Cuadernos de Economía (2023) Volume 46, Issue 132, 157-169

Cuadernos de economía

www.cude.es

ARTÍCULO

The Role of Green Finance and Green Technology in Improving Environmental Performance Across OECD Economies: An in-depth Investigation Using Advanced Quantile Modeling

Muhammad Nauman Khan[1*], Abdullah Bin Omar[2], Noor Azlinna Azizan[3], Sazali Zainal Abidin[4]

[1] Faculty of Business Studies, Arab Open University, Jeddah, Saudi Arabia.
Email: m.nauman@arabou.edu.sa
[2] Department of Business Administration, National College of Business Administration & Economics (NCBA&E) Lahore, (Sub-campus Multan), Pakistan.
Email: abo776@gmail.com
[3] SolBridge International School of Business, Woosong University, Daejeon 34613 Republic of Korea.
Email: nazlinna@solbridge.ac.kr
[4] UBD School of Business and Economics, Universiti Brunei Darussalam.
Email: sazali.zainal@ubd.edu.bn

**Corresponding Author Email: m.nauman@arabou.edu.sa*

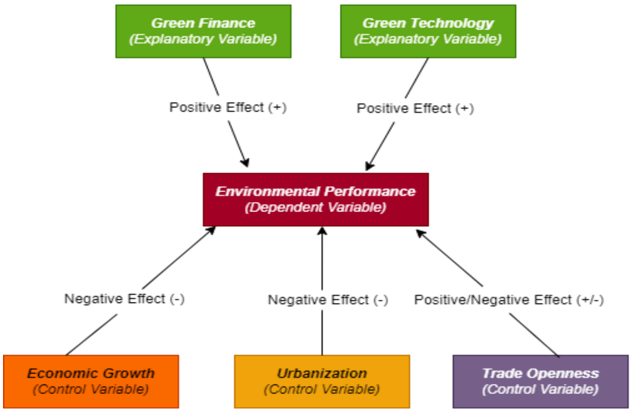
Jel Codes:
F64, O13

Keywords:
Green Finance, Green Technology Innovation, Environmental Performance, Co_2 Emissions, OECD Countries, Environmental Degradation.

Abstract: Green finance and green technology play a crucial role in achieving sustainable environmental performance by channelizing funds into eco-friendly projects and driving the development of environmentally responsible technologies and solutions. Traditional finance and technology innovation are not capable enough to facilitate the transition to a low-carbon economy, reduce resource consumption, emissions, and environmental impact, and contribute to environmentally responsible economic growth. Modern literature lacks enough evidence on the effect of green finance and green technology on environmental performance, especially for OECD countries. By using a panel dataset of OECD countries from 2010 to 2021, this paper probes into the status quo to what extent green finance, green technology, and selected control variables (economic growth, urbanization, and trade openness) are successful to mitigate environmental degradation. Utilizing robust methodology, study employs second-generation unit root tests, cointegration frameworks tailored for cross-sectionally correlated panel variables and quantile regression. The study finds the presence of enduring relationships among said factors. Quantile regressions at varying points of the environmental performance spectrum reveal that green finance and green technology play pivotal roles in enhancing environmental sustainability, with amplified benefits for OECD countries. Economic growth exhibits a context-dependent U-shaped relationship with environmental performance. Urbanization consistently hampers environmental performance, particularly in high-performing nations. Trade openness displays mixed findings. The study has some important policy implications. Policy-wise, global governments should prioritize green innovations and sustainable finance since fostering sustainable finance environments and eco-friendly technology research are crucial for greener futures and essential to achieve sustainable development goals.

Author Correspondence: m.nauman@arabou.edu.sa

https://doi.org/10.32826/cude.v46i132.1215



Graphical Abstract

1. Introduction

World economies have embarked on an ambitious journey towards a sustainable future to protect the planet by changing the climate and controlling environmental degradation after the development of United Nations Sustainable Development Goals (SDGs) 2030 and commitments outlined in Paris Climate Agreement formed by global agencies and national governments. In this context, Asian Development Bank also played its vital role by initiating multiple projects (like climate change finance) to ensure eco-friendly sustainable growth in Asia and Pacific (Khan et al., 2022). Environmental pollution spawned several problems adversely affecting the economies, global ecological system, plants and ground soil and even changed people's life style (Intui et al., 2022; Khoshnevis Yazdi & Khanalizadeh, 2017; Zaidi & Saidi, 2018) therefore, the existing body of literature extensively examining the environmental performance as healthy environment is essential for sustainable economy, individual health and industrial activities (Alharthi et al., 2022; Javaid et al., 2022; Khan et al., 2020).

The term 'green finance' has gained a considerable interest in academia, among global organizations and economies and considered a key element in achieving SDGs (Lazaro et al., 2023). According to the European Banking Federation (EBF), green finance refers to the ecological elements such as air quality, water, biodiversity, greenhouse gas emissions; and the elements related to climate change such as renewable energy, energy efficiency, mitigation and prevention of climate change (EBF, 2017). Green bonds are first issued in 2007 by the European Investment Bank, and later on the green bonds market took off in 2013 but it is still in its infancy and rapidly expanding in developed economies (Wang et al., 2020). There is an extensive debate among different market participants on the meaning of 'green' and what makes the finance 'green' (Eunomia et al., 2017), however, green finance supporters claimed that the key advantage of developing green finance is to reinforce the characteristics of finance in order to improve the environmental quality (Zhou et al., 2020) as most of them found the positive effect of green finance on economic activities, sustainable social development and environmental performance (Brand, 2012; Iqbal et al., 2021). Green finance has a strong relation with several SDGs that can be obtained by increasing investment in green finance (Taghizadeh-Hesary & Yoshino, 2019). The green finance market comprised of financial products such as ecological options, nature-linked securities, environmental funds, and market-oriented mechanism such as emissions trading and both control pollution emission to save enterprise from unanticipated nature change (Wang & Zhi, 2016). Nowadays, the required targets of SDGs 2030, actions on climate change and consensus to protect the environment have drawn attention to and raised the importance of green finance. In empirical literature, the term green finance often mixed with sustainable finance, environmental finance, climate finance, green loans, green bonds and green investment (Dörry & Schulz, 2018; Zhang et al., 2019) and these terms are interchangeably used to refer green finance (Akomea-Frimpong et al., 2022).

It is generally accepted that global economies have been rapidly evolving and people's productivity and living standard have been significantly improved (Dao, 2021), but on the other side, this improvement and activities of human and industries (e.g., burning oil and coal) are brough about the sever environmental pollution worldwide. Therefore, it can be said that polluted activities on the planet are the genesis of global warming require urgent measures to protect the earth from climate changes and green technology is considered as a dominant factor in protecting the environment. Green technology can be differentiated from conventional technology by its complex evaluation, lengthy cycle time, high risk, and slow return which creates a challenging situation for an enterprise to arrange internal financing to promote green innovation activities (Jiang et al., 2022). Green technology is deemed as a core means to handle issues related to environmental pollution (Feng et al., 2022) concentrate on synergistic development, assists in reducing emissions in the production process and improvs the efficiency of natural and industrial resources (Alshammari, 2018; Kammerer, 2009; Marshall et al., 2005) thus, contributing in the coordinated development of environment and economy (Musa et al., 2021; Zhang et al., 2022). But, on the other hand, infant stage of the green market, meticulousness and complexity of green technology innovation lead to greater market risks, high costs and longer payback period for green technological activities in industry and economy (Anas et al., 2020; Handam & Al Smadi, 2022; Hottenrott & Peters, 2012) raising strong financial constraints.

Understanding the contribution of green finance and green technology in improving environmental performance deserves further investigation. Motivated by the lack of green financing and technological insight in The Organization for Economic Cooperation and Development (OECD) markets, this study aims to fill in the existing gap and pose two fundamental questions in context of OECD economies which essentially needs to be addressed: (1) How green finance affects the environmental quality; (2) How green technological innovation influence the environmental quality.

Contributions of this study with the relevance of environmental issues are fourfold. First, existing studies examined the effect of financial development on environmental pollution using the traditional measurements and few studies investigate the role of green finance. This paper provides fresh evidence on the impact of green finance on environmental performance. Second, previous studies mainly focus on the impact of general technological advancement on environment with some exceptions. This study provides a new insight on how environmental performance is affected using green technological innovation. Third, past studies used the traditional measurements for the environmental performance like CO_2 emissions, while this study uses a comprehensive environmental performance index compiled by Yale Center for Environmental Law and Policy, covering several factors of environment which is relatively a better and comprehensive measurement than other single environmental indicators that exhibit a small part of environmental quality. Fourth, most of the previous studies focused Asian countries with the more inclination towards China (Sek & Chu, 2017), few considered developing and developed economies, while the OECD economies are being ignored in literature for the analysis of green finance and green technology effect on environmental quality. This investigation for OECD economies is imperative as they are the world's largest industrialized countries, having significant contribution and economic influence in the world. Additionally, the top largest OECD countries are highly developed and most advanced in terms of resources, development and innovation (Frondel et al., 2007), hence, play their significant part in designing global economic and financial policies. Although during the last decade, the OECD countries make a significantly development in green finance and green technology to reduce environmental pollution (Umar & Safi, 2023), however, during 2019 the per capita rate in OECD economies of Cox emission is 8.5 kg, NOx rate is 19.3 kg, GHG emission is 11.3 tons, and CO_2 emission is 8.3 which is far away from net-zero emission target (Behera & Sethi, 2022) that warrants in-depth investigation to comprehensively understand the subject.

The remainder of the paper is organized as follows. Next section summarizes the past studies based on the selected variables, section 3 presents the econometric model and methodology, section 4 explains the empirical results and discussion of obtained findings and last section provides the conclusion of the study with some policy implications.

2. Literature Review and Hypothesis Development

2.1 Green Finance and Environmental Performance

Green finance exhibits a novel ecological approach and deemed as a best tool to protect the environment, mobilizing financial resources (Akomea-Frimpong et al., 2022) and attain sustainable investment and resource utilization (Hemanand et al., 2022). The role of green finance in mitigating environmental degradation and its benefits towards improving the environment is examined by several past studies. The relationship between green finance and environmental performance is tested by Afzal et al. (2022) by using a sample of 40 European countries and confirms the inverse relationship between green finance and environmental degradation. Chin et al. (2022) investigated the role of green finance in reducing environmental degradation in the Belt and Road Initiative (BRI) region using the Generalized Method of Moments approach and found that green finance is significantly and inversely correlated with environmental degradation. Glomsrød and Wei (2018) claimed that if the policies regarding the utilization of green finance are properly formulated and implemented at global level, the global coal consumption can be reduced by 2.5% by 2030, while the contribution of non-fossil electricity can be enhanced from 42 to 46% at worldwide level. The sustainable development in Asian economies requires a drastic shift from fossil fuel consumption and greenhouse gas emission towards green business models and resource efficient technologies (Dkhili, 2019; Volz, 2018). Instead of directly effecting the environment, green finance provides support to the projects related to environmental protection and eco-friendly enterprises, which resultantly improves environmental quality (Zhou et al., 2020).

The study of Gianfrate and Peri (2019) analyzed the 121 European green bonds using propensity score matching approach and found them more financially suitable as compared to non-green bonds as green bonds play a significant role in greening the economy without financially damaging the issuers. The hypothesis that the green finance plays a significant role in mitigating the deterioration of environmental quality is supported by Khan et al. (2022) who utilized the data of 26 economies from Asia, Africa, Europe and the United States and employed fixed effect regression model. The findings of Iqbal et al. (2021) supports the view that green finance play a significant role in mitigation of carbon footprints. To measure the joint effect of environment, energy and financial variables, their study applied sensitivity analysis along with the formulation of a composite indicator in data envelopment analysis technique to develop a green finance index for a mix of developed and developing economies, concluding green finance fosters the mitigation of environmental degradation.

China is considered as a forefront leader in adopting green finance and one of its major policies is green credit policy to promote green development (Zhang et al., 2021). Its green finance industry is rapidly growing through the transformation of financial structure, specially by proposing a rigorous green financial system in their 13th five-year plan that stimulate the industrial sector to play their critical role in assuring sustainable development (Muganyi et al., 2021). Therefore, a comprehensive analysis on the influence of green finance policies of China on carbon emissions was conducted by Muganyi et al. (2021) using a panel dataset of 290 cities by utilizing Semi-parametric Difference-in-Difference approach. Their results confirmed a significant reduction in industrial gas emissions by the means of implementing green finance policies in China. Similarly, using the data of 30 municipalities and provinces in China, Zhou et al. (2020) examined the relationship between green finance and environmental performance and found the heterogeneous impact of green finance on ecological indicators but, at the nationwide level, a significant role of green finance was observed in improving the environment. Likewise, based on a panel data of thirty Chinese provinces, Zhang et al. (2022) analyzed the spatial-temporal properties and driving forces of the coordinated development of environmental performance and green finance in Chinese economy. Their findings reveal an overall upward trend in green finance and environmental performance and these results are also confirmed by Huang and Chen (2022), Gao et al. (2023), Li and Gan (2021), and Deng and Zhang (2023). In a same way, Zhang et al. (2021) examined the environmental effects of the green credit policy by using a panel data of 30 provinces and 945 listed companies of China and difference-in-difference model, concluding that green credit policy contributes to the mitigation of various types of emissions.

Apart from green finance, several studies concluded that environmental degradation can be controlled by other means as well such as renewable energy and trade (Dogan & Seker, 2016), financial development and market value of listed companies (Guo et al., 2019), industrialization, urbanization and fossil fuels' contribution in energy (Aller et al., 2021). Therefore, summarizing the preceding discourse, the following hypothesis is put forth.

H_1: *Green finance has a significant positive impact on environmental performance.*

2.2 Green Technology and Environmental Performance

A plethora of studies about green technology address the conjecture whether green technology contributes to mitigate environmental degradation. Chen and Lee (2020), for example, provided a cross country evidence by employing a panel of 96 economies and their group-based results indicated that CO_2 emissions can be significantly reduced by green technological innovation in high-CO_2 emissions, high-technology, and high-income economies. Based on a survey data of 198 Chinese manufacturing firms, Chen et al. (2015) posited that green innovation is the critical factor of environmental product quality and has a positive effect on environmental performance. A study of Du et al. (2019) investigated the extent to which green technology contributes in reducing Carbon dioxide emissions by considering certain income level threshold for 71 economies, concluding carbon dioxide emissions cannot be significantly reduced using green technology for economies whose income level below the threshold but do for the economies whose income level exceed the threshold. By using the data of 2010 Eurostat Community Innovation Survey, Robinson and Stubberud (2015) examined the motive behind environmental innovation among small, medium, and large-sized enterprises involved in process innovation, finding that objective of reducing adverse environmental impact by green innovation process is an important and key objective for large-sized enterprises than other small and medium enterprises (SMEs).

Introducing green technology in industry along with effective trade-in program can significantly reduce environmental degradation (Dou & Choi, 2021). On the relationship between environmental performance and green innovation, some researchers such as Cai and Zhou (2014), Darnall et al. (2008) and Frondel et al. (2007) claimed that some internal and external forces, related to the environmental policy formation, compel businesses to promote green innovation. Green innovation in production processes should also be introduced along with following environment related rules and regulations as argued by Chen et al. (2015). The viewpoint that environmental quality can be improved by decreasing carbon dioxide emission using green environmental technology is also supported by Bashir et al. (2020) and Nesta et al. (2014) who utilized the data of OECD economies, Sun et al. (2008) and Wei and Yang (2010) who observed the case of China, and Kahouli (2018) who focused Mediterranean countries. Green innovation assists firms to bring advancement in the consumption of resources and production process which ultimately enable them to achieve legal environmental protection requirement (Chan, 2005; Oliva et al., 2019).

The study of Singh et al. (2020) used the data of 309 manufacturing SMEs and concluded that SMEs' environmental performance is significantly influence by green innovation. By applying the panel quantile regression, Chen and Lei (2018) provide evidence on global thirty economies that environmental quality can be improved by mitigating the carbon dioxide emissions using green technologies. Kratzer et al. (2017) and Fousteris et al. (2018) argued that firms can obtain strong competitive edged and improve environmental performance with the help of green innovation. The investigation on the impact of green innovation on environmental performance conducted by Kraus et al. (2020) by utilizing the data of 297 Malaysian manufacturing firms reveals that green innovation is positively related with environmental performance. Another evidence on Malaysian economy was provided by Sohag et al. (2015) revealed that the level of carbon footprints can be reduced by technological innovation. Other significant benefits, such as enhancement in overall firm's performance (Mahto et al., 2020), mitigation of adverse environmental impact of industries (Lin et al., 2013; Weng et al., 2015), reduction in industrial waste and costs (Day & Schoemaker, 2011; Millard, 2011) and improvement in customers' green demand for environmental protection (Handfield et al., 2002) can be obtained through green technology. An investigation on eight industrial sectors of Taiwan was conducted by Chiou et al. (2011) by applying structural equation modeling on survey data of 124 companies and found significant benefits of green innovation on environmental performance. A sectoral analysis of Italian regions regarding the effect of environmental innovations on environmental performance was undertook by Ghisetti and Quatraro (2017) and posit that sectors with higher level of green technologies exposed better environmental performance. Green technology is now becoming the mandatory part of firms' policies related to environmental management, signifying green technology aids to protect the environment (Adegbile et al., 2017; Kammerer, 2009). Energy intensity can be reduced by green energy innovations which resultantly improved environmental quality and mitigate carbon dioxide emissions (Shahbaz et al., 2018; Shahbaz et al., 2020). The conjecture that green innovation positively affect the environmental performance is supported by Seman et al. (2019) who utilized 123 ISO-14001 certified manufacturing firms. Finally, long-term relationship between green technology and environmental performance is also confirmed by Wang et al. (2022) utilizing the data of 57 developing economies. Based on above discussion, the following hypothesis can be formulated.

H_2: *Green technology has a significant positive effect on environmental performance.*

The above discourse discloses that the connection between green finance, green innovation and environmental performance has not become successful to draw authors' attention, particularly considering environmental performance index. Specifically, most of the author's attention were diverted towards Chinese economy among Asian economies, while OECD economies were being neglected for this investigation. Therefore, the current research fills in the gap by investigating the impact of green finance and green innovation on the environmental performance index for OECD economies during 2010 to 2021.

3. Data, Econometric Model and Methodology

3.1 Data and Variables' Description

The study investigates the effect of green finance and green technology along with control variables on environmental performance using the panel country-level data of 33 OECD economies during 2010 to 2021 due to data constraints. Chile, Colombia, Costa Rica, Korea, and Mexico are dropped due to unavailability of data for some variables. Rationales behind selecting the OECD economies are threefold. Most of the OECD countries are advanced and developed about resources and, according to the Worldwide Air Quality ranking[1], most of the OECD economies have serious air quality issues and pollution problems that warrants this investigation. Second, most OECD economies are technologically advanced and great contributor of green technological innovations. Third, mostly OECD economies are subject to high capitalization in green bonds.

Environmental performance index is a dependent variable; green finance and green technology are explanatory variables; while economic growth, urbanization and trade openness are the control variables. The description, measurement and data source of each variable are given below and illustrated in Table 1.

3.1.1 Environmental Performance Index (denoted by EPI)

Following Wang et al. (2022) and Niu et al. (2017), environmental performance is measured by the index of environmental performance compiled by Yale Center for Environmental Law and Policy which is a better proxy than traditional individual environmental measures like CO_2 emissions and greenhouse gas emissions (Yang et al., 2021). Based on how well countries perform under several types of core environmental policies such as energy, habitat and biodiversity, climate change, environmental health, agriculture, water and forests, this index offers a weighted score of an economy's environmental quality. In addition, two broad categories are covered under EPI: *environmental health* which includes water, waste management, heavy metals, sanitation and drinking, and air quality, and *ecosystem vitality* which covers air pollution, energy, biodiversity, climate change, habitat, agriculture, forests, environmental health and fisheries. Therefore, EPI is a more comprehensive measure that gives picture of overall country's environmental quality as compared to traditional environmental indicators that reflect a sub-part of environmental performance (Ansari et al., 2019; Rogge, 2012).

3.1.2 Green Finance (denoted by LnGF)

Similar to Meo and Karim (2022), Rasoulinezhad and Taghizadeh-Hesary (2022) and Al Mamun et al. (2022), green finance is proxied by natural logarithm of green bonds issued by a country and data is obtained from climatebonds.net. Muganyi et al. (2021) argued that issuance of green bonds is supported by shareholders as they have potential to enhance firm value in future. In financial market, the 'green' label with corporate bonds signifies the accountability and willingness of issuers to invest in environment-friendly projects (Zerbib, 2019).

3.1.3 Green Technology (denoted by LnGT)

In line with Wang et al. (2022) and Zheng et al. (2021), green technology is proxied by the value of patent applications related to environmental technologies such as soil remediation, waste management, air and water pollution abatement. The data of green technology is obtained from OECD statistics website[2].

3.1.4 Control Variables

Consistent with Du et al. (2019) and Chin et al. (2022), this study also accounts for important control variables such as economic growth, urbanization and trade openness measured as gross domestic product (GDP) per capita (denoted by *LnYP*), urban population as a percentage of total population (denoted by *URB*) and total trade as a percentage of GDP (denoted by *TOP*) respectively. Control variables are added into the model to avoid issues from omitted variables bias and to examine their effect on environmental quality of OECD countries. Data of all control variables is obtained from the renowned world bank database[3], i.e., World Development Indicators (WDI).

Table 1: Variables' Description.

Variable	Symbol	Measurement	Source
Environmental performance index	*EPI*	Covers various environmental aspects like air quality, sanitation & drinking water, heavy metals.	Yale Center for Environmental Law and Policy
Green Finance	*LnGF*	Green bonds	climatebonds.net
Green Technology	*LnGT*	Total amount of patent applications	OECD database
Economic growth	*LnYP*	GDP per capita	WDI
Urbanization	*URB*	Urban population as a percentage of total population	WDI
Trade openness	*TOP*	total trade as a percentage of GDP	WDI

3.2 Econometric Model

Environmental performance is influenced by various factors such as green financing, green innovations, population, urbanization, GDP per capita, the square of GDP per capita, and trade openness (Wang & Zhang, 2021). The econometric model, given in equation 1, integrates insights from economic and environmental studies that propose various determinants affecting a country's environmental performance (Wang & Zhang, 2021)

$$EPI = X\beta + \theta + e \quad (1)$$

where *EPI* is a vector of Environmental Performance Index for all countries over the 12-year time period. *X* is a matrix of all explanatory variables and control variables. *β* is a vector of coefficients to be estimated. *θ* is a vector of individual fixed effects for each country, capturing unobserved and country-specific characteristics. *e* is a matrix of error terms.

[1] https://aqicn.org/rankings/
[2] https://stats.oecd.org/
[3] https://www.worldbank.org/

3.3 Cross-Sectional Dependence (CSD)

The panel data have observations across multiple cross-sectional units and time periods which is widely used in econometric analysis. However, the presence of cross-sectional dependence can affect the reliability of panel data models. In this section, the study outlined the various approaches to detect cross-sectional dependence in panel dataset. The present study, utilize the Breusch-Pagan LM test, Pesaran Scaled LM test, Bias-Corrected Scaled LM test, and Pesaran CD test to ensure the robustness of our analysis. All these tests have a null hypothesis of no cross-sectional dependence.
The Breusch-Pagan (BP) LM test serves as a first step to identify cross-sectional dependence. It is formulated as follows:

$$LM_{BP} = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij}\,\hat{\rho}_{ij} \rightarrow \chi^2_{\frac{N(N-1)}{2}} \quad (2)$$

LM_{BP} represents the BP LM test statistic, $\hat{\rho}_{ij}$ is correlation coefficient, N denotes the number of cross-sectional units, T is time period, LM_{BP} is asymptotically distributed as x^2 distribution with degree of freedom $N(N-1)/2$ for fixed N and $T_{ij} \rightarrow \infty$.
Building upon the LM_{BP} test, the Pesaran Scaled LM (LM_{PS}) test is incorporate to account for the panel's time dimension in case of $N \rightarrow \infty$ and $T_{ij} \rightarrow \infty$, which is formulated as under:

$$LM_{PS} = \sqrt{\frac{N}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (T_{ij}\hat{\rho}_{ij} - 1) \rightarrow N(0,1) \quad (3)$$

The LM_{PS} test is asymptotically standard normal and provides a scaled metric that accommodates the panel's temporal dimension, enhancing the ability to detect cross-sectional dependence (Pesaran, 2004). The LM_{BP} and LM_{PS} tests may have size distortion, meaning that the actual significance level of the test may differ from the nominal level. This test may have inadequacy to not obtaining value of $E(T_{ij}\hat{\rho}_{ij} - 1)$ around zero for T_{ij} (Pesaran, 2004) and can lead to incorrect inferences about the CSD of the data. To address this issue, Pesaran (2004) proposed following alternative test:

$$CD_P = \sqrt{\frac{2}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij}\hat{\rho}_{ij} \rightarrow N(0,1) \quad (4)$$

The CD_P represents the Pesaran CD test statistic which is asymptotically normally distributed when both $N \rightarrow \infty$ and $T_{ij} \rightarrow \infty$. In addition to these tests, the study also utilized Baltagi, Feng, and Kao (BFK) bias-corrected scaled LM (LM_{BCS}) test which is extended based on LM_{PS} test proposed by Pesaran (2004) to resolve the issue of size distortion in the LM_{BP} and LM_{PS} tests (Baltagi, Feng, & Kao, 2012). The BFK test corrects for the bias introduced by the lagged dependent variable in the scaled LM test by subtracting a bias term (N/2(T-1)) from the test statistic. The BFK test has better size and power properties than the LM_{BP} and LM_{PS} tests, and it is robust to different forms of CSD, which is calculated as follows:

$$LM_{BCS} = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (T_{ij}\hat{\rho}^2_{ij} - 1) - \frac{N}{2(T-1)} \rightarrow N(0,1) \quad (5)$$

The LM_{BCS} test provides an adjusted statistic that accounts for finite sample biases in large panel datasets i.e. $N \rightarrow \infty$ and $T_{ij} \rightarrow \infty$.

3.4 Panel Unit Root Tests

In panel data analysis, unit root tests are essential in determining whether the variables under investigation exhibit non-stationary behavior. However, panel data variables often exhibit cross-sectional dependence, which can lead to size distortions and incorrect inferences (Gengenbach et al., 2009; Pesaran, 2004). To solve this issue, our study used second-generation unit root tests such the Pesaran (2007) Panel Unit Root test (CIPS) and the Maddala and Wu (1999) Panel Unit Root test (MW).
The *MW* test statistic is formulated as follows:

$$MW = \frac{T}{(nT)^{1/3}} \cdot \frac{\sum_{i=1}^{n}(\hat{r}_i)}{\sqrt{\frac{\sum_{i=1}^{n}(\hat{r}_i^2)}{n}}} \quad (6)$$

where T denotes total number of time periods, n represents the count of cross-sectional units. $\hat{r}_i$ is an estimated residual resulting from regressing the variable of interest on its lagged values for each individual cross-sectional unit. The *MW* test operates under the assumption that the variable is non-stationary for each individual cross-sectional unit.
The current study also employed the CIPS test developed by Pesaran (2007), a robust tool for testing unit roots in cross-sectional dependent panels. The test statistic is given by:

$$CIPS = \frac{T}{\beta^2} \cdot \frac{1}{n} \sum_{i=1}^{n} (\hat{r}_i^2) \quad (7)$$

where *CIPS* denotes the Pesaran panel unit root test statistic. T is total number of time periods, and n is the count of cross-sectional units. T stands for total time periods and n for cross-sectional units. β is the coefficient of the autoregressive process and it is estimated from the panel regression. $\hat{r}_i$ is the estimated residual resulting from regressing the variable of interest on its lagged values. The CIPS test is conducted with the null hypothesis that the variable is non-stationary for each individual cross-sectional unit.

3.5 Panel Cointegration

The next step involves investigating potential long-term relationships among the variables specified in equation (1). The study utilized the second-generation panel cointegration test introduced by Westerlund (2007) in four different forms which considers diverse panel characteristics and presence of CSD. These tests, which rely on structural dynamics rather than residual dynamics, avoid imposing common factor restrictions. To assess the null hypothesis of no cointegration, it is examined whether the error-correction term in a conditional error model is statistically different from zero. Rejecting the null hypothesis of no error correction implies the rejection of the null hypothesis of no cointegration. The error-correction model, assuming all variables are integrated of order 1, can be succinctly represented as follows:

$$(1-L)EPI_{it} = \hat{\delta}_i d_t + \alpha_i\left(EPI_{i,t-1} - \hat{\beta}_i x_{i,t-1}\right) + \sum_{j=1}^{p_i} \alpha_{ij}(1-L)EPI_{i,t-j} + \sum_{j=-q_i}^{p_i} \gamma_{ij}(1-L)x_{i,t-j} + \varepsilon_{it} \quad (8)$$

where L is lag operator, ε_{it} is usual error term for country i at time t, d_t encompasses the deterministic elements within the model. There are three possible cases to consider: 1). d_t equals 0, equation (8) contains no deterministic terms, 2). d_t equals 1, the term (1-*L*)EPI_{it} is generated with a constant, and 3). d_t is represented as $(1, t\acute{})$, the term (1-*L*)EPI_{it} is generated with both a constant and a trend component. The potential dependence across individual units is addressed using bootstrap methods. Here, the null hypothesis of no cointegration (a_i = 0) is tested against alternate hypothesis of cointegration (a_i < 0) between EPI_{it} and x_{it} (for detail see Westerlund (2007)). Two out of the four tests are referred to as group-mean statistics, and they do not necessitate the equality of a_is. These statistics are presented as follows:

$$G_\tau = \frac{1}{N}\sum_{j=1}^{N}\frac{\hat{\alpha}_i}{SE(\hat{\alpha})} \quad (9)$$

$$G_\alpha = \frac{1}{N}\sum_{j=1}^{N}\frac{T\hat{\alpha}_i}{\hat{\alpha}(1)} \quad (10)$$

where $SE(\hat{\alpha})$ is the standard error of $\hat{\alpha}$ and $\hat{\alpha}(1) = \frac{\hat{\omega}_{ui}}{\hat{\omega}_{yi}}$ is calculated using Newey & West (1994) long-run variance estimators based on $\hat{\omega}_{ui}$ and $\hat{\omega}_{yi}$. These estimators rely on $\hat{u}_{it} = \sum_{j=-q_i}^{p_i}\hat{\gamma}_{ij}\,(1-L)x_{i,t-j} + \hat{\varepsilon}_{it}$ and (1-*L*) EPI_{it}. The Gτ and Gα statistics test for cointegration. H_0 assumes no cointegration across all units (a_i = 0 for all *i*), while H_a suggests cointegration for at least one unit (a_i < 0 for at least one *i*). Rejecting H_0 implies cointegration exists in the panel for at least one unit.

The remaining two tests are referred to as panel statistics. These tests operate under the assumption that a_i is equal for all *i*, and their expressions are as follows:

$$P_\tau = \frac{\hat{\alpha}_i}{SE(\hat{\alpha})} \quad (11)$$

$$P_\tau = T\hat{\alpha}_i \quad (12)$$

The Pτ and Pα statistics combine data from all units to test if there's cointegration across the entire panel. H_0 assumes no cointegration for all units (a_i = 0 for all *i*), while H_a suggests cointegration for all units (a_i = *a* < 0 for all *i*).

3.6 Quantile Regression

This study uses quantile regression to analyze the link between various factors and the EPI in 33 OECD countries from 2010 to 2021. Unlike traditional linear regression models, quantile regression models, conditional quantiles of the dependent variable shed light on how relationships between variables vary across different points of the distribution.

To capture this variability and account for heterogeneity, the quantile regression for panel data is applied. Specifically, models are estimated at the 0.25th, 0.50th, and 0.75th quantiles. The quantile regression model for the q-th quantile (q = 0.25, 0.50, 0.75) within our econometric framework (Eq. 1) is as follows:

$$EPI(q) = X\beta(q) + \varepsilon(q) \quad (13)$$

where EPI(q) is a vector representing the EPI values at the *q*-th quantile for all countries over time. X is a matrix of explanatory variables, including a column of ones for the intercept and other explanatory variables for all countries and years. *B(q)* is a vector of coefficients to be estimated for the explanatory variables at the *q*-th quantile. *ε(q)* is a vector of error terms at the *q*-th quantile.

4. Empirical Results

This section presents the findings of a thorough econometric analysis. Starting with the correlation matrix (Table 2), this study continues by examining cross-sectional dependence among panel variables using various tests (Table 3). Furthermore, the study proceeds to evaluate the stationarity or level of integration of these variables using second-generation panel unit root tests (Tables 4 and Table 5). To investigate long-term relationships, a panel cointegration test was conducted (Table 6). Finally, quantile regression is used for parameter estimations, as shown in Tables 7. The correlation matrix among variables can be found in Table 2.

Table 2: Correlation Matrix.

Variables	EPI_{it}	$LnGF_{it}$	$LnGT_{it}$	$LnYP_{it}$	URB_{it}	TOP_{it}
EPI_{it}	1					
$LnGF_{it}$	0.0240	1				
$LnGT_{it}$	0.5083	0.1345	1			
$LnYP_{it}$	0.248	0.1036	0.6129	1		
URB_{it}	0.1111	0.0132	0.3515	0.4199	1	
TOP_{it}	-0.2458	-0.0942	-0.2982	0.2224	-0.1176	1

4.1 Cross-Section Dependence

The cross-sectional dependence tests (Table 3) reveal robust evidence for variables *EPI*, *LnGT*, *LnYP*, *URB*, and *TOP*, as indicated by highly significant p-values in all four test statistics. However, for *LnGF*, there is mixed evidence with some tests suggesting less pronounced cross-sectional dependence. These findings emphasize the importance of considering cross-sectional dependence in subsequent analyses.

Table 3: Cross Section Dependence Tests.

Variables		Cross Section Dependence Test			
		Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
EPI_{it}	Statistic	15915.38	405.70	404.97	125.38
	Prob.	0.0000	0.0000	0.0000	0.0000
$LnGF_{it}$	Statistic	1120.91	11.15	10.41	-0.17
	Prob.	0.0000	0.0000	0.0000	0.8670
$LnGT_{it}$	Statistic	12525.88	315.30	314.57	109.76
	Prob.	0.0000	0.0000	0.0000	0.0000
$LnYP_{it}$	Statistic	15373.91	391.26	390.53	122.69
	Prob.	0.0000	0.0000	0.0000	0.0000
URB_{it}	Statistic	14019.59	355.14	354.41	66.00
	Prob.	0.0000	0.0000	0.0000	0.0000
TOP_{it}	Statistic	8962.72	220.28	219.55	63.86
	Prob.	0.0000	0.0000	0.0000	0.0000

4.2 Panel Unit Root Tests - MW and CIPS

Table 4 presents the results of the Maddala & Wu (1999) Panel Unit Root test (MW) and the Pesaran (2007) Panel Unit Root test (CIPS) conducted at the level of panel variables. For *EPI*, both the MW and CIPS tests, with or without trend, show very high p-values, suggesting that the null hypothesis of non-stationarity cannot be rejected. Similar results are observed for *LnYP* and *TOP*. In contrast, for *LnGF*, *LnGT*, and *URB* all four tests (MW and CIPS, with or without trend) yield very low p-values (close to 0.000), indicating strong evidence to reject the null hypothesis. This suggests that these variables are likely stationary and do not possess a unit root.

Table 5 presents results from unit root tests (MW and CIPS) conducted on first differences of panel variables. The low p-values close to 0.000 for all variables indicate that the null hypothesis of non-stationarity or having a unit root is rejected. These results suggest that after differencing the data, the variables become stationary at the first difference, confirming that they are integrated at *I (1)*.

Table 4: MW and CIPS Panel Unit Root Tests at Level.

Variables	Panel Unit Root test (MW)				Panel Unit Root test (CIPS)			
	Without trend		With trend		Without trend		With trend	
	x^2	p-value	x^2	p-value	Z_t-bar	p-value	Z_t-bar	p-value
EPI_{it}	40.691	0.990	1.929	1.000	0.517	0.697	3.433	1.000
$LnGF_{it}$	366.844	0.000	317.366	0.000	-10.099	0.000	-9.263	0.000
$LnGT_{it}$	413.767	0.000	116.355	0.000	-2.876	0.002	-1.552	0.060
$LnYP_{it}$	25.547	1.000	15.116	1.000	-1.506	0.066	-1.064	0.144
URB_{it}	205.497	0.000	201.712	0.000	9.237	1.000	9.013	1.000
TOP_{it}	59.880	0.623	125.868	0.000	0.894	0.814	3.702	1.000

Table 5: MW and CIPS Panel Unit Root Tests at 1st Difference.

Variables	Panel Unit Root test (MW)				Panel Unit Root test (CIPS)			
	Without trend		With trend		Without trend		With trend	
	x^2	p-value	x^2	p-value	Z_t-bar	p-value	Z_t-bar	p-value
ΔEPI_{it}	225.120	0.000	127.108	0.001	-7.382	0.000	-6.444	0.000
$\Delta LnGF_{it}$	1496.020	0.000	1266.57	0.000	-24.81	0.000	-23.36	0.000
$\Delta LnGT_{it}$	550.654	0.000	602.632	0.000	-17.83	0.000	-16.52	0.000
$\Delta LnYP_{it}$	365.622	0.000	249.147	0.000	-14.31	0.000	-12.73	0.000
ΔURB_{it}	242.835	0.000	120.700	0.003	-8.261	0.000	-6.802	0.000
ΔTOP_{it}	717.036	0.000	564.931	0.000	-11.77	0.000	-9.478	0.000

4.3 Cointegration

Table 6 presents the results of Westerlund's ECM based Cointegration Test. The aim is to detect long-term relationships (cointegration) among the variables. The results of Gt, Ga and Pa show strong evidence of cointegration, while Pt does not. These findings offer valuable insights into the enduring relationships among the variables over time.

Table 6: Westerlund's ECM based Cointegration Test.

Statistic	Value	Z-value	P-value
Gt	-1.565	-2.301	0.011
Ga	-12.629	4.755	0.000
Pt	-5.330	2.127	0.983
Pa	-10.299	5.885	0.000

4.4 Quantile Regression Estimates

Table 7 presents the results of Quantile Regression at three quantiles (Tau 0.25, Tau 0.50, Tau 0.75) for the dependent variable (i.e., EPI), and various independent variables. These results reveal how different factors influence EPI across different quantiles, offering a comprehensive understanding of the relationships.

To begin with, the green finance (*LnGF*), a similar pattern of positive influence is observed on EPI across all quantiles confirming our H_1. In essence, a more substantial presence of green finance is associated with improved environmental performance. This aligns with the notion that financial mechanisms, such as green bonds and sustainable investment funds, can channel resources towards environmentally responsible projects and initiatives (Batten et al., 2016). Thus, countries that prioritize green finance tend to exhibit higher EPI scores, reflecting their commitment to sustainability. Much like green technology, the effect of green finance becomes more pronounced at higher quantiles. This underscores the significance of green financial instruments aimed at fostering sustainable practices, particularly for countries that are already environmentally proactive. For these nations, leveraging green finance can further amplify their efforts to protect the environment and transition towards greener, more sustainable economies (Muchiri et al., 2022).

Turning our attention to the green technology (*LnGT*), our analysis reveals a consistently positive relationship with EPI across all quantiles which supports H_2. This implies that, irrespective of a country's position on the EPI spectrum, a higher degree of green technological innovations is associated with better environmental performance. These findings align with the extensive body of literature emphasizing the pivotal role of innovation in promoting sustainable practices and mitigating environmental degradation (De Medeiros et al., 2014; Ryszko, 2016; Severo et al., 2018). In essence, countries that invest in green technologies tend to exhibit superior environmental performance. Remarkably, the magnitude of this positive effect intensifies as moved towards higher quantiles. This signifies green technologies have a more pronounced impact on countries that already perform well in environmental sustainability. This trend underscores the idea that, as countries reach higher levels of environmental performance, investing in innovative, eco-friendly technologies becomes increasingly beneficial. These innovations allow nations to reduce their environmental footprint, enhance resource efficiency, and adopt cleaner production methods.

The impact of economic development, proxied by GDP per capita (*LnYP*), on environmental performance, is a critical aspect of understanding the relationship between economic growth and environmental sustainability. The consistent negative coefficient of *LnYP* across all quantiles signals a fundamental trend. This indicates that, on average, as a country's GDP per capita increases, its environmental performance tends to decline initially. This finding aligns with the EKC hypothesis, which posits that environmental degradation initially worsens during the early stages of economic development but eventually improves as countries become wealthier (Grossman & Krueger, 1991). However, our results indicate that this trend persists even at higher quantiles, suggesting that the inverse relationship between economic development and environmental performance holds true across the entire spectrum of countries, including those with higher EPI scores.

Moving beyond the linear relationship between GDP per capita and EPI, the quadratic term, $(LnYP)^2$ is introduced which captures the non-linear dynamics of the relationship. The positive coefficient of this quadratic term across all quantiles signifies a critical insight. It suggests that, up to a certain threshold, an increase in GDP per capita is associated with an improvement in environmental performance. This threshold signifies the point where higher income levels enable countries to invest in cleaner technologies, adopt stricter environmental regulations, and foster a culture of sustainability (Stern, 2004).

Beyond this threshold, further economic growth harms environmental performance, forming a U-shaped relationship, in line with the EKC hypothesis. This non-linear effect intensifies at higher quantiles, signifying a higher income threshold where growth negatively affects the environment in countries with superior environmental performance. This aligns with prior research suggesting that economic growth initially degrades the environment but can later facilitate environmental improvements (Destek et al., 2020; Shafik, 1994). However, the turning point's variation among countries hinges on factors like policies, technology, and cultural attitudes toward the environment.

Table 7: Quantile Regression Estimates - Dependent Variable: EPI.

Variable	Tau 0.25 (Q1)	Tau 0.50 (Median)	Tau 0.75 (Q3)
$LnGF_{it}$	0.0015***	0.0018***	0.0059***
	(0.0002)	(0.0004)	(0.0006)
$LnGT_{it}$	0.0041***	0.0099***	0.0256***
	(0.0007)	(0.0012)	(0.0014)
$LnYP_{it}$	-0.0401***	-0.0404**	-0.2745***
	(0.0121)	(0.0173)	(0.0479)
$(LnYP_{it})^2$	0.0020***	0.0021**	0.0140***
	(0.0006)	(0.0009)	(0.0026)
URB_{it}	-0.0002***	-0.0004***	-0.0009***
	(0.0001)	(0.0001)	(0.0003)
TOP_{it}	-0.0019	-0.0058***	0.0118
	(0.0020)	(0.0029)	(0.0091)
Constant	0.2088***	0.2241***	1.3090***
	(0.0566)	(0.0821)	(0.2246)
Observations	1026	1026	1026
Pseudo R-squared	0.6092	0.6505	0.6286
Adjusted R-squared	0.6028	0.6545	0.6235
Quasi-LR statistic	312.40	506.5224	885.5199
Prob (Quasi-LR stat)	0.0000	0.0000	0.0000

Note: Standard errors are in parentheses

Urbanization, as represented by the variable *URB*, consistently exerts a significant negative influence on a country's EPI across all quantiles. As its coefficient remains negative, it implies that as the urban population's proportion increases, environmental performance tends to decline. This aligns with prior research highlighting the environmental challenges linked to urbanization (Seto et al., 2012). Urbanization often entails elevated industrialization, infrastructure development, and energy consumption, contributing to pollution and resource depletion (Wang & Zhang, 2021). Urban areas also generate more waste and emissions, exacerbating environmental degradation (Basu & Chakraborty, 2016; Yu et al., 2020). Remarkably, the adverse impact of urbanization on environmental performance intensifies at higher quantiles. This suggests that in countries excelling in environmental sustainability, urbanization poses a more significant threat to their environmental achievements. These environmentally conscious nations are more susceptible to the environmental externalities associated with urbanization (Seto et al., 2010).

Lastly, trade openness (*TOP*) shows mixed results with environmental performance across quantiles. At the median (Tau 0.50), higher trade openness associates with lower environmental performance, aligning with the EKC hypothesis (Stern, 2004). However, a striking reversal occurs at the 0.75 quantile, where increased trade openness coincides with superior environmental performance. This implies that highly environmentally conscious nations can harness trade's benefits, including cleaner technologies and sustainable practices (Antweiler, Copeland, & Taylor, 2001).

5. Conclusion and Policy Implications

The primary aim of this study was to assess the influence of green finance and green technology on environmental performance across a panel of 33 OECD countries spanning from 2010 to 2021. In essence, this study offers valuable insights into the dynamics of environmental performance and its drivers.

The comprehensive analysis sheds light on the pivotal role that green finance and green technology play in sustaining environmental performance. The findings highlight the universality of this positive relationship, demonstrating that regardless of a country's initial standing on the EPI spectrum, investments in innovative, eco-friendly technologies, and the cultivation of sustainable financial mechanisms contribute to superior environmental sustainability. These benefits are most pronounced for countries already excelling in environmental performance, highlighting the compounding advantages of such initiatives. Furthermore, the impact of economic growth on the environment is context-dependent, with the most substantial adverse effects occurring in countries already demonstrating superior environmental performance. The study also found that urbanization emerges as a consistent factor negatively influencing EPI across all quantiles. This implies that as urbanization increases, environmental performance tends to deteriorate. On the other hand, trade openness exhibits a more nuanced relationship with environmental performance. Around the median EPI quantile, higher trade openness corresponds to lower environmental performance, aligning with the EKC hypothesis.

These results carry significant policy implications. Firstly, governments and policymakers worldwide should prioritize the promotion of green finance and green innovation as central pillars of their environmental agendas. Secondly, fostering an environment conducive to sustainable finance, including incentives for green investments and responsible lending practices, can facilitate the transition towards a greener and more environmentally responsible future. Thirdly, encouraging research, development, and implementation of eco-friendly technologies can yield tangible benefits. Policymakers and governments must take heed of these findings when crafting strategies to address environmental challenges, promote sustainable development, foster a greener and more environmentally responsible future for all OECD nations.

This study has some limitations. It is conducted on OECD economies only; therefore, future studies can expand this subject on other countries like European economies, belt, and road initiative (BRI) region. Secondly, more advanced methodologies can be applied to future similar studies like Method of Moments Quantile Regression (MMQR).

6. Statements and Declarations

Declaration of Generative AI and AI-assisted technologies in the writing process: N/A

Ethical Approval: This study was conducted in accordance with the ethical standards set by the responsible committee for human experimentation. The study did not involve any human or animal subjects, and the data on economic variables for OECD economies was obtained through lawful and ethical methods.

Consent to Participate: N/A

Competing Interests: The authors affirm that they possess no apparent conflicting financial interests or personal relationships that could have influenced the work presented in this paper.

Data Availability Statement: The data that support the findings of this study are openly available in World Bank and OECD Statistics websites at https://data.worldbank.org/ and https://data-explorer.oecd.org/ respectively.

Funding Statement: The authors extend their appreciation to the Arab Open University for funding this work through research fund.

References

Abu Seman, N. A., Govindan, K., Mardani, A., Zakuan, N., Mat Saman, M. Z., Hooker, R. E., & Ozkul, S. (2019). The mediating effect of green innovation on the relationship between green supply chain management and environmental performance. *Journal of Cleaner Production, 229*, 115-127. doi: https://doi.org/10.1016/j.jclepro.2019.03.211

Adegbile, A., Sarpong, D., & Meissner, D. (2017). Strategic Foresight for Innovation Management: A Review and Research Agenda. *International Journal of Innovation and Technology Management, 14*(04), 1750019. doi: https://doi.org/10.1142/S0219877017500195

Afzal, A., Rasoulinezhad, E., & Malik, Z. (2022). Green finance and sustainable development in Europe. *Economic Research-Ekonomska Istraživanja, 35*(1), 5150-5163. doi: https://doi.org/10.1080/1331677X.2021.2024081

Akomea-Frimpong, I., Adeabah, D., Ofosu, D., & Tenakwah, E. J. (2022). A review of studies on green finance of banks, research gaps and future directions. *Journal of Sustainable Finance & Investment, 12*(4), 1241-1264. doi: https://doi.org/10.1080/20430795.2020.1870202

Al Mamun, M., Boubaker, S., & Nguyen, D. K. (2022). Green finance and decarbonization: Evidence from around the world. *Finance Research Letters, 46*, 102807. doi: https://doi.org/10.1016/j.frl.2022.102807

Alharthi, M., Hanif, I., & Alamoudi, H. (2022). Impact of environmental pollution on human health and financial status of households in MENA countries: Future of using renewable energy to eliminate the environmental pollution. *Renewable Energy, 190*, 338-346. doi: https://doi.org/10.1016/j.renene.2022.03.118

Aller, C., Ductor, L., & Grechyna, D. (2021). Robust determinants of CO2 emissions. *Energy Economics, 96*, 105154. doi: https://doi.org/10.1016/j.eneco.2021.105154

Ansari, M., Ehrampoush, M. H., Farzadkia, M., & Ahmadi, E. (2019). Dynamic assessment of economic and environmental performance index and generation, composition, environmental and human health risks of hospital solid waste in developing countries; A state of the art of review. *Environment International, 132*, 105073. doi: https://doi.org/10.1016/j.envint.2019.105073

Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is Free Trade Good for the Environment? *American Economic Review, 91*(4), 877-908. doi: https://doi.org/10.1257/aer.91.4.877

Baltagi, B. H., Feng, Q., & Kao, C. (2012). A Lagrange Multiplier test for cross-sectional dependence in a fixed effects panel data model. *Journal of Econometrics, 170*(1), 164-177. doi: https://doi.org/10.1016/j.jeconom.2012.04.004

Bashir, M. F., Ma, B., Shahbaz, M., & Jiao, Z. (2020). The nexus between environmental tax and carbon emissions with the roles of environmental technology and financial development. *PloS One, 15*(11), e0242412. doi: https://doi.org/10.1371/journal.pone.0242412

Basu, P., & Chakraborty, J. (2016). Environmental justice implications of industrial hazardous waste generation in India: a national scale analysis. *Environmental Research Letters, 11*(12), 125001. doi: https://dx.doi.org/10.1088/1748-9326/11/12/125001

Batten, S., Sowerbutts, R., & Tanaka, M. (2016). *Let's talk about the weather: the impact of climate change on central banks* (Staff Working Paper No. 603). Bank of England. doi: https://dx.doi.org/10.2139/ssrn.2783753

Behera, P., & Sethi, N. (2022). Nexus between environment regulation, FDI, and green technology innovation in OECD countries. *Environmental Science and Pollution Research, 29*(35), 52940-52953. doi: https://doi.org/10.1007/s11356-022-19458-7

Brand, U. (2012). No Lessons Learned from Failures of Implementing Sustainable Development. *GAIA - Ecological Perspectives for Science and Society, 21*(1), 28-32. doi: https://doi.org/10.14512/gaia.21.1.9

Chan, R. Y. K. (2005). Does the Natural-Resource-Based View of the Firm Apply in an Emerging Economy? A Survey of Foreign Invested Enterprises in China*. *Journal of Management Studies, 42*(3), 625-672. doi: https://doi.org/10.1111/j.1467-6486.2005.00511.x

Chen, W., & Lei, Y. (2018). The impacts of renewable energy and technological innovation on environment-energy-growth nexus: New evidence from a panel quantile regression. *Renewable Energy, 123*, 1-14. doi: https://doi.org/10.1016/j.renene.2018.02.026

Chen, Y., & Lee, C.-C. (2020). Does technological innovation reduce CO2 emissions?Cross-country evidence. *Journal of Cleaner Production, 263*, 121550. doi: https://doi.org/10.1016/j.jclepro.2020.121550

Chen, Y., Tang, G., Jin, J., Li, J., & Paillé, P. (2015). Linking Market Orientation and Environmental Performance: The Influence of Environmental Strategy, Employee's Environmental Involvement, and Environmental Product Quality. *Journal of Business Ethics, 127*(2), 479-500. doi: https://doi.org/10.1007/s10551-014-2059-1

Chin, M.-Y., Ong, S.-L., Ooi, D. B.-Y., & Puah, C.-H. (2022). The impact of green finance on environmental degradation in BRI region. *Environment,* *Development and Sustainability, 26*(1), 303-318. `doi: https://doi.org/10.1007/s10668-022-02709-5

Chiou, T.-Y., Chan, H. K., Lettice, F., & Chung, S. H. (2011). The influence of greening the suppliers and green innovation on environmental performance and competitive advantage in Taiwan. *Transportation Research Part E: Logistics and Transportation Review, 47*(6), 822-836. doi: https://doi.org/10.1016/j.tre.2011.05.016

Dao, T. H. (2021). Determinants of linkages between foreign direct investment firms and domestic firms in Vietnam. *International Journal of Advanced and Applied Sciences, 8*(6), 94-102. doi: https://doi.org/10.21833/ijaas.2021.06.011

de Medeiros, J. F., Ribeiro, J. L. D., & Cortimiglia, M. N. (2014). Success factors for environmentally sustainable product innovation: a systematic literature review. *Journal of Cleaner Production, 65*, 76-86. doi: https://doi.org/10.1016/j.jclepro.2013.08.035

Deng, W., & Zhang, Z. (2023). Environmental regulation intensity, green finance, and environmental sustainability: empirical evidence from China based on spatial metrology. *Environmental Science and Pollution Research, 30*(24), 66228-66253. doi: https://doi.org/10.1007/s11356-023-26946-x

Destek, M. A., Shahbaz, M., Okumus, I., Hammoudeh, S., & Sinha, A. (2020). The relationship between economic growth and carbon emissions in G-7 countries: evidence from time-varying parameters with a long history. *Environmental Science and Pollution Research, 27*(23), 29100-29117. doi: https://doi.org/10.1007/s11356-020-09189-y

Dkhili, H. (2019). Does foreign direct investment spur economic growth in an oil-based country? Evidence from Saudi Arabia. *International Journal of Advanced and Applied Sciences, 6*(1), 73-80. doi: https://doi.org/10.21833/ijaas.2019.01.010

Dogan, E., & Seker, F. (2016). Determinants of CO2 emissions in the European Union: The role of renewable and non-renewable energy. *Renewable Energy, 94*, 429-439. doi: https://doi.org/10.1016/j.renene.2016.03.078

Dörry, S., & Schulz, C. (2018). Green financing, interrupted. Potential directions for sustainable finance in Luxembourg. *Local Environment, 23*(7), 717-733. doi: https://doi.org/10.1080/13549839.2018.1428792

Dou, G., & Choi, T.-M. (2021). Does implementing trade-in and green technology together benefit the environment? *European Journal of Operational Research, 295*(2), 517-533. doi: https://doi.org/10.1016/j.ejor.2021.03.017

Du, K., Li, P., & Yan, Z. (2019). Do green technology innovations contribute to carbon dioxide emission reduction? Empirical evidence from patent data. *Technological Forecasting and Social Change, 146*, 297-303. doi: https://doi.org/10.1016/j.techfore.2019.06.010

EBF. (2017). *Towards A Green Finance Framework*. European Banking Federation. Retrieved from https://www.ebf.eu/wp-content/uploads/2017/09/Geen-finance-complete.pdf

European Commission, Directorate-General for Environment, Eisinger, F., Hogg, D., Cochu, A., Georgiev, I., & Walter, K. (2017). *Defining "green" in the context of green finance - Final report*. Publications Office. doi: https://doi.org/10.2779/285586

Fousteris, A. E., Didaskalou, E. A., Tsogas, M.-M. H., & Georgakellos, D. A. (2018). The Environmental Strategy of Businesses as an Option under Recession in Greece. *Sustainability, 10*(12), 4399. doi: https://doi.org/10.3390/su10124399

Frondel, M., Horbach, J., & Rennings, K. (2007). End-of-pipe or cleaner production? An empirical comparison of environmental innovation decisions across OECD countries. *Business Strategy and the Environment, 16*(8), 571-584. doi: https://doi.org/10.1002/bse.496

Gao, J., Wu, D., Xiao, Q., Randhawa, A., Liu, Q., & Zhang, T. (2023). Green finance, environmental pollution and high-quality economic development—a study based on China's provincial panel data. *Environmental Science and Pollution Research, 30*(11), 31954-31976. doi: https://doi.org/10.1007/s11356-022-24428-0

Gengenbach, C., Palm, F. C., & Urbain, J.-P. (2009). Panel Unit Root Tests in the Presence of Cross-Sectional Dependencies: Comparison and Implications for Modelling. *Econometric Reviews, 29*(2), 111-145. doi: https://doi.org/10.1080/07474930903382125

Ghisetti, C., & Quatraro, F. (2017). Green Technologies and Environmental Productivity: A Cross-sectoral Analysis of Direct and Indirect Effects in Italian Regions. *Ecological Economics, 132*, 1-13. doi: https://doi.org/10.1016/j.ecolecon.2016.10.003

Gianfrate, G., & Peri, M. (2019). The green advantage: Exploring the convenience of issuing green bonds. *Journal of Cleaner Production, 219*, 127-135. doi: https://doi.org/10.1016/j.jclepro.2019.02.022

Glomsrød, S., & Wei, T. (2018). Business as unusual: The implications of fossil divestment and green bonds for financial flows, economic growth and energy market. *Energy for Sustainable Development, 44*, 1-10. doi: https://doi.org/10.1016/j.esd.2018.02.005

Grossman, G. M., & Krueger, A. B. (1991). *Environmental Impacts of a North American Free Trade Agreement* (Working Paper 3914). National Bureau of Economic Research Cambridge, Mass., USA. doi: https://doi.org/10.3386/w3914

Guo, M., Hu, Y., & Yu, J. (2019). The role of financial development in the process of climate change: Evidence from different panel models in China. *Atmospheric Pollution Research, 10*(5), 1375-1382. doi: https://doi.org/10.1016/j.apr.2019.03.006

Hemanand, D., Mishra, N., Premalatha, G., Mavaluru, D., Vajpayee, A., Kushwaha, S., & Sahile, K. (2022). Applications of Intelligent Model to Analyze the Green Finance for Environmental Development in the Context of Artificial Intelligence. *Computational Intelligence and Neuroscience, 2022*, 2977824. doi: https://doi.org/10.1155/2022/2977824

Huang, Y., & Chen, C. (2022). The spatial spillover and threshold effect of green finance on environmental quality: evidence from China. *Environmental Science and Pollution Research, 29*(12), 17487-17498. doi: https://doi.org/10.1007/s11356-021-16892-x

Intui, S., Inazumi, S., & Soralump, S. (2022). Sustainability of Soil/Ground Environment under Changes in Groundwater Level in Bangkok Plain, Thailand. *Sustainability, 14*(17), 10908. doi: https://doi.org/10.3390/su141710908

Iqbal, S., Taghizadeh-Hesary, F., Mohsin, M., & Iqbal, W. (2021). Assessing the Role of the Green Finance Index in Environmental Pollution Reduction. *Studies of Applied Economics, 39*(3), 1-15. doi: https://doi.org/10.25115/eea.v39i3.4140

Javaid, M., Haleem, A., Singh, R. P., Suman, R., & Gonzalez, E. S. (2022). Understanding the adoption of Industry 4.0 technologies in improving environmental sustainability. *Sustainable Operations and Computers, 3*, 203-217. doi: https://doi.org/10.1016/j.susoc.2022.01.008

Jiang, S., Liu, X., Liu, Z., Shi, H., & Xu, H. (2022). Does green finance promote enterprises' green technology innovation in China? *Frontiers in Environmental Science, 10*, 981013. doi: https://doi.org/10.3389/fenvs.2022.981013

Kahouli, B. (2018). The causality link between energy electricity consumption, CO2 emissions, R&D stocks and economic growth in Mediterranean countries (MCs). *Energy, 145*, 388-399. doi: https://doi.org/10.1016/j.energy.2017.12.136

Kammerer, D. (2009). The effects of customer benefit and regulation on environmental product innovation.: Empirical evidence from appliance manufacturers in Germany. *Ecological Economics, 68*(8), 2285-2295. doi: https://doi.org/10.1016/j.ecolecon.2009.02.016

Khan, M. A., Riaz, H., Ahmed, M., & Saeed, A. (2022). Does green finance really deliver what is expected? An empirical perspective. *Borsa Istanbul Review, 22*(3), 586-593. doi: https://doi.org/10.1016/j.bir.2021.07.006

Khan, S. A. R., Zhang, Y., Kumar, A., Zavadskas, E., & Streimikiene, D. (2020). Measuring the impact of renewable energy, public health expenditure, logistics, and environmental performance on sustainable economic growth. *Sustainable Development, 28*(4), 833-843. doi: https://doi.org/10.1002/sd.2034

Khoshnevis Yazdi, S., & Khanalizadeh, B. (2017). Air Pollution, Economic Growth and Health Care Expenditure. *Economic Research-Ekonomska Istraživanja, 30*(1), 1181-1190. doi: https://doi.org/10.1080/1331677X.2017.1314823

Kratzer, J., Meissner, D., & Roud, V. (2017). Open innovation and company culture: Internal openness makes the difference. *Technological Forecasting and Social Change, 119*, 128-138. doi: https://doi.org/10.1016/j.techfore.2017.03.022

Kraus, S., Rehman, S. U., & García, F. J. S. (2020). Corporate social responsibility and environmental performance: The mediating role of environmental strategy and green innovation. *Technological Forecasting and Social Change, 160*, 120262. doi: https://doi.org/10.1016/j.techfore.2020.120262

Lazaro, L. L. B., Grangeia, C. S., Santos, L., & Giatti, L. L. (2023). What is green finance, after all? – Exploring definitions and their implications under the Brazilian biofuel policy (RenovaBio). *Journal of Climate Finance, 2*, 100009. doi: https://doi.org/10.1016/j.jclimf.2023.100009

Li, C., & Gan, Y. (2021). The spatial spillover effects of green finance on ecological environment—empirical research based on spatial econometric model. *Environmental Science and Pollution Research, 28*(5), 5651-5665. doi: https://doi.org/10.1007/s11356-020-10961-3

Maddala, G. S., & Wu, S. (1999). A Comparative Study of Unit Root Tests with Panel Data and a New Simple Test. *Oxford Bulletin of Economics and Statistics, 61*(S1), 631-652. doi: https://doi.org/10.1111/1468-0084.0610s1631

Muchiri, M. K., Erdei-Gally, S., Fekete-Farkas, M., & Lakner, Z. (2022). Bibliometric Analysis of Green Finance and Climate Change in Post-Paris Agreement Era. *Journal of Risk and Financial Management, 15*(12), 561. doi: https://doi.org/10.3390/jrfm15120561

Muganyi, T., Yan, L., & Sun, H.-p. (2021). Green finance, fintech and environmental protection: Evidence from China. *Environmental Science and Ecotechnology, 7*, 100107. doi: https://doi.org/10.1016/j.ese.2021.100107

Musa, A. A., Brika, S. K. M., Chergui, K., Mukhtar, M. A., & Almezher, M. A. N. (2021). The impact of conscious consumer behavior on environmental friendliness: Saudi Arabia's sustainable vision 2030. *International Journal of Advanced and Applied Sciences, 8*(7), 31-40. doi: https://doi.org/10.21833/ijaas.2021.07.005

Nesta, L., Vona, F., & Nicolli, F. (2014). Environmental policies, competition and innovation in renewable energy. *Journal of Environmental Economics and Management, 67*(3), 396-411. doi: https://doi.org/10.1016/j.jeem.2014.01.001

Newey, W. K., & West, K. D. (1994). Automatic lag selection in covariance matrix estimation. *The Review of Economic Studies, 61*(4), 631-653. doi: https://doi.org/10.2307/2297912

Niu, J., Chang, C.-P., Yang, X.-Y., & Wang, J.-S. (2017). The long-run relationships between energy efficiency and environmental performance: Global evidence. *Energy & Environment, 28*(7), 706-724. doi: https://doi.org/10.1177/0958305X17724210

Oliva, F. L., Semensato, B. I., Prioste, D. B., Winandy, E. J. L., Bution, J. L., Couto, M. H. G., et al. (2019). Innovation in the main Brazilian business sectors: characteristics, types and comparison of innovation. *Journal of Knowledge Management, 23*(1), 135-175. doi: https://doi.org/10.1108/JKM-03-2018-0159

Pesaran, M. H. (2004). General Diagnostic Tests for Cross Section Dependence in Panels. *Available at SSRN 572504*. doi: http://dx.doi.org/10.2139/ssrn.572504

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics, 22*(2), 265-312. doi: https://doi.org/10.1002/jae.951

Rasoulinezhad, E., & Taghizadeh-Hesary, F. (2022). Role of green finance in improving energy efficiency and renewable energy development. *Energy Efficiency, 15*(2), 14. doi: https://doi.org/10.1007/s12053-022-10021-4

Robinson, S., & Stubberud, H. A. (2015). Green innovation and environmental impact in Europe. *Journal of International Business Research, 14*(1), 127-138. Retrieved from https://www.proquest.com/openview/bfe7c58363737fcfe5d643e67d74360d

Rogge, N. (2012). Undesirable specialization in the construction of composite policy indicators: The Environmental Performance Index. *Ecological Indicators, 23*, 143-154. doi: https://doi.org/10.1016/j.ecolind.2012.03.020

Ryszko, A. (2016). Proactive Environmental Strategy, Technological Eco-Innovation and Firm Performance—Case of Poland. *Sustainability, 8*(2), 156. doi: https://doi.org/10.3390/su8020156

Saeed Meo, M., & Karim, M. Z. A. (2022). The role of green finance in reducing CO2 emissions: An empirical analysis. *Borsa Istanbul Review, 22*(1), 169-178. doi: https://doi.org/10.1016/j.bir.2021.03.002

Sek, S. K., & Chu, J. F. (2017). Investigating economic growth-energy consumption-environmental degradation nexus in China. *International Journal of Advanced and Applied Sciences, 4*(12), 21-25. doi: https://doi.org/10.21833/ijaas.2017.012.005

Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences, 109*(40), 16083-16088. doi: https://doi.org/10.1073/pnas.1211658109

Seto, K. C., Sánchez-Rodríguez, R., & Fragkias, M. (2010). The New Geography of Contemporary Urbanization and the Environment. *Annual Review of Environment and Resources, 35*(1), 167-194. doi: https://doi.org/10.1146/annurev-environ-100809-125336

Severo, E. A., de Guimarães, J. C. F., & Henri Dorion, E. C. (2018). Cleaner production, social responsibility and eco-innovation: Generations' perception for a sustainable future. *Journal of Cleaner Production, 186*, 91-103. doi: https://doi.org/10.1016/j.jclepro.2018.03.129

Shafik, N. (1994). Economic Development and Environmental Quality: An Econometric Analysis. *Oxford Economic Papers, 46*(Supplement_1), 757-773. doi: https://doi.org/10.1093/oep/46.Supplement_1.757

Shahbaz, M., Nasir, M. A., & Roubaud, D. (2018). Environmental degradation in France: The effects of FDI, financial development, and energy innovations. *Energy Economics, 74*, 843-857. doi: https://doi.org/10.1016/j.eneco.2018.07.020

Shahbaz, M., Raghutla, C., Song, M., Zameer, H., & Jiao, Z. (2020). Public-private partnerships investment in energy as new determinant of CO2 emissions: The role of technological innovations in China. *Energy Economics, 86*, 104664. doi: https://doi.org/10.1016/j.eneco.2020.104664

Singh, S. K., Giudice, M. D., Chierici, R., & Graziano, D. (2020). Green innovation and environmental performance: The role of green transformational leadership and green human resource management. *Technological Forecasting and Social Change, 150*, 119762. doi: https://doi.org/10.1016/j.techfore.2019.119762

Sohag, K., Begum, R. A., Abdullah, S. M. S., & Jaafar, M. (2015). Dynamics of energy use, technological innovation, economic growth and trade openness in Malaysia. *Energy, 90*, 1497-1507. doi: https://doi.org/10.1016/j.energy.2015.06.101

Stern, D. I. (2004). The Rise and Fall of the Environmental Kuznets Curve. *World Development, 32*(8), 1419-1439. doi: https://doi.org/10.1016/j.worlddev.2004.03.004

Sun, Y., Lu, Y., Wang, T., Ma, H., & He, G. (2008). Pattern of patent-based environmental technology innovation in China. *Technological Forecasting and Social Change, 75*(7), 1032-1042. doi: https://doi.org/10.1016/j.techfore.2007.09.004

Taghizadeh-Hesary, F., & Yoshino, N. (2019). The way to induce private participation in green finance and investment. *Finance Research Letters, 31*, 98-103. doi: https://doi.org/10.1016/j.frl.2019.04.016

Umar, M., & Safi, A. (2023). Do green finance and innovation matter for environmental protection? A case of OECD economies. *Energy Economics, 119*, 106560. doi: https://doi.org/10.1016/j.eneco.2023.106560

Volz, U. (2018). *Fostering Green Finance for Sustainable Development in Asia* (ADBI Working Paper 814). Asian Development Bank Institute. doi: https://dx.doi.org/10.2139/ssrn.3198680

Wang, J., Chen, X., Li, X., Yu, J., & Zhong, R. (2020). The market reaction to green bond issuance: Evidence from China. *Pacific-Basin Finance Journal, 60*, 101294. doi: https://doi.org/10.1016/j.pacfin.2020.101294

Wang, Q.-J., Wang, H.-J., & Chang, C.-P. (2022). Environmental performance, green finance and green innovation: What's the long-run relationships among variables? *Energy Economics, 110*, 106004. doi: https://doi.org/10.1016/j.eneco.2022.106004

Wang, Q., & Zhang, F. (2021). The effects of trade openness on decoupling carbon emissions from economic growth – Evidence from 182 countries. *Journal of Cleaner Production, 279*, 123838. doi: https://doi.org/10.1016/j.jclepro.2020.123838

Wang, Y., & Zhi, Q. (2016). The Role of Green Finance in Environmental Protection: Two Aspects of Market Mechanism and Policies. *Energy Procedia, 104*, 311-316. doi: https://doi.org/10.1016/j.egypro.2016.12.053

Wei, W. X., & Yang, F. (2010). Impact of technology advance on carbon dioxide emission in China. *Statistical Research, 27*(7), 36-44. Retrieved from https://www.cqvip.com/qk/96472x/201007/34642488.html

Westerlund, J. (2007). Testing for Error Correction in Panel Data*. *Oxford Bulletin of Economics and Statistics, 69*(6), 709-748. doi: https://doi.org/10.1111/j.1468-0084.2007.00477.x

Yang, Q.-C., Feng, G.-F., Chang, C.-P., & Wang, Q.-J. (2021). Environmental protection and performance: A bi-directional assessment. *Science of The Total Environment, 774*, 145747. doi: https://doi.org/10.1016/j.scitotenv.2021.145747

Yu, X., Wu, Z., Zheng, H., Li, M., & Tan, T. (2020). How urban agglomeration improve the emission efficiency？A spatial econometric analysis of the Yangtze River Delta urban agglomeration in China. *Journal of Environmental Management, 260*, 110061. doi: https://doi.org/10.1016/j.jenvman.2019.110061

Zaidi, S., & Saidi, K. (2018). Environmental pollution, health expenditure and economic growth in the Sub-Saharan Africa countries: Panel ARDL approach. *Sustainable Cities and Society, 41*, 833-840. doi: https://doi.org/10.1016/j.scs.2018.04.034

Zerbib, O. D. (2019). The effect of pro-environmental preferences on bond prices: Evidence from green bonds. *Journal of Banking & Finance, 98*, 39-60. doi: https://doi.org/10.1016/j.jbankfin.2018.10.012

Zhang, D., Zhang, Z., & Managi, S. (2019). A bibliometric analysis on green finance: Current status, development, and future directions. *Finance Research Letters, 29*, 425-430. doi: https://doi.org/10.1016/j.frl.2019.02.003

Zhang, H., Geng, C., & Wei, J. (2022). Coordinated development between green finance and environmental performance in China: The spatial-temporal difference and driving factors. *Journal of Cleaner Production, 346*, 131150. doi: https://doi.org/10.1016/j.jclepro.2022.131150

Zhang, S., Wu, Z., Wang, Y., & Hao, Y. (2021). Fostering green development with green finance: An empirical study on the environmental effect of green credit policy in China. *Journal of Environmental* Management*, 296*, 113159. doi: https://doi.org/10.1016/j.jenvman.2021.113159

Zheng, M., Feng, G.-F., Jang, C.-L., & Chang, C.-P. (2021). Terrorism and green innovation in renewable energy. *Energy Economics, 104*, 105695. doi: https://doi.org/10.1016/j.eneco.2021.105695

Zhou, X., Tang, X., & Zhang, R. (2020). Impact of green finance on economic development and environmental quality: a study based on provincial panel data from China. *Environmental Science and Pollution Research, 27*(16), 19915-19932. doi: https://doi.org/10.1007/s11356-020-08383-2