0.000	38.154***	0.000
ENU	2963.307***	0.000	85.489	0.000	83.712	0.000	5.761***	0.000
FDI	848.475***	0.000	35.475	0.000	33.847	0.000	7.753***	0.000
TOP	1198.649***	0.000	74.523	0.000	72.547	0.000	18.893***	0.000

Note: *** showing the level of significance at 1%

Table 4 Unit root tests

Indicators	CPIS			CADF		
	Level	1st difference	Order	Level	1st difference	Order
CO_{2PC}	−2.247*	–	I(0)	−2.659***	–	I(0)
CO_{2HE}	−2.139***	–	I(0)	−2.714***	–	I(0)
CO_{2FL}	−2.558***	–	I(0)	−2.347***	–	I(0)
CO_{2IS}	−2.419***	–	I(0)	−2.138***	–	I(0)
FDV	−3.523	−2.569***	I(1)	−2.437	−2.719***	I(1)
TINNOV	−2.759***	–	I(0)	−2.198**	–	I(0)
VOS	−1.625***	–	I(0)	−2.847***	–	I(0)
POS	−1.267***	–	I(0)	−2.418***	–	I(0)
ROQ	−1.479***	–	I(0)	−2.657***	–	I(0)
GOV	−1.627***	–	I(0)	−2.317***	–	I(0)
ROL	−1.214***	–	I(0)	−2.118***	–	I(0)
COC	−1.578***	–	I(0)	−2.367***	–	I(0)
GDPG	−3.143***	–	I(0)	−1.186**	–	I(0)
ENU	−2.639***	–	I(0)	−2.497***	–	I(0)
FDI	−2.441**	–	I(0)	−1.632	−3.513***	I(1)
TOP	−1.427**	–	I(0)	−2.658**	–	I(0)

Note: Represent 1%, 5%, and 10%, significant levels ***, **, and *, respectively

in the Table 8, ranges from value −0.089 to value −0.118 indicates surging TINNOV leading to mitigates CO_2_Emiss in OECD economies. Ganda (2019) found that TINNOV has an environmentally friendly influence on CO_2_Emiss. Thus, with the increase in TINNOV, the result decreases the CO_2_Emiss. This inverse relation was also supported by Sohag et al. (2015), Salahuddin and Gow (2016), Ozcan and Apergis (2018), Godil et al. (2020), and Bakhsh et al. (2021).

Our study also examined the essential gap in the current study and investigated the mediating role between TINNOV and FDV on the consideration of CO_2_Emiss variable indicators. Table 8 indicates that the moderating role between TINNOV and FDV on considering CO_2_Emiss dimensions showed negative and statistically significant scores across proposed models. These outcomes imply for the sample countries that technology development is the principal situation FDV reduces CO_2_Emiss. The findings of our study are also coherent with Batool et al. (2020), Fan et al. (2019), Rafique et al. (2020), and Tan et al. (2019), confirming that technological developments and innovations in the impact of the technological spillover of FDV, therefore, reduce CO_2_Emiss indicators and improve quality of environment.

Lastly, regarding the relation between FDV, INSQ, TINNOV, and CO_2_Emiss indicators, our research analyzed that the control variable (the coefficient) and the sign of GDP growth (openness to trade and energy usage) have been statistically significant and positively effecting the CO_2_Emiss. The outcomes of our study are consistent with the results of Bakhsh et al. (2021). Moreover, our findings have been verified by Khan and Ozturk (2020), when GDP growth contributes to the increased atmospheric pollution. Furthermore, the correlation between energy use and CO_2_Emiss is significantly positive. This refers to the conclusion that the rise in energy usages indicates an upsurge in CO_2_Emiss. The coefficient of trade openness, which directly or indirectly influences CO_2_Emiss, proved to positively affect on the CO_2_Emiss indicators.

Table 5 The Westerlund (2007) panel cointegration results

Statistics	Values	Z-value	Robust *p* value
Gt	−3.984**	2.183	0.021
Ga	−21.363	−4.738	0.619
Pt	−9.378**	−0.063	0.036
Pa	−11.328	−2.266	0.563

Note: ** indicates rejection of the null hypothesis of no cointegration at 5% level

Robustness check

To ensure that the main findings are robust, we developed the institutional quality index and the quality governance (QOG) based on the vital component analysis and evaluated the overall effect on CO_2_Emiss indicators. Results are

Table 6 INSTQ, FDV, and CO_2_Emiss

	DV: CO_2_Emiss indicators											
	CO_2pc, carbon emissions, per capita						CO_{2HE}, heat and electricity production					
	ROQ	GOE	VOA	POS	ROL	COC	ROQ	GOE	VOA	POS	ROL	COC
	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)	(IX)	(X)	(XI)	(XII)
Constant	4..987**	2.625***	1.493**	−2.258**	0.249**	1.429***	3.789*	7.521***	4.578**	14.597**	7.145**	6.478**
	(2.990)	(7.851)	(2.874)	(2.108)	(2.905)	(4.874)	(1.890)	(5.503)	(2.997)	(2.103)	(2.047)	(2.937)
$LogCO2_{PC}$	0.970***	0.758***	0.543***	0.678***	0.520***	0.571***						
	(9.874)	(7.541)	(4.860)	(6.589)	(3.990)	(7.583)						
$LogCO2_{HE}$							0.963***	0.886***	0.912***	0.752***	0.964***	0.830***
							(9.524)	(7.526)	(3.986)	(4.609)	(4.963)	(3.099)
FDV	0.658**	0.456*	0.287**	0.583***	0.225*	0.367***	0.453*	0.356**	0.226**	0.239***	0.475**	0.657***
	(2.993)	(1.453)	(2.341)	(7.206)	(1.510)	(3.998)	(1.026)	(2.002)	(2.870)	(3.102)	(2.687)	(5.364)
ROQ	−0.241**						−0.672**					
	(−2.360)						(−2.048)					
GOE		−0.458*						−0.354**				
		(−1.001)						(−2.678)				
VOA			−0.210						−0.106*			
			(−0.453)						(−1.589)			
POS				−0.402**						−0.364*		
				(−2.305)						(−1.990)		
ROL					−0.426***						−0.132**	
					(−3.658)						(−2.602)	
COC						−0.102*						−0.360**
						(−1.026)						(−2.009)
ROQ*FDV	−0.326*						−0.009					
	(−1.008)						(−0.047)					
GOE*FDV		−0.260**						−0.137**				
		(−2.093)						(−2.024)				
VOA*FDV			−0.098						−0.402			
			(−0.587)						(−0.849)			
POS*FDV				−0.487***						−0.249**		
				(−4.359)						(−2.213)		
ROL*FDV					−0.219***						−0.220**	
					(−3.001)						(−2.069)	
COC*FDV						−0.203**						−0.429**
						(−2.119)						(−2.610)
GDPG	0.423**	0.256*	0.049	0.310**	−0.318*	−0.301**	0.097	0.152*	0.050	0.142*	0.119	0.087*
	(2.551)	(1.099)	(0.842)	(2.540)	(−1.621)	(−2.357)	(0.152)	(1.058)	(0.009)	(1.642)	(0.621)	(1.897)
FDI	0.842***	0.510**	0.782	0.998***	0.299**	0.389**	0.369**	0.598**	0.359***	0.652**	0.287*	0.652*
	(5.578)	(2.589)	(0.899)	(5.260)	(2.901)	(2.520)	(2.006)	(2.852)	(3.687)	(2.623)	(1.927)	(1.920)

Table 6 (continued)

	DV: CO_2_Emiss indicators											
	CO_2pc, carbon emissions, per capita						CO_{2HE}, heat and electricity production					
	ROQ	GOE	VOA	POS	ROL	COC	ROQ	GOE	VOA	POS	ROL	COC
	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)	(IX)	(X)	(XI)	(XII)
ENU	0.098***	0.182**	0.101**	0.009	0.131***	0.180**	0.088*	0.100**	0.001**	0.159	0.998*	0.093*
	(3.526)	(2.087)	(1.040)	(0.196)	(4.852)	(2.562)	(1.093)	(2.750)	(2.106)	(0.870)	(1.893)	(1.520)
TOP	0.280***	0.210**	0.186	0.160*	0.105***	0.054	−0.145**	0.009*	0.123***	0.168**	0.253*	−0.087
	(3.821)	(2.415)	(0.840)	(1.524)	(3.992)	(0.570)	(−2.982)	(1.113)	(4.521)	(2.105)	(1.263)	(−0.521)
N	764	713	669	713	713	759	556	669	712	712	769	713
S. period	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018
No of countries (*N*)	37	37	37	37	37	37	37	37	37	37	37	37
No of IV	25	27	25	23	28	25	27	23	25	19	27	22
No of time	21	21	21	21	21	21	21	21	21	21	21	21
AR_1	0.058	0.014	0.051	0.007	0.034	0.015	0.001	0.003	0.002	0.001	0.002	0.001
AR_2	0.504	0.472	0.542	0.149	0.354	0.270	0.409	0.301	0.189	0.216	0.367	0.273
Sargan T, *p* value	0.930	0.895	0.827	1.000	0.565	0.773	0.995	0.761	0.351	0.657	0.998	0.852
Hansen, *p* value	0.459	0.327	0.607	0.189	0.478	0.451	0.950	0.667	0.784	0.250	0.846	0.669

*, **, and *** indicate that the coefficients are significant at 10%, 5%, and 1%, respectively; *t*-statistics are reported in the parenthesis. The estimations are based on xtabond2 (Roodman, 2009)

consistent with our primary outcome robustness control (as seen in Table 9 in Appendix).

Conclusion and policy implications

This study investigated the linkage among financial development (FDV), institutional quality (INSTQ), and technological innovation (TINNOV) on carbon emissions (CO_2_Emiss) indicators in OECD countries over the period 1998–2018, employing GMM method. Precisely, our research investigated the conditioning effect of INSTQ and TINNOV on the relation between FDV and CO_2_Emiss. TINNOV and INSTQ indicators are used for policy proxies in our study, attempt to imitate FDV to reduce CO_2_Emiss. Additionally, four CO_2_Emiss dimensions and six INSTQ indicators, and FDV index indicators for the financial institution and financial market (depth, efficiency, and access) were incorporated into our study. The outcomes provide significant results for the mediating role of INSTQ and TINNOV in reducing CO_2_Emiss in OECD economies. The empirical outcomes indicate the significant and positive relation between FDV and different dimensions of carbon emission. On contrary, institutional quality and technology innovations are negatively affecting the carbon emission dimensions. Secondly, we identified a negative moderating role of institutional quality and technology innovations with financial development on different carbon emission dimensions.

Our research addresses important implications for policymakers. There is a trend to neglect the association between financial development, technology innovation, institution quality, and environmental quality in OECD economies. Though, inadequate external analyses often result in significant environmental effects. Our results suggest that, the extent of financial development and the CO_2 emission connection is highly dependent on institution quality and technology innovation. Environmentally friendly technologies could also been an essential factor in decreasing the adverse impact of FDV on the quality of environment. The study recommends that more investments in the technology field are needed, which could provide an incentive to import new technology to carbon reduction. Similarly, the authorities should also introduce effective regulations to encourage financial development and innovation measures in clean energy sources to offset the environmental damages. Finally, environmentally sound technologies could assist to protect the environmental quality by reduction of toxic waste and energy preservation.

We address some of our study's limitations. The scope of our analysis is confined to one indication of technological innovation; however, other indicators such as government expenditure on R&D, the number of research articles

Table 7 INSTQ, FDV, and CO_2_Emiss indicators

	DV: CO_2_Emiss dimensions											
	CO_{2LF}, carbon emission liquid fuel						CO_{2IS}, carbon emission intensity					
	ROQ	GOE	VOA	POS	ROL	COC	ROQ	GOE	VOA	POS	ROL	COC
	(XIII)	(XIV)	(XV)	(XVI)	(XVII)	(XVIII)	(XIX)	(XX)	(XXI)	(XLII)	(XLIII)	(LXIV)
Constant	0..982**	0.480**	0.979*	0.647	0.528*	0.780**	0.857***	0.781***	0.546***	0.801***	0.621***	0.549***
	(2.809)	(2.580)	(1.608)	(0.489)	(1.008)	(2.901)	(5.507)	(3.987)	(6.520)	(3.574)	(4.581)	(5.827)
$LogCO2_{FL}$	1.985***	1.697***	1.246***	1.115***	1.098***	1.108***						
	(7.508)	(5.057)	(3.902)	(3.089)	(6.517)	(3.001)						
$LogCO2_{IS}$							0.918***	0.879***	0.650***	0.810***	0.741***	0.614***
							(6.089)	(4.115)	(3.010)	(7.105)	(3.990)	(4.108)
FDV	0.547***	0.389**	0.301***	0.180**	0.274**	0.180*	0.401**	0.308*	0.103*	0.298**	0.281**	0.095*
	(7.804)	(2.018)	(3.981)	(1.587)	(2.480)	(1.501)	(2.870)	(1.092)	(1.992)	(2.014)	(2.682)	(1.067)
ROQ	−0.801**						−0.611*					
	(−2.956)						(−1.990)					
GOE		−0.983*						−0.401**				
		(−1.051)						(−2.087)				
VOA			−0.233**						0.129*			
			(−2.560)						(1.092)			
POS				−0.501*						−0.089*		
				(−1.050)						(−0.159)		
ROL					−0.710**						0.901*	
					(−2.389)						(1.409)	
COC						−0.090*						−0.527**
						(−2.034)						(−2.058)
ROQ*FDV	−58.687**						−0.892*					
	(−2.058)						(−1.025)					
GOE*FDV		−85.309*						−0.254**				
		(−1.590)						(−2.938)				
VOA*FDV			−32.685**						−0.389			
			(−2.749)						(−0.674)			
POS*FDV				−19.740*						−0.628**		
				(−1.990)						(−2.287)		
ROL*FDV					−39.397***						−0.198*	
					(−8.741)						(−1.024)	
COC*FDV						11.879**						−0.745**
						(2.419)						(−2.076)
GDPG	5.968**	0.847*	3.997	1.879***	0.947*	0.4778**	0.897***	0.501*	1.273**	0.387***	1.284**	0.551**
	(2.254)	(1.859)	(0.984)	(3.851)	(1.902)	(2.055)	(7.527)	(1.471)	(2.009)	(5.065)	(2.083)	(2.869)
FDI	2.925***	7.998**	3.582***	0.963*	11.854**	5.987*	0.957**	0.714***	0.602*	0.283**	0.502*	0.061**
	(7.520)	(2.906)	(5.025)	(1.904)	(2.097)	(1.879)	(2.300)	(3.009)	(1.587)	(2.009)	(1.014)	(2.002)

Table 7 (continued)

	DV: CO_2_Emiss dimensions											
	CO_{2LF}, carbon emission liquid fuel						CO_{2IS}, carbon emission intensity					
	ROQ	GOE	VOA	POS	ROL	COC	ROQ	GOE	VOA	POS	ROL	COC
	(XIII)	(XIV)	(XV)	(XVI)	(XVII)	(XVIII)	(XIX)	(XX)	(XXI)	(XLII)	(XLIII)	(LXIV)
ENU	0.782**	1.005*	0.987**	1.986	1.990**	2.073**	5.809**	0.524*	3.389***	1.874***	7.547**	0.210**
	(2.951)	(1.578)	(2.837)	(0.994)	(2.001)	(2.509)	(2.396)	(1.506)	(6.002)	(3.784)	(2.463)	(2.061)
TOP	9.125**	15.874	−21.412*	7.267	−3.109**	11.547	2.510*	4.147**	0.410*	0.087*	−5.987	0.071*
	(2.514)	(0.9745)	(1.087)	(0.921)	(2.478)	(0.963)	(1.521)	(2.005)	(1.401)	(1.551)	(−0.801)	(1.093)
N	702	669	669	589	713	702	543	672	702	708	702	669
S. period	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018	1998–2018
No of countries (*N*)	37	37	37	37	37	37	37	37	37	37	37	37
No of IV	25	23	25	21	25	25	27	23	23	25	27	21
No of time	21	21	21	21	21	21	21	21	21	21	21	21
AR_1	0.099	0.057	0.081	0.097	0.092	0.098	0.047	0.034	0.078	0.059	0.054	0.034
AR_2	0.578	0.469	0.514	0.347	0.451	0.362	0.289	0.371	0.287	0.169	0.281	0.297
Sargan T, *p* value	0.269	0.667	0.897	0.960	0.549	0.715	0.972	1.000	0.378	0.995	0.981	0.998
Hansen, *p* value	0.645	0.347	0.741	0.874	0.341	0.678	0.472	0.754	0.549	0.379	0.467	0.941

*, **, and *** indicate that the coefficients are significant at 10%, 5%, and 1%, respectively; t-statistics are reported in the parenthesis. The estimations are based on xtabond2 (Roodman 2009)

Table 8 TINNOV, FDV, and CO_2_Emiss indicators

Independent variables	Dependent variables: carbon CO_2 _Emiss			
	CO_{2PC}	CO_{2HE}	CO_{2FL}	CO_{2IS}
	(I)	(II)	(III)	(IV)
Constant	25.214***	38.125**	2.671*	4.508***
	(8.217)	(9.247)	(1.315)	(6.115)
$LogCO2_{PC}$	0.610***			
	(5.154)			
$LogCO2_{HE}$		0.428**		
		(2.960)		
$LogCO2_{FL}$			0.987***	
			(6.417)	
$LogCO2_{IS}$				0.325***
				(3.981)
FDV	0.852***	0.185***	0.402***	0.389**
	(7.251)	(0.003)	(5.214)	(2.517)
TINNOV	−0.109***	−0.118	−0.089***	−0.098**
	(−4.251)	(−0.079)	(−3.892)	(−2.541)
TINNOV*FDV	−0.261***	−0.389*	−0.098***	−0.352**
	(−7.015)	(−1.819)	(−4.214)	(−2.581)
GDPC	0.081*	0.815	0.987*	0.518**
	(1.850)	(0.624)	(1.659)	(2.851)
ENU	0.152***	0.089*	0.358**	0.109*
	(5.810)	(1.928)	(2.620)	(1.109)
FDI	0.110**	0.209***	0.419***	0.090**
	(2.520)	(4.109)	(3.990)	(2.105)
TOP	0.205***	0.308**	0.052***	0.009*
	(6.098)	(2.957)	(5.210)	(1.019)
N	713	752	669	745
S. period	1998–2018	1998–2018	1998–2018	1998–2018
No of countries (*N*)	37	37	37	37
No of IV	25	23	25	22
No of time	21	21	21	21
AR-1	0.003	0.005	0.010	0.001
AR-2	0.475	0.251	0.764	0.327
Sargan T, *p* values	0.347	0.224	0.207	0.453
Hansen, *p* values	0.629	0.469	0.243	0.567

*, **, and *** indicate that the coefficients are significant at 10%, 5%, and 1%, respectively; *t*-statistics are reported in the parenthesis. The estimations are based on xtabond2 (Roodman, 2009b)

published per 1000 citizens in-country, and the global innovation index can be used in future research studies. Moreover, the same methodology and indicators can be utilized for the sample countries of other regions, and the countries classified on the level of income and development to ensure the significance of analyzed variables in environmental sustainability.

Appendix

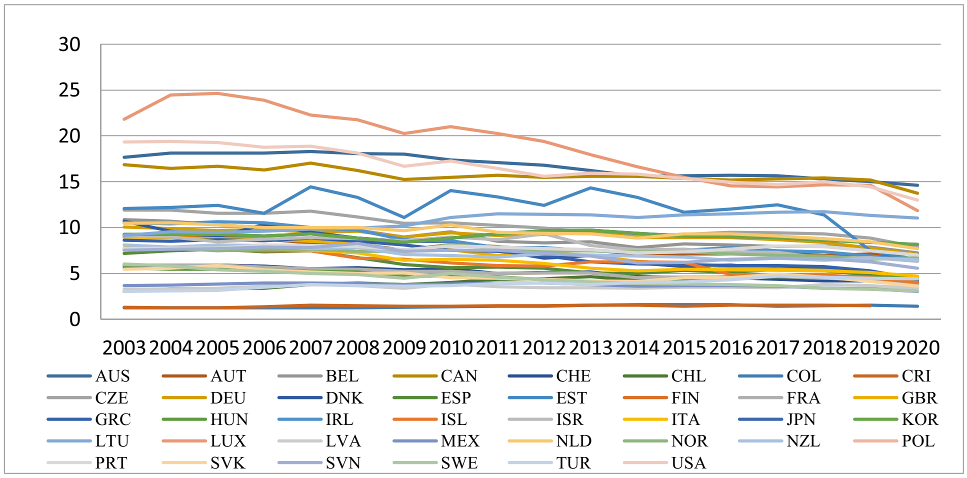


Fig. 5 Trends in the CO2_Ems (metric tons/capita) in OECD economies. Source: Authors' own calculations based on OECD database (2020)

Table 9 Robustness check with an alternative measure of INSTQ_QOG (QOG*FDV)

	(I) CO_{2PC}	(II) CO_{2HE}	III CO_{2FL}	IV CO_{2IS}
Cons	3.968***	1.765**	5.263***	1.879*
	(7.320)	(2.469)	(5.308)	(1.008)
$CO_{2pc}(t-1)$	0.299**			
	(2.145)			
$CO_{2HE}(t-1)$		0.986***		
		(4.053)		
$CO_{2FL}(t-1)$			0.829**	
			(2.009)	
$CO_{2IS}(t-1)$				0.529**
				(2.109)
FDV	0.477**	0.372***	0.507**	0.372**
	(5.441)	(4.205)	(3.101)	(2.001)
INSTQ_QOG	0.540*	0.358**	0.369*	0.208**
	(1.509)	(2.015)	(1.047)	(2.054)
QOG*FDV	0.209**	0.548**	0.174*	0.428***
	(2.007)	(2.367)	(0.247)	(3.009)
TINNOV	0.587*	0.893**	0.687*	0.157*
	(1.325)	(2.541)	(1.024)	(1.087)
GDPG	0.029***	0.046***	0.009***	0.175**
	(5.033)	(7.017)	(4.254)	(2.547)
FDI	−0.022**	−0.033**	−0.142**	−0.527**
	(−2.037)	(−2.039)	(−2.014)	(−2.153)
TOP	0.078*	0.091**	0.029*	0.254**
	(1.011)	(2.890)	(1.125)	(2.425)
ENU	0.025**	0.031***	0.147**	0.125***
	(2.405)	(5.819)	(2.025)	(4.257)
N	713	752	761	752
S. period	1998–2018	1998–2018	1998–2018	1998–2018
No of countries	37	37	37	37
No of IV	25	23	27	23
No of time	21	21	21	21
AR_1	0.003	0.001	0.019	0.009
AR_2	0.475	0.251	0.508	0.121
Sargan T, *p* value	0.347	0.224	0.451	0.293
Hansen, *p* value	0.629	0.469	0.579	0.512

*, **, and *** indicate the coefficients are significant at 10%, 5%, and 1%, respectively; *t*-statistics are reported in the parenthesis. The estimations are based on xtabond2 (Roodman, 2009b)

Author contribution Responsibilities are as follows:

Du Jianguo: conceptualization; supervision; validation; writing—review and editing.

Kishwar Ali: conceptualization; writing—original draft preparation; formal analysis; validation; data curtain; methodology.

Faisal Alnori: conceptualization; methodology; formal analysis; validation; writing—review and editing.

Sami Ullah: conceptualization; methodology; writing—original draft reviews; validation.

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

Declarations

Ethics approval Study did not use any data which need approval.

Consent to participate All authors have participated in the process, read and agreed to the published version of the manuscript.

Consent for publication All authors have read and agreed to the published version of the manuscript.

Competing interests The authors declare no competing interests.

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