Economic Research-Ekonomska Istraživanja

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rero20

# Ecological innovation for environmental sustainability and human capital development: the role of environmental regulations and renewable energy in advanced economies

Nguyen Binh An, Yen-Lin Kuo, Fatma Mabrouk, Shouvik Sanyal, Iskandar Muda, Sanil S. Hishan & Niamat Abdulrehman

**To cite this article:** Nguyen Binh An, Yen-Lin Kuo, Fatma Mabrouk, Shouvik Sanyal, Iskandar Muda, Sanil S. Hishan & Niamat Abdulrehman (2023) Ecological innovation for environmental sustainability and human capital development: the role of environmental regulations and renewable energy in advanced economies, Economic Research-Ekonomska Istraživanja, 36:1, 243-263, DOI: 10.1080/1331677X.2022.2120046

**To link to this article:** https://doi.org/10.1080/1331677X.2022.2120046

ECONOMIC RESEARCH-EKONOMSKA ISTRAŽIVANJA
2022, VOL. 36, NO. 1, 243–263
https://doi.org/10.1080/1331677X.2022.2120046



# Ecological innovation for environmental sustainability and human capital development: the role of environmental regulations and renewable energy in advanced economies

Nguyen Binh An[a], Yen-Lin Kuo[b], Fatma Mabrouk[c], Shouvik Sanyal[d], Iskandar Muda[e], Sanil S. Hishan[f] and Niamat Abdulrehman[g]

[a]Faculty of Law, Binh Duong University, Thủ Dầu Một, Vietnam; [b]Bachelor Program of Digital Media, Commercial College, Chinese Culture University, Taipei City, Taiwan; [c]Department of Economics, College of Business Administration, Princess Nourah Bint Abdulrahman University, Riyadh, Saudi Arabia; [d]Department of Marketing and Entrepreneurship, Dhofar University, Salalah, Sultanate of Oman; [e]Faculty Economic and Business, Universitas Sumatera Utara, Medan, Indonesia; [f]Azman Hashim International Business School, Universiti Teknologi Malaysia, Johor Bahru, Malaysia; [g]Faculty of Economics & Management Sciences, University of Garden City, Khartoum, Sudan

**ABSTRACT**

This study examines the trends in environmental sustainability and human well-being through green technologies, clean energy, and environmental taxes using panel data for the top eight advanced economies from 1990 to 2018. The study applies an advanced panel technique, cross-sectionally augmented distributed lags (CS-ARDL), to find long-run and short-run associations between these variables. Moreover, the role of foreign investment is added as a control variable. The CS-ARDL estimation confirms the productive impact of green technologies on environmental and human well-being, providing that it helps to reduce haze pollution while promoting human development. Moreover, clean energy and environmental taxes contribute toa sustainable environment and human development. Moreover, foreign investment is a direct source of haze pollution because of more industrialization and economic activities. The study finally recommends strengthening the promotion of green technology and clean energy to achieve both environmental and human well-being in the long run.

**ARTICLE HISTORY**
Received 26 May 2022
Accepted 26 August 2022

**KEYWORDS**
Ecological innovation; environmental tax; environmental sustainability; clean energy; green innovation; CS-ARDL

**JEL CODES**
Q00; Q56; E24; Q29

## 1. Introduction and background

Recent years have seen a tremendous shift in research on environmental protection from conventional technologies to environmental-friendly, sustainable, and cost-

**CONTACT** Niamat Abdulrehman zeinazeni@hotmail.com
*Researcher, THRIVE Projects, Australia.

effective technologies, also called green technologies (Razzaq et al., 2021; Shan et al., 2021). Implementing green technologies provides various practical aspects for environmental pollution control and developing renewable energy technologies for a sustainable future (Rene et al., 2021). Non-renewable energy consumption has led to several threats such as exhaustion of natural resources, environmental degradation, and climate change due to fast industrial development in advanced economies including Belgium, Canada, France, Germany, Italy, Japan, Netherlands, and Sweden. However, technologically-advanced economies bring innovative technologies for green development for overall well-being (Ikram et al., 2021). According to the report of OECD, 'Towards Green Growth,' policymakers must follow the regulations on clean energy (CENG) utilization in advanced economies.CENG utilization forecast depends on several aspects such as GINV, technology development, and increased productivity with reduced emissions, especially $PM_{2.5}$ in the air (Watson & Kaarsberg, 2021). Increased green innovation (GINV) stimulates sustainable development, and utilization of CENG effectively reduces environmental degradation. Innovative technology development is required to achieve sustainable development goals (Adedoyin et al., 2021; Irfan et al., 2022). The goal of GINV is to create high-quality new goods with a low environmental impact. Meanwhile, the value of sustainable GINV will be widely recognized if environmental concerns exist (Sun et al., 2022).

In addition, technological development is considered the main factor for the socio-economic well-being of a country. Innovations based on ICTs have been a significant shift in sustainable process development. GINV and CENG utilization has modernized societies and contributed to human well-being by promoting financial development, renewable energy, and improved processes in all sectors (Azam et al., 2021). Implementing technological innovations for CENG production significantly alleviates poverty through improved resources and opportunities for people. GINV also plays a vital role in eliminating technological constraints toward generating renewable energy. Production and utilization of CENG have obtained great significance because of the depleting impact of non-renewable energy resources that can hinder human development (H. Zhang, 2021). The sustainable development program provided by United Nations also aims to reduce environmental deterioration through GINV and the Utilization of CENG. Hence, many countries have initiated renewable energy production through green technology innovation, eliminating the detrimental impacts of fossil fuel consumption on the environment. Under the given circumstances, it is vital to shift traditional sources to energy towards CENG for a sustainable future.

It is hypothesized that increasing the share of renewable in aggregate energy consumption levels will facilitate economic growth without negatively impacting environmental quality. It is also critical to enact environmental legislation simultaneously to mitigate the severe environmental effects of financial progress (Natha, 21; Razzaq et al., 2022). Moreover, environmental tax (ENTX) can help mitigate the adverse impacts of foreign direct investment (FDI) and international trade. For instance, if two countries have different environmental regulations, trade on the international level can end up causing environmental degradation for a country with weaker environmental considerations (Murshed et al., 2021). Environmental regulations' stringency can play a critical role in eliminating the deteriorating impacts of non-renewable energy utilization and trade on environmental sustainability. It is further stated that strict regulations can also reduce energy intensity levels and improve environmental quality by reducing carbon emissions. Thus, strict regulations in curbing carbon emissions and other particulate matter can be related to CENG utilization and environmental sustainability. In contrast, weaker environmental regulations can induce higher environmental pollution and negatively impact economic growth, encouraging economies to attract FDI to deteriorate further environmental sustainability (Ansari et al., 2022).

Moreover, the human development index (HDI) is a vital tool to measure a country's prosperity in terms of social well-being. World societies with improved HDI provide freedom to people with new opportunities and well-being in all fields. On the other hand, HDI is not a one-time achievement; it necessitates ongoing efforts from both government and academia to contribute to the survival of informed, happy, and healthy individuals(Arocena & Sutz, 2020).Besides the economic benefits, GINV improves life quality by creating social development opportunities that significantly impact social abilities. Thus, the improvement of a country is related to ecological and economic development and depends upon human well-being. Researchers believe that green development through technological innovation brings societal well-being in the given context. Many argue that technical advancement spurred by local diversity is more advantageous to society's development in this environment. According to proponents of this method, local biodiversity can 'pace the development path' through 'dynamic knowledge spillover.' On the other hand, the many modalities of innovation tend to bring general development and are more oriented to physical technology, thinking it is valuable based on how it is approved and used by the residents. In this regard, information and communication technology development garnersmuch attention because it is easier to mobilize and has a higher penetration rate (Asongu & Le Roux, 2017).

Renewable energy development is the main aspect of the production and utilization of CENG based on sources like hydropower, biomass, wind, solar, wave, and geothermal (Doğan et al., 2020). It is further stated that renewable energy consumption is the primary source of cleaner and sustainable energy for better environmental quality. Advanced economies like Canada, France, Germany, Japan, and Italy focus on developing renewable energy to bring environmental sustainability. In addition, environmental tax (ENTX) and ecological regulations are also observed in various research studies to improve environmental quality. Advanced economies with higher production levels demand more energy, thus causing environmental deterioration through carbon emissions (Sun et al., 2022a). Environmental regulations play a vital role in ecological practices towards a sustainable future based on the implementation of green innovation.

It is stated that Particulate matter ($PM_{2.5}$) is also a major source of environmental degradation through air pollution. PM is a mixture of particles like dirt, dust, smoke, or soot of minute sizes, creating severe environmental pollution (EPA., 2021). Different countries are going through industrialization and urbanization that utilize more fossil fuel energy, which has significantly increased the concentration of $PM_{2.5}$ in the air (Gorelick & Walmsley, 2020). The rapid development in advanced economies has also increased non-renewable energy resources in the industrial sector, becoming the main source of $PM_{2.5}$ in the air (Xu & Lin, 2018). Air quality restrictions have lowered pollutant emissions from conventional fossil fuel sources in the United States in recent decades. The average annual $PM_{2.5}$ concentration in the United States has fallen by 42% between 2000 and 2015, and the accompanying $PM_{2.5}$ death burden has also dropped substantially. Thus, the rise in the concentration of these particulate matters causes severe economic, environmental, and social challenges, which need to be addressed through the development of CENG and improved GINV for the world's advanced economies.

The remainder paper is as follows. Section two explains empirical literature; section three explores the research methods employed; section four covers the results and discussion of both supporting and contrary studies; section five concludes the study with some tremendous policy implications.

## 2. Literature review

### 2.1. Green innovation and environmental sustainability

Higher levels of fine particulate matter ($PM_{2.5}$) are one of the air pollutants that cause serious health issues. The tiny particles present in the air cause visibility reduction and a hazy appearance of the air at elevated levels of $PM_{2.5}$ particulate. Particulate matters are various chemicals emitted from fires, construction sites, and unpaved roads (EPA., 2021). According to Awe et al. (2022), due to particulate matter, haze pollution caused nearly 6.4 million deaths globally in 2019. Air pollution significantly impacts a country's health, society, and economy. Advanced economies are concerned about environmental pollution due to enhanced industrial development, which damages 6.1% of the global GDP.

Sun et al. (2022) explore the asymmetric effect of green innovation (GINV) on carbon emission levels and $PM_{2.5}$ abundance in the environment in the top 10 polluted economies. The panel data between 1991 and 2018 is employed based on the STRIPAT model. The study utilizes a novel Method of Moment Quantile Regression (MMQR). The MMQR approach provides efficient results in structural changes and data variations. Findings of the empirical study reveal that GINV in energy production and utilization significantly reduces the emission of particulate matter in the air, leading to a sustainable environment. Moreover, GINV eliminates carbon emissions for higher quantiles and provides insignificant impacts in the case of lower quantiles. Green investment leads toward GINV with higher environmental governance in the industrial sector of advanced economies. Yiting et al. investigate the impact of GINV on haze pollution using the mediating effect approach with technological innovation as a mediating variable. The study employs data from 639 enterprises in China between 2016 and 2019. The study states that higher investment in GINV impacts environmental sustainability with reduced haze pollution $PM_{2.5.}$ Empirical findings of the study reveal that a rise of one standard deviation in GINV reduces the concentration of $PM_{2.5}$ by 8.8 $\mu g/m^3$. In addition, green investment in technological innovation also boosts environmental quality, developing a sustainable environment. The study suggests GINV tools that promote eco-friendly development in all sectors.

Fast development industrial economy caused an ecological footprint and an abundance of particulate matter in the air causing detrimental pollution. Sahoo and Sethi (2021) investigate the dynamic impact of GINV on the air quality index ($PM_{2.5}$) based on technological innovation in newly industrialized countries. The study employs panel data between 1990 and 2017 to determine the long-run cointegration between the given variables. They implement the Mean Group (MG), and Westerlund cointegration approaches to develop long- and short-term correlations between GINV and environmental sustainability. The Augmented Mean Group (AMG) model is also employed to check the robustness of the given approach. Empirical findings of the study state that the industrial sector highly affects $PM_{2.5}$ with insignificant changes in environmental sustainability. GINV in the services sector reduces particulate matter ($PM_{2.5}$), while the agricultural sector enhances $PM_{2.5}$.

Industrial development brings massive economic growth, which causes serious environmental concerns such as the development of haze pollution. Shi and Zhang (2022) analyze the effect of haze control (PM2.5) by increasing GINV and technological development. The study employs panel data between 2005 and 2018 for 30 provinces of China and additional data based on $PM_{2.5}$ concentration in the air. They implement the Spatial Durbin and Threshold impact model for the empirical analysis of GINV impact on controlling haze pollution in China. The study shows that GINV reduces $PM_{2.5}$ concentration showing a positive control over haze pollution. Moreover, the GINV control effect of haze pollution ($PM_{2.5}$) provides a mixed impact in the case of low-income provinces of China. It further states that the haze control impact of GINV is higher in the Central region and lowest in the Western region of China. Demand for natural resources has been on the rise, which causes severe environmental deterioration. Gupta et al. (2022) investigated the relationship between GINV and $PM_{2.5}$ concentration using the data between 1990 and 2016. It also determines the presence of the EKC hypothesis. The study implements the Single structural break model to develop a correlation between the given variables. A long-term relationship between GINV and $PM_{2.5}$ is also found through ARDL bound testing method. Results of the empirical study reveal that enhanced GINV reduces the abundance of $PM_{2.5}$ in developing countries. Governments of advanced economies must develop such policy implications to enhance green investment toward a sustainable environment and reduce levels of $PM_{2.5}$ in the air.

### *2.2. Green innovation and human well-being*

The human development index (HDI) emphasizes that people and their attributes must be the optimum standard to assess a country's development. HDI can also be employed to determine a country's national policy options when two nations with the same levels of GDP perform differently in terms of HDI. The HDI can be cointegrated with green innovation development for a country (UNDP, 2022).

With success in advanced countries' economic and industrial sectors, it has become essential to discuss the impacts of GINV on the human development index in terms of economic well-being. (H. Wang et al., 2021) analyzes the impacts of GINV on environmental sustainability that, in turn, increase or decrease the HDI. A random sampling approach is utilized to determine the relationship between given variables. Findings of the study state that GINV practices also bring social well-being and environmental sustainability development. Improvement in GINV is a major aspect of societal well-being and sustainability development. Huang et al. (2021) investigate the impacts of GINV on social well-being in terms of urbanization, government competition, and industrial development. The study analyzes the data between 1997 and 2018 for China, employing a super-efficiency Ray slacks approach. The study's findings reveal that cointegration is found between GINV and social well-being factors stated earlier. The empirical findings demonstrate that China's GINV is just 0.4813 at the national level, and that more than 80% of regions are still far from reaching the green innovation frontier. Furthermore, the observed GINV disparity across regions is worsening; this, in turn, aligns with establishing a pattern in which the north-south divide is growing.

Asif et al. (2020) determine the correlation between technology innovation and HDI in advanced economies by employing panel data from the first two decades of the 21st century. The study utilizes a Quantile-on-Quantile approach and Granger Causality test to determine the correlation between the given variables. Outcomes of the study reveal a close positive correlation between technology innovation and HDI in technologically-advanced economies. Moreover, the Granger causality test provides a bi-directional cointegration between the given variables. The research approach () investigates the current innovation development in ICT and its impact on overall HDI for developing countries. The study employs primary data to determine the impacts of social, technological, and institutional innovations on HDI within the healthcare sector. A positive correlation is found between the ICT innovation and FDI of developing nations with enhanced human well-being. Thus, it is important to take GINV and ICT under revised policies to enhance the HDI in developing and developed economies. GINV can be brought the implementation of ICT in a country's production and industrial sectors that will reduce energy consumption and increase the CENG.

### 2.3. Clean energy and environmental sustainability

Clean energy is produced through renewable energy resources that are infinite in duration but limited in the amount of energy available. Consumption of renewable energy can play a vital role in providing clean energy (CENG) and reducing greenhouse gas emissions. It can also reduce fossil fuel consumption and imports (EIA., 2021).

Kirikkaleli and Adebayo (2021) explore the long-term relationship between renewable energy consumption and environmental sustainability. The study implements the fully modified OLS (FMOLS) and frequency-domain causality tests to determine the cointegration between given variables. Empirical findings of the study reveal the presence of long-term cointegration between CENG production and utilization and environmental sustainability. Thus, to improve environmental quality, it is important to invest in CENG and the consumption of renewable energy resources. In addition, Yang et al. (2021) investigated the impact of CENG on ambient $PM_{2.5}$ for different countries based on the data between 1980 and 2018. The study employs the Super-SBM-GML approach to determine the correlation between CENG and $PM_{2.5}$ concentration in the air. Results indicate that CENG consumption can significantly reduce the $PM_{2.5}$ concentration. The influence of energy efficiency on PM2.5 is variable, as evidenced by the different aspects of energy efficiency breakdown. PM2.5 concentrations can be reduced by increasing energy efficiency, and the inhibitory effect is primarily due to the generation and use of CENG. Hence, development in renewable energy consumption can significantly impact environmental quality.

Khan et al. (2020) examine how CENG consumption impacts environmental sustainability regarding $PM_{2.5}$ concentration in the air. The study employs the CIPS unit root test to determine the cross-sectional dependence based on the data between 2001 to 2018 for Nordic countries. The study also utilizes the dynamic common correlated effect model to test the robustness of given variables. Empirical findings of the study reveal that renewable energy consumption improves environmental quality by reducing the concentration of $PM_{2.5}$. Thus, it is important to devise policies for renewable energy resources to generate CENG that will ultimately impact environmental sustainability. Chien et al. (2021) fills the gap in studying and reducing haze pollution $PM_{2.5,}$ considering the relationship between renewable energy utilization and $PM_{2.5}$ concentration in higher-income Asian countries. The study analyzes the data between 1990 and 2017, employing a cross-sectional dependence test, slope heterogeneity test, and Westerlund panel cointegration analysis to determine the long-term effect between given variables. Empirical results of the study reveal that CENG significantly impact the $PM_{2.5}$ concentration and provides sustainable environment. They also provide policy implications regarding haze pollution $PM_{2.5}$ reducing detrimental impacts on environmental quality. Thus, implementing regulations for the production and consumption of CENG will bring environmental sustainability.

### *2.4. Clean energy and human well-being (HDI)*

Renewable energy utilization has attracted many researchers based on its growing importance in replacing fossil fuel energy. Non-renewable energy is the main reason for environmental deterioration. With this rationale, Sasmaz et al. research study determine the correlation between CENG and HDI for OECD economies. The study analyzes the panel data between 1990 to 2017, employing the Edgerton and Westerlund cointegration approach. Results of the empirical study reveal that CENG positively impacts the HDI. Moreover, the causality test is also employed to determine the bidirectional relationship between the given variables. The study also provides specific policies to increase investment in renewable energy utilization for a sustainable environment based on CENG. Azam et al. (2021) investigate the correlation between renewable energy utilization and HDI based on the data between 1990 and 2017 for developing economies. The study employs the panel vector autoregressive (PVAR) model to determine the cointegration between the variables. Empirical findings of the study state that a favorable relationship is present between CENG and HDI. The study also investigates the bidirectional correlation between CENG consumption and HDI. The research recommends implementing green investment for enhanced CENG utilization for improved HDI in developing nations.

The HDI inculcates three different aspects, including life, living standards, and people's education. Renewable energy utilization impacts these factors directly or indirectly; thus, countries should focus on reducing GHG emissions to improve the HDI. Amer (2020) provides the relationship between CENG and HDI through PVAR analysis. The study employs four different panels representing four income levels around the globe while analyzing the data between 1990 and 2015. The study applies cointegration and unit root tests for given data to determine the cross-sectional relationship between each income panel. Results of the study show that the impacts of CENG on HDI are insignificant for the selected developing countries of all income levels. CENG production is mainly based on advancing renewable energy resources to enhance HDI. Zheng and Wang (2022) observe the impact of CENG and renewable energy consumption on HDI, employing the dynamic and static panel models for developed economies from 2000 to 2018. The study reveals that the impact of renewable and CENG utilization is insignificant for HDI in short- and long-term relationships. Moreover, enhanced investment in green energy production can also raise the HDI for developed economies with higher economic growth and foreign direct investment (FDI). Advanced economies thus increase the utilization of CENG through green technology innovation that will ultimately boost the HDI and social well-being.

### *2.5. Environmental tax and environmental sustainability*

$PM_{2.5}$ is found to be detrimental to human health around the globe. The research study of Han and Li (2020) estimates the variations in $PM_{2.5}$ concentrations on implementing the environmental tax in capital cities of China. The study employs a Counterfactual Curve-fitting Simulation approach to estimate the correlation between ENTX and $PM_{2.5}$. The study implements a regression model called 'Bayesian LASSO' to determine the impacts of CENG on environmental sustainability. It is stated that the ENTX reduces annual concentrations of $PM_{2.5}$ in China. The major driving forces of climate change policy are improving energy efficiency and reducing environmental concerns through environmental regulations and levies.X. Li et al. (2022) analyzes the varying trends of ENTX and regulations for China based on the panel data between 2004 and 2017. The study employs a Spatial Durbin approach to investigate the impact of ENTX on varying pollutants on $PM_{2.5}$ concentration in the air. Empirical findings reveal that a negative correlation is present between the given variables. $PM_{2.5}$ has a regional overflow impact and is negatively linked with various pollutants' ENTX measures. PM2.5 will be lowered by 0.02 percent (0.04%), 0.05 percent (0.10 percent), and 0.04 percent (0.08 percent) for every 1% increase in the environmental regulatory intensity of the above three pollutants, respectively. Inter-regional cooperation has a significant and long-term influence on $PM_{2.5}$ and is beneficial to enhancing ENTX efficiency.

The literature contribution of Wolde-Rufael and Mulat-Weldemeskel (2022) determines the effectiveness of ENTX and the utilization of renewable energy on carbon emissions that ultimately affects the environmental sustainability in Latin American countries. The study employs Moments Quantile Regression (MMQR) approach for the data between 1994 and 2018. The study also applies conventional estimators such as AMG and DOLS to verify the cointegration between the given variables. The results show a heterogeneous effect between ENTX and environmental sustainability and a negative impact in higher carbon-emitting economies. Empirical findings of the MMQR approach reveal that ENTX can reduce environmental degradation and enhance sustainability. Proper implementation of ENTX can significantly reduce the emission of dangerous particles in the air and promote renewable energy consumption. It further states that ENTX and other regulations on the concentration of PM significantly promote environmental sustainability. The ENTX reforms were implemented in 2018 for China, one of the biggest carbon emitters. Based on the environmental regulations, (Z. Li, 2022) employs the PSM model to determine the impact of ENTX on environmental quality in terms of $PM_{2.5}$ concentration. It provides that the Chinese provinces with higher regulations on ENTX effectively reduce the concentration of $PM_{2.5}$ in the air and boost environmental quality. The study shows that a 1 unit raise in ENTX causes a reduction of 5,616 deaths by developing environmental sustainability and welfare development of $28.25 billion in Chinese provinces.

### *2.6. Environmental tax and human well-being*

Lai and Chen (2020) investigates the correlation between environmental performance and HDI. An approved method is employed to determine the impact of environmental regulations' performance on HDI. Empirical findings of the study reveal that implementing environmental regulations plays a vital role in environmental performance and thus impacts HDI. Environmental performance affects the life expectancy and GDP of a country. At the same time, the HDI contains the highest explanatory power of 80% for environmental regulations, including ENTX. Xiaoyu Li and Xu's (2021) research study aims to determine the relationship between environmental quality and HDI in China. The study employs provincial data between 2004 and 2017 to determine the cointegration between the environmental degradation index (EDI) and HDI based on the Simultaneous Equations Model. Results of the empirical study reveal that a U-shaped cointegration is found between the given variables. It further states that increased regulations for environmental sustainability can positively impact the HDI. (Hassan et al., 2021) determines the correlation between ENTX and economic well-being using the data obtained for OECD economies from 1994 to 2013. The study's findings reveal that increased ENTX leads to economic well-being and GDP growth. It also states that increased levels of ENTX can promote social well-being through economic growth.

### *2.7. Control variable*

The control variable is also considered to attain accurate results from the model proposed for the given research study. Foreign direct investment (FDI) is the control variable that impacts the haze pollution $PM_{2.5}$ and the human development index (IMF., 2021).

#### 2.7.1. Foreign direct investment and $PM_{2.5}$

Foreign direct investment (FDI) also plays a vital role in determining environmental sustainability and social well-being. FDI is the transfer of various kinds of capital inputs, which cannot be attained through investment, trade, and financial development. Cheng et al. (2020) empirically analyze the impact of FDI on $PM_{2.5}$ concentration polluting the air. The study employs a dynamic spatial panel approach to the data between 2003 and 2016 for China. Findings of the study reveal that FDI significantly enhances the $PM_{2.5}$ concentration and thus environmental pollution in China. However, this impact is based on the level of urban economic progress. FDI increases the concentration of $PM_{2.5}$ in the mid-level stage of industrialization. It further states that in later stages of industrialization, the FDI improves the air quality while minimizing $PM_{2.5}$ pollution. Another research approach by F. Wang et al. (2022) investigates the impact of FDI on haze pollution $PM_{2.5}$ in China based on spatial econometrics. The study utilizes a spatial two-stage Least Squares method to determine the correlation between given variables. It employs the data between 2004 and 2018 from different Chinese cities. Findings show that FDI positively impacts haze pollution. Evidence shows that with a rise of one standard deviation in FDI, the average annual concentration of $PM_{2.5}$ increases by 1.5% in China. However, this impact can very across different regions based on the economic growth.

#### 2.7.2. Foreign direct investment and human well-being

The literature contribution provides impacts of FDI on human well-being regarding poverty alleviation and economic growth for developing nations. The study analyzes panel series data between 1990 and 2017, employing the ARDL approach to evaluate the impact of FDI on HDI in developing nations like Africa. The study findings reveal no significant correlation between FDI and HDI in shirt- and long-term relationships. Economic development is essential to HDI; thus, researchers should consider it. Gökmenoğlu et al. (2018) investigated the impact of FDI on HDI in Nigeria's case, based on the data between 1972-2013. The study employs the Johansen correlation approach, which provides a long-run relationship between the given variables. Bidirectional causality is also determined between the FDI and life expectancy in Nigeria. The research findings reveal that FDI significantly impacts the HDI for the given sample period.

## 3. Research methods

This research applies a range of statistical estimations to resolve the data-related issues appropriately. Firstly, as Pesaran (2015) suggested, the cross-sectional dependence test has been applied. The reason for testing the CD test in the same step is that if this test is ignored, the estimations at later stages will lead to unreliable findings, hence the wrong inferences and generalization. After the CD test, the assumption of stationarity has been checked with the help of Pesaran's (2007)' test and Bai &

Carrion-i-Silvestre, 2009), which also considers the CD presence in the data along with slope heterogeneity. Therefore, the tests will help examine the non-stationarity issues and CD.

In addition, the testing for the slope heterogeneity is very important; therefore, this research adopted the modified version of Swamy's (1970s) test, which is further discussed by Pesaran and Yamagata (2008). The null hypothesis assumes no slope heterogeneity, whereas H1 demonstrates that slope heterogeneity exists. As the conventional tests fail to generate accurate findings in the presence of CD, the consideration of Banerjee and Carrion-i-Silvestre and Westerlund and Edgerton (2008) tests are obvious for checking the cointegration properties of the data.

Moreover, as the presence of CD is an ongoing phenomenon where the dataset belongs to similar sections or regions, the reliability of the findings will remain questionable. Hence, estimations for the long and short run through the CS-ARDL approach are dynamic because of common correlated effects. The traditional equation to reflect the relationship between the study variable is presented in Eq. 1.

$$\mathrm{Y}_{,\mathrm{i,t}} = \mathrm{f}\ (\mathrm{X1}_{\mathrm{i,t}},\ \mathrm{X2}_{\mathrm{i,t}},\ \mathrm{X3}_{\mathrm{i,t}}, \mathrm{Control}_{\mathrm{i,t}}) \tag{1}$$

In the above Equation, Y indicates the dependent variable, whereas X1-X3 covers the entitled key explanatory variables. Finally, the control variable is added in the model. Equation 2 shows the regression form of Eq. 1.

$$\mathrm{Y} = X1\beta_{1it} + X2\beta_{2it} + X3\beta_{3it} + control\beta_{4it}\alpha_i + \delta_{it} \tag{2}$$

$$W_{i,t} = \sum_{i=0}^{pw} \varphi_{i,t} W_{i,t-1} + \sum_{i=0}^{pz} \gamma_{i,t} Z_{i,t-1} + \varepsilon_{i,t} \tag{3}$$

The autoregressive distributed lag (ARDL) model is defined as Eq.3. However, Eq. 3 was used for each cross-section average repressor and extended into Eq. 4. The cross-section average reduced the CSD effects.

$$W_{it} = \sum_{i=0}^{pw} \varphi_{i,t} W_{i,t-1} + \sum_{i=0}^{pz} \gamma_{i,t} Z_{i,t-1} + \sum_{i=0}^{px} \alpha_i \overline{X}_{t-1} + \varepsilon_{i,t} \tag{4}$$

Where

$$\overline{X}_{t-1} = (\overline{W}_{i,t-1}, \overline{Z}_{i,t-1})$$

where $W_{it}$ is used to reflect the main dependent variable of interest and $\overline{Z}_{i,t-1}$ covers the rest of the study variables. Meanwhile, the average for both dependent and independent variables has been taken through $\overline{X}_{t-1}$ so that the issue of CD could be handled in a batter way. Besides, $P_w$, $P_z$, and $P_x$shows the lagged variables. Additionally, long-run coefficients are estimated through a short run with the help of CS-ARDL estimation long-run coefficients.

Table 1. Description and data sources of the variables.

| Variables | Description | Data source |
|---|---|---|
| 1. Green Innovation GINV | Patents Data | OECD |
| 2. Clean Energy CENG | Renewable energy consumption(% of total final energy usage) | WDI |
| 3. Environmental tax ENTX | Environment-related tax revenue(% of total tax revenues) | OECD |
| 4. Environmental Sustainability | Haze pollution PM2.5 | WDI DV1 |
| 5. Social well-being through the Human development index | HDI | Penn world table |
| 6. Foreign Direct Investment | FDI as a control variable | WDI |

Note: Data is taken from 1990 to 2019.

Table 2. Results of cross-sectional dependence test.

| Variable | t-statistics (sig.) |
|---|---|
| GINV | 29.205*** |
| CENG | 33.248*** |
| ENTX | 21.669*** |
| HPOL | 30.637*** |
| HDI | 26.207*** |
| FDI | 31.689*** |

Note: significance level at 1%, 5% and 10% are explained by ***, ** & * respectively.

## 4. Details of the variables

Before applying any econometric model, it is crucial to describe the study variables. Table 1 shows that green innovation, clean energy, and environmental taxes are the key explanatory variables, whereas haze pollution through PM2.5 and human development index (HDI) are dependent variables. Moreover, our study adds foreign direct investment as a control variable. The data sources are also presented in the last column of Table 1.

## 5. Results and related discussions

The implication of the cross-sectional dependence test is crucial in estimating reliable results because missing CD tests will lead to incorrect estimations at later stages. Therefore, the results of the CD test are demonstrated in Table 2. There are three core independent variables: green innovation, clean energy, and environmental taxes, whereas haze pollution and human development index are dependent variables. The results show that t-statistics for these variables are significant at 1%, which implies that H1 is accepted for the presence of CD in the study data.

In current literature, countless studies state that checking for the stationarity properties is very important (Cai & Menegaki, 2019; Phillips & Perron, 1988; Webb et al., 2020). For this reason, this research also investigates the stationarity properties of the data with the help of Pesaran (2007) and Bai & Carrion-i-Silvestre (2009) tests in Table 3. The core benefit of applying the stated test is that it mainly focuses on the CD existence in the data. Moreover, the study findings report that the null hypothesis failed to reject at the level, which assumes the non-existence of stationarity while considering all the demonstrated issues. Meanwhile, the data has become stationarity (Pesaran, 2007). Therefore, we have taken the first-order difference and applied the

**Table 3.** Unit root test output for Psarian’s test.

| | Level I(0) | | | First Difference I(1) | | |
|---|---|---|---|---|---|---|
| Variables | CIPS | M-CIPS | | | CIPS | M-CIPS |
| GINV | −3.628*** | −6.257** | | | – | – |
| CENG | −4.528*** | −5.357** | | | – | – |
| ENTX | −3.662*** | −6.258** | | | – | – |
| HPOL | −3.578*** | −7.518* | | | – | – |
| HDI | −4.072*** | −6.207** | | | – | – |
| FDI | −3.668*** | −5.662*** | | | | |
| Variables | Z | Pm | *p* | Z | Pm | *p* |
| GINV | 0.108 | 0.352 | 19.505 | −2.982*** | 6.508*** | 77.205*** |
| CENG | 1.013 | −0.627 | 25.075 | −8.203*** | 3.257*** | 56.278*** |
| ENTX | 0.168 | 0.708 | 15.638 | −5.538*** | 9.528*** | 71.053*** |
| HPOL | 0.418 | 0.805 | 18.208 | −5.206*** | 8.509*** | 61.082*** |
| HDI | 0.228 | 0.619 | 19.228 | −3.993*** | 4.528*** | 68.205*** |
| FDI | 0.159 | 0.358 | 19.528 | −2.987*** | −5.159*** | −71.320*** |

Note: significance level at 1%, 5% and 10% are explained by ***, ** & * respectively.

**Table 4.** Slope heterogeneity.

| DV: HPOL | t-statistics |
|---|---|
| Δ tilde | 36.207*** |
| Δ tilde Adjusted | 29.278*** |
| DV: HDI | |
| Δ tilde | 30.628*** |
| Δ tilde Adjusted | 28.207*** |

Note: significance level at 1%, 5% and 10% are explained by ***, ** & * respectively.

Bai et al. test. The results confirm that H1 is accepted, which assumes a presence of stationarity in the data along with the CD; hence, all the variables are integrated and stationery.

In addition, the slope heterogeneity is also an important query for which results have been covered in Table 4. More specifically, the null hypothesis assumes a presence of homogeneity in the slope coefficients, whereas H1 significantly rejects it. For both dependent variables named haze pollution and human development index, the results confirm that Δ tilde and Δ tilde Adjusted are statistically significant at 1%. This supports the acceptance of H1 while rejecting H0; therefore, it is stated that there exists significant heterogeneity in the slope coefficients when regressed for the human development index and haze pollution in the selected economies.

The testing for the cointegration relationship between the study variables is observed with the help of Westerlund and Edgerton (2008). The null hypothesis assumes no cointegration exists, whereas H1 indicates that cointegration exists. The results in Table 5 report that for both dependent variables under no break, mean shift, and regime shift categories, the results are highly significant at 1%. This means that H1 is significantly supported for the presence of cointegration for the haze pollution and human development index.

Moreover, this research provides the cointegration analysis based on Banerjee and Carrion-i-Silvestre’s. The findings (Table 6) also support the presence of cointegration for the key-dependent variables while considering the overall sample and for the

**Table 5.** Westerlund and Edgerton (2008) panel cointegration analysis.

| Dependent Variable: HPOL | No break | Mean shift | Regime shift |
|---|---|---|---|
| $Z_\varphi$(N) | −4.320*** | −3.269*** | −5.258*** |
| Sig. | (0.000) | (0.000) | (0.000) |
| $Z_\tau$(N) | −4.258*** | −4.510*** | −6.368*** |
| Sig. | (0.000) | (0.000) | (0.000) |
| Dependent Variable: HDI | **No break** | **Mean shift** | **Regime shift** |
| $Z_\varphi$(N) | −4.082*** | −3.662*** | −2.982*** |
| Sig. | (0.000) | (0.000) | (0.000) |
| $Z_\tau$(N) | −3.072*** | −3.159*** | −4.517*** |
| Sig. | (0.000) | (0.000) | (0.000) |

Note: significance level at 1%, 5% and 10% are explained by ***, ** & * respectively.

**Table 6.** Results of Banerjee and Carrion-i-Silvestre's cointegration analysis.

| DV: HPOL | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Full Sample | −4.204*** | −6.207*** | −5.627*** | −3.257*** | −4.268*** | −6.257*** |
| Belgium | −5.350*** | −3.252*** | −5.157*** | −5.357*** | −4.107*** | −5.207*** |
| Canada | −6.278*** | −5.207*** | −7.509*** | −6.207*** | −5.309*** | −5.033*** |
| France | −3.208*** | −5.008*** | 6.357*** | −4.218*** | −7.559*** | −6.876*** |
| Germany | −3.610*** | −4.119*** | −6.382*** | −6.092*** | −5.357*** | −3.229*** |
| Italy | −6.257*** | −3.668*** | −4.507*** | −5.108*** | −4.357*** | −6.887*** |
| Japan | 3.205*** | −5.2018*** | −3.625*** | −7.108*** | −4.008*** | −6.357*** |
| Netherlands | −3.668*** | −4.263*** | −5.605*** | −5.306*** | −6.205*** | −3.669*** |
| Sweden | −3.552*** | −5.209*** | −7.616*** | 4.505*** | −6.205*** | −7.516*** |
| Note: | | | | | | |

Note: A&D; No deterministic specification, B&E; With constant, C&F; With the trend, Critical Value (CV) at 5%** and 10% *with constant is −2.32, −2.18 and with the trend is −2.92 and − 2.82.

**Table 7.** Results of CS-ARDL analysis (long run CS-ARDL results).

| DV: HPOL | Coefficients | DV: HDI | Coefficients |
|---|---|---|---|
| GINV | −0.428** | GINV | 0.174** |
| CENG | −0.527* | CENG | −0.119** |
| ENTX | −0.301** | ENTX | 0.301 |
| FDI | 0.493** | FDI | 0.228** |
| CSD-Statistics *p*-value | 0.351 | CSD-Statistics *p*-value | 0.128 |

Note: significance level at 1%, 5% and 10% are explained by ***, ** & * respectively.

individual selected economies. The findings are presented through no deterministic specification, constant, and with the trend, respectively.

The above discussion confirms the existence of cross-sectional dependence, unit root properties, slope heterogeneity, and cointegration between the study variables. Therefore, in the final step, the discussion of the analyses has been covered for the long run and short run, respectively.

Initially, long-run findings (Table 7) through the CS-ARDL approach have been covered while considering haze pollution and human well-being through the human development index. The results show that green innovation significantly reduces haze pollution from PM2.5. More profoundly, these results show that a 1% change in green innovation is directly responsible for a decline of 25.7% in the PM2.5 among all the eight advanced economies of the world. The stated results are highly significant at 1%, which justifies that green innovation is significantly linked with haze pollution in the form of Pm2.5. The literature justification for the impact of green technology innovations on haze pollution has also been provided in Yi et al. (2022) research contribution. They claim that with the growing trend of industrialization in the world economy, the issue of haze pollution is becoming severe too. Moreover, their study mainly focuses on the Chinese region for testing the trends in PM2.5 among 30 provinces while considering the role of green innovation as among the key determinants. The results reflect that green innovation with foreign investment has a spillover and negative effect on the haze pollution in China. One of the key suggestions by Yi et al. (2022) states that the government of China should strengthen innovative practices while improving its economic level so that environmental pollution would be controlled in a better way. Liu et al. (2021) also explore the environmental pollution in the form of PM2.5 and state that there is immense pressure to adopt those policies and related strategies to control such environmental degradation. More specifically, it is suggested that combining big data technology and green technologies may help minimize environmental concerns like PM2.5. In addition, clean and green energy utilization also reflects a reduction in the value of air pollution like PM2.5.

Moreover, it is examined that environmental taxes also play a role in reducing the PM2.5 in overall sampled economies. This is because higher environmental regulations like taxes will pressure the industries and households to consume less energy and lower environmental pollution. In this regard, the lower level of environmental pollution like PM2.5 has been examined among the study countries. More specifically, the results show a coefficient of −0.301, significant at 1%. M. Zhang et al. (2019) consider the panel data for the Chinese provinces to examine whether the role of environmental regulations is productive enough towards haze pollution both in direct and indirect ways. The results confirm that a reasonable transformation and up-gradation in the industrial structure has been observed with the implementation of environmental governance.

Consequently, environmental regulations help achieve expected results in China regarding reducing haze pollution. Zhou et al. (2019) conducted a city-level panel analysis in China to measure the non-linear impact of environmental regulation on haze pollution. It is inferred that both formal and informal impacts of environmental regulation on haze pollution exist. Finally, our study finds that FDI in the panel economies is directly responsible for environmental pollution where the coefficient size is largest. This means that more FDI inflow in all the targeted countries creates an upward shift of 49.3% in PM2.5. Tang et al. (2016) confirm the positive association between FDI and haze pollution in China, whereas F. Wang et al. (2022) have also claimed that an increase in FDI with one standard deviation is causing an upward shift of 1.5% in the air pollution. Finally, for model 1, where haze pollution (PM2.5) is considered the main dependent variable, the outcomes for CSD statistics are insignificant.

The association between the human development index (HDI) as a proxy for human well-being and the rest of the study variables, in the long run, is also covered in Table 7. The results show that green innovation is positive and significantly associated with HDI, where technological innovations have observed an overall change of

**Table 8.** Results of CS-ARDL analysis (short run CS-ARDL results).

| DV: HPOL | Coefficients | DV: HDI | Coefficients |
|---|---|---|---|
| GINV | −0.137* | GINV | 0.108** |
| CENG | −0.237** | CENG | −0.027* |
| ENTX | −0.193* | ENTX | 0.276 |
| FDI | 0.183** | FDI | 0.123* |
| CSD-Statistics *p*-value | 0.307 | CSD-Statistics *p*-value | 0.118 |

Note: significance level at 1%, 5% and 10% are explained by ***, ** & * respectively.

17.4% in HDI. This is because more technological advancement helps improve the standard of living, educational facilities, and other life-related dynamics. The historical review of the selected economies has made it clear that some outstanding technological advancement has been experienced over the past many years. Similar is found in HDI, where the selected economies have gained some remarkable positions in the well-being of their community members. The positive nexus between green innovations and HDI has also been explored and justified in past studies. Qureshi et al. (2020) apply quantile-on-quantile regression estimation and the granger-causality association between technological innovation and human development among technologically advanced countries. Their results confirm the positive relationship between technological advancement and HDI among all the sampled countries. Moreover, a two-way causal relationship was also found between technological innovations and HDI.

Moreover, the impact of clean energy on HDI is also presented in Table 6. The results show a negatively significant coefficient for HDI as determined through clean energy. More specifically, it implies that one standard deviation change in CENG causes a change of −11.9% in human development in all the eight selected countries. However, the literature has mixed evidence justifying the relationship between HDI and CENG. For example, Z. Wang et al. (2018) state that clean energy from renewable sources is discoursing the human development process in Pakistan. On the other side, Z. Wang et al. (2021) claim that renewable energy helps in enhancing human development among the BRICS countries. Finally, the findings for the association between environmental taxes and human development are positively insignificant. One of the critical reasons for this insignificant association is that

Meanwhile, such taxes have major spending on sustainable development like environmental protection from carbon emission and other air pollution like PM2.5. It indicates that there is no direct spending of such taxes on human development among the targeted economies; hence the relationship between both is insignificant. Besides, FDI reflects a highly significant and positive role in HDI among the sample countries. The nexus between FDI and HDI is also supported in different studies (Akisik et al., 2020; Lehnert et al., 2013; Reiter & Steensma, 2010).

Table 8 confirms the association between study variables based on the short-run outcomes. The result shows that green innovation, clean energy, and environmental taxes help reduce haze pollution. However, the size of the coefficients is significantly higher in the long run. However, the influence of FDI on haze pollution is positive and similar to long-run results. It confirms that FDI is causing more air pollution in both time horizons. Green innovations are positively and significantly linked with HDI, whereas clean energy is not.

## 6. Conclusion and policy recommendations

Both environmental sustainability and human well-being are integral components for the betterment of society and the community. However, because of the growing trend in industrialization, cross-border investments, and rapid economic growth, the pressure on the natural environment in the form of haze pollution and carbon emission has dramatically increased in recent years. Many factors have been observed while playing their role as a panacea for protecting the natural environment and strengthening human development. The above arguments have motivated us enough to examine the role of green technologies, clean energy, and environmental regulations(environmental taxes)towards environmental sustainability and human well-being (reflected through the human development index). This research focuses on advanced countries where governments and various environmental stakeholders have conducted remarkable human development and environmental protection practices. Advanced tests such as cross-sectional dependence, slope heterogeneity, unit root, and cointegration have been applied to investigate the relationships. Empirical findings confirm the presence of cross-sectional dependence, heterogeneity in the slope coefficients, stationarity in the data, and cointegration, respectively. Moreover, for checking the association between the stated variables, both time horizons ranging from short to long run were under observation. The results confirm that green technology, clean energy, and environmental taxes help reducehaze pollution like PM2.5. However, foreign investment among the selected economies is directly responsible for more haze pollution.

Additionally, the promotion of HDI through green technology and clean energy also exists in the long run, whereas environmental tax does not show any role in human well-being. For the short run, the results are similar to the long run; however, significant regression coefficient changes were found. More specifically, environmental taxes do not promote the HDI among these economies in the short run, whereas FDI does. Based on the stated results, it has been observed that green technology and related innovations play a major role in enhancing the environmental protection and human development index. Therefore, governments should take adequate measures to switch towards efficient and productive technologies in all economic sectors. Similarly, there is a need to promote sustainable business practices among different industries to reduce haze pollution significantly. The promotion of green technology innovations is much desired due to its other benefits, encouraging sustainable economic growth.

Moreover, it is further suggested that there is a need for reinvestigating the role of environmental taxes towards human development as a current study has found an insignificant association between both. In this regard, some strategic policies should be determined to enable a fruitful utilization of environmental taxes for human development. Finally, we confirm that foreign investment helps promote human development. However, at the same time, it hurts environmental sustainability while adding more haze pollution. To control these adverse effects, it is recommended to build collaboration between industry and environmental departments to devise long-term policies. Despite substantial contributions to the literature, the current study also highlights some limitations. Firstly, only eight advanced economies were selected from a larger sample in the world economy. Secondly, cross-sectional comparative analyses are also missing in this study. Thirdly, the role of environmental policy stringency, information and communication technologies, green growth, and other macroeconomic variables is also missing under current research. Therefore, the consideration of these limitations in the future can provide some different empirical findings.

## Acknowledgements

Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2022R260), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia

## Disclosure statement

No potential conflict of interest was reported by the authors.

## ORCID

Nguyen Binh An http://orcid.org/0000-0001-5154-5906
Iskandar Muda http://orcid.org/0000-0001-6478-9934

## References

Adedoyin, F. F. (2021). Global sustainability in the presence of green technology transfer. In Brinkmann, R., & Garren, S. J. *(Eds.), The Palgrave handbook of global sustainability*. (pp. 1–11). Springer.

Akisik, O., Gal, G., & Mangaliso, M. P. (2020). IFRS, FDI, economic growth and human development: The experience of anglophone and francophone African countries. *Emerging Markets Review*, *45*, 100725. https://doi.org/10.1016/j.ememar.2020.100725

Amer, H. (2020). The impact of renewable energy consumption on the human development index in selected countries: Panel analysis (1990-2015). *International Journal of Economy, Energy and Environment*, *5*(4), 47. https://doi.org/10.11648/j.ijeee.20200504.12

Ansari, M. A., Haider, S., Kumar, P., Kumar, S., & Akram, V. (2022). Main determinants for ecological footprint: An econometric perspective from G20 countries. *Energy, Ecology and Environment*, 1–18.

Arocena, R., & Sutz, J. (2020). The need for new theoretical conceptualizations on national systems of innovation, based on the experience of Latin America. *Economics of Innovation and New Technology*, *29*(7), 814–829. https://doi.org/10.1080/10438599.2020.1719640

Asif, J., Ammar, S., & Ramsha, A. (2020). The dynamic relationship between technology innovation and human development in technologically advanced countries: Fresh insights from quantiles-on-quantile approach. *Social Indicators Research*, *152*(2), 555–580.

Asongu, S. A., & Le Roux, S. (2017). Enhancing ICT for inclusive human development in Sub-Saharan Africa. *Technological Forecasting and Social Change*, *118*, 44–54. https://doi.org/10.1016/j.techfore.2017.01.026

Awe, Y. A., Larsen, B. K., & Sanchez-Triana, E. (2022). *The global health cost of PM2. 5 air pollution: A case for action beyond 2021*.

Azam, A., Rafiq, M., Shafique, M., Yuan, J., & Salem, S. (2021). Human development Index, ICT and renewable energy-growth nexus for sustainable development: A novel PVAR analysis. *Frontiers in Energy Research*, *760*.

Bai, J., & Carrion-i-Silvestre, J. L. (2009). *Testing panel cointegration with unobservable dynamic common factors*.

Cai, Y., & Menegaki, A. N. (2019). Convergence of clean energy consumption—Panel unit root test with sharp and smooth breaks. *Environmental Science and Pollution Research International*, *26*(18), 18790–18803. https://doi.org/10.1007/s11356-019-04911-x

Chien, F., Sadiq, M., Nawaz, M. A., Hussain, M. S., Tran, T. D., & Le Thanh, T. (2021). A step toward reducing air pollution in top Asian economies: The role of green energy, eco-innovation, and environmental taxes. *Journal of Environmental Management*, *297*, 113420.

Cheng, Z., Li, L., & Liu, J. (2020). The impact of foreign direct investment on urban PM2. 5 pollution in China. *Journal of Environmental Management*, *265*, 110532.

Doğan, B., Balsalobre-Lorente, D., & Nasir, M. A. (2020). European commitment to COP21 and the role of energy consumption, FDI, trade and economic complexity in sustaining economic growth. *Journal of Environmental Management*, *273*, 111146. https://doi.org/10.1016/j.jenvman.2020.111146

EIA. (2021). *Renewable energy explained*.

EPA. (2021). *Particulate matter (PM) basics*.

Gorelick, J., & Walmsley, N. (2020). The greening of municipal infrastructure investments: Technical assistance, instruments, and city champions. *Green Finance*, *2*(2), 114–134. https://doi.org/10.3934/GF.2020007

Gupta, M., Saini, S., & Sahoo, M. (2022). Determinants of ecological footprint and PM2. 5: Role of urbanization, natural resources and technological innovation. *Environmental Challenges*, *7*, 100467. https://doi.org/10.1016/j.envc.2022.100467

Han, F., & Li, J. (2020). Environmental protection tax effect on reducing PM2. 5 pollution in China and its influencing factors. *Polish Journal of Environmental Studies*, *30*(1), 119–130. https://doi.org/10.15244/pjoes/122228

Hassan, M., Oueslati, W., & Rousselière, D. (2021). Energy taxes and economic growth in OECD countries: A simultaneous equations approach. *Journal of Environmental Economics and Policy*, 1–24.

Huang, H., Wang, F., Song, M., Balezentis, T., & Streimikiene, D. (2021). Green innovations for sustainable development of China: Analysis based on the nested spatial panel models. *Technology in Society*, *65*, 101593. https://doi.org/10.1016/j.techsoc.2021.101593

Irfan, M., Razzaq, A., Sharif, A., & Yang, X. (2022). Influence mechanism between green finance and green innovation: Exploring regional policy intervention effects in China. *Technological Forecasting and Social Change*, *182*, 121882. https://doi.org/10.1016/j.techfore.2022.121882

Ikram, M., Ferasso, M., Sroufe, R., & Zhang, Q. (2021). Assessing green technology indicators for cleaner production and sustainable investments in a developing country context. *Journal of Cleaner Production*, *322*, 129090. https://doi.org/10.1016/j.jclepro.2021.129090

IMF. (2021). *How beneficial is foreign direct investment for developing countries?*

Khan, S. A. R., Yu, Z., Belhadi, A., & Mardani, A. (2020). Investigating the effects of renewable energy on international trade and environmental quality. *Journal of Environmental Management*, *272*, 111089.

Kirikkaleli, D., & Adebayo, T. S. (2021). Do renewable energy consumption and financial development matter for environmental sustainability? New global evidence. *Sustainable Development*, *29*(4), 583–594. https://doi.org/10.1002/sd.2159

Lai, S. L., & Chen, D.-N. (2020). A research on the relationship between environmental sustainability management and human development. *Sustainability*, *12*(21), 9001. https://doi.org/10.3390/su12219001

Lehnert, K., Benmamoun, M., & Zhao, H. (2013). FDI inflow and human development: Analysis of FDI's impact on host countries' social welfare and infrastructure. *Thunderbird International Business Review*, *55*(3), 285–298. https://doi.org/10.1002/tie.21544

Li, Z. (2022). Can environmental tax curb air pollution: Evidence from China. *Applied Economics Letters*, 1–4.

Li, X., Xue, W., Wang, K., Che, Y., & Wei, J. (2022). Environmental regulation and synergistic effects of PM2. 5 control in China. *Journal of Cleaner Production*, *337*, 130438. https://doi.org/10.1016/j.jclepro.2022.130438

Liu, Y., Fang, Z., & Chen, F. (2021). Retracted article: Impact of PM2.5 environmental regulation based on big data for green technology development. *Arabian Journal of Geosciences*, *14*(7), 649. https://doi.org/10.1007/s12517-021-06900-2

Murshed, M., Rahman, M. A., Alam, M. S., Ahmad, P., & Dagar, V. (2021). The nexus between environmental regulations, economic growth, and environmental sustainability: Linking environmental patents to ecological footprint reduction in South Asia. *Environmental Science and Pollution Research International*, *28*(36), 49967–49988.

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. https://doi.org/10.1002/jae.951

Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econometric Reviews*, *34*(6-10), 1089–1117. https://doi.org/10.1080/07474938.2014.956623

Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of Econometrics*, *142*(1), 50–93. https://doi.org/10.1016/j.jeconom.2007.05.010

Phillips, P. C. B., & Perron, P. (1988). Testing for a unit root in time series regression. *Biometrika*, *75*(2), 335–346. https://doi.org/10.1093/biomet/75.2.335

Qureshi, M. A., Qureshi, J. A., Ahmed, A., Qaiser, S., Ali, R., & Sharif, A. (2020). The dynamic relationship between technology innovation and human development in technologically advanced countries: Fresh insights from quantiles-on-quantile approach. *Social Indicators Research*, *152*(2), 555–580. https://doi.org/10.1007/s11205-020-02451-3

Razzaq, A., Wang, Y., Chupradit, S., Suksatan, W., & Shahzad, F. (2021). Asymmetric inter-linkages between green technology innovation and consumption-based carbon emissions in BRICS countries using quantile-on-quantile framework. *Technology in Society*, *66*, 101656. https://doi.org/10.1016/j.techsoc.2021.101656

Razzaq, A., Sharif, A., An, H., & Aloui, C. (2022). Testing the directional predictability between carbon trading and sectoral stocks in China: New insights using cross-quantilogram and rolling window causality approaches. *Technological Forecasting and Social Change*, *182*, 121846. https://doi.org/10.1016/j.techfore.2022.121846

Reiter, S. L., & Steensma, H. K. (2010). Human development and foreign direct investment in developing countries: The influence of FDI policy and corruption. *World Development*, *38*(12), 1678–1691. https://doi.org/10.1016/j.worlddev.2010.04.005

Rene, E. R., Bui, X. T., Ngo, H. H., Nghiem, L. D., & Guo, W. (2021). Green technologies for sustainable environment: An introduction. *Environmental Science and Pollution Research International*, *28*(45), 63437–63439. https://doi.org/10.1007/s11356-021-16870-3

Sahoo, M., & Sethi, N. (2021). The dynamic impact of urbanization, structural transformation, and technological innovation on ecological footprint and PM2. 5: Evidence from newly industrialized countries. *Environment, Development and Sustainability*, 1–34.

Shan, S., Genç, S. Y., Kamran, H. W., & Dinca, G. (2021). Role of green technology innovation and renewable energy in carbon neutrality: A sustainable investigation from Turkey. *Journal of Environmental Management*, *294*, 113004. https://doi.org/10.1016/j.jenvman.2021.113004

Shi, W., & Zhang, L. (2022). Does technological innovation promote haze pollution control? New evidence based on panel threshold model and spatial econometric model. *Frontiers in Environmental Science*, *658*.

Sun, Y., Anwar, A., Razzaq, A., Liang, X., & Siddique, M. (2022). Asymmetric role of renewable energy, green innovation, and globalization in deriving environmental sustainability: Evidence from top-10 polluted countries. *Renewable Energy*. *185*, 280–290. https://doi.org/10.1016/j.renene.2021.12.038

Sun, Y., Guan, W., Razzaq, A., Shahzad, M., & An, N. B. (2022). Transition towards ecological sustainability through fiscal decentralization, renewable energy and green investment in OECD countries. *Renewable Energy*. *190*, 385–395. https://doi.org/10.1016/j.renene.2022.03.099

Tang, D., Li, L., & Yang, Y. (2016). Spatial econometric model analysis of foreign direct investment and haze pollution in China. *Polish Journal of Environmental Studies*, *25*(1), 317–324. https://doi.org/10.15244/pjoes/60856

UNDP. (2022). *Human development index (HDI).*

Wang, Z., Bui, Q., Zhang, B., Nawarathna, C. L. K., & Mombeuil, C. (2021). The nexus between renewable energy consumption and human development in BRICS countries: The moderating role of public debt. *Renewable Energy*. *165*, 381–390. https://doi.org/10.1016/j.renene.2020.10.144

Wang, Z., Zhang, B., & Wang, B. (2018). Renewable energy consumption, economic growth and human development index in Pakistan: Evidence form simultaneous equation model. *Journal of Cleaner Production*, *184*, 1081–1090. https://doi.org/10.1016/j.jclepro.2018.02.260

Wang, F., He, J., & Niu, Y. (2022). Role of foreign direct investment and fiscal decentralization on urban haze pollution in China. *Journal of Environmental Management*, *305*, 114287. https://doi.org/10.1016/j.jenvman.2021.114287

Wang, H., Khan, M. A. S., Anwar, F., Shahzad, F., Adu, D., & Murad, M. (2021). Green innovation practices and its impacts on environmental and organizational performance. *Frontiers in Psychology*, *11*, 3316. https://doi.org/10.3389/fpsyg.2020.553625

Watson, L. S., & Kaarsberg, V. (2021). *Is economic growth compatible with a sustainable Nordic future?: A review of literature.*

Webb, C., Linn, S., & Lebo, M. J. (2020). Beyond the unit root question: Uncertainty and inference. *American Journal of Political Science*, *64*(2), 275–292. https://doi.org/10.1111/ajps.12506

Westerlund, J., & Edgerton, D. L. (2008). A simple test for cointegration in dependent panels with structural breaks. *Oxford Bulletin of Economics and Statistics*, *70*(5), 665–704. https://doi.org/10.1111/j.1468-0084.2008.00513.x

Wolde-Rufael, Y., & Mulat-Weldemeskel, E. (2022). The moderating role of environmental tax and renewable energy in CO2 emissions in Latin America and Caribbean countries: Evidence from method of moments quantile regression. *Environmental Challenges*, *6*, 100412. https://doi.org/10.1016/j.envc.2021.100412

Xu, B., & Lin, B. (2018). What cause large regional differences in PM2. 5 pollutions in China? Evidence from quantile regression model. *Journal of Cleaner Production*, *174*, 447–461. https://doi.org/10.1016/j.jclepro.2017.11.008

Yang, C., Li, T., & Albitar, K. (2021). Does energy efficiency affect ambient PM2. 5? The moderating role of energy investment. *arXiv preprint arXiv:2105.11080.*

Yi, M., Lu, Y., Wen, L., Luo, Y., Xu, S., & Zhang, T. (2022). Whether green technology innovation is conducive to haze emission reduction: Empirical evidence from China. *Environmental Science and Pollution Research International*, *29*(8), 12115–12127. https://doi.org/10.1007/s11356-021-16467-w

Zhang, H. (2021). Trade openness and green total factor productivity in China: The role of ICT-based digital trade. *Frontiers in Environmental Science*, *9*. https://doi.org/10.3389/fenvs.2021.809339

Zhang, M., Liu, X., Ding, Y., & Wang, W. (2019). How does environmental regulation affect haze pollution governance?—An empirical test based on Chinese provincial panel data. *The Science of the Total Environment*, *695*, 133905. https://doi.org/10.1016/j.scitotenv.2019.133905

Zheng, J., & Wang, X. (2022). Impacts on human development index due to combinations of renewables and ICTs––New evidence from 26 countries. *Renewable Energy*, *191*, 330–344. https://doi.org/10.1016/j.renene.2022.04.033

Zhou, Q., Zhang, X., Shao, Q., & Wang, X. (2019). The nonlinear effect of environmental regulation on haze pollution: Empirical evidence for 277 Chinese cities during 2002–2010. *Journal of Environmental Management*, *248*, 109274. https://doi.org/10.1016/j.jenvman.2019.109274