Heliyon 10 (2024) e33526

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Role of natural resources, renewable energy sources, eco-innovation and carbon taxes in carbon neutrality: Evidence from G7 economies

Wenze Jiang [a], Songrui Chen [a], Peibei Tang [b], Yuhang Hu [c], Muyao Liu [a,*], Shi Qiu [d,**], Mujahid Iqbal [e]

[a] Business School, Nanjing University, Nanjing, 210093, China
[b] Business School, Xi'an Jiaotong-Liverpool University, Suzhou, 215028, China
[c] School of Environment, Environment Science (Sino-foreign Cooperation), Hohai University, Nanjing, 210024, China
[d] Lanzhou University, Lanzhou City, Gansu Province, 730000, China
[e] Schools of Economics, Bahauddin Zakaryia University, Multan, Pakistan

ARTICLE INFO

Keywords:
Resource reliance
Biofuels carbon neutrality
Renewable energy
Financial development
Environmental policy
Carbon tax

ABSTRACT

Global warming has created problems for human life, and it has been increasing for a few years. All the developing and developed countries are establishing policies to attain zero carbon status. This study extends the ongoing debate on carbon emissions. It examines the effect of natural resources and RE (Biofuel and other renewable sources) on greenhouse gas (CO_2 emission and PM2.5) emissions while using data over 22 years (1999–2021) from G7 countries. In addition, this study has investigated the effect of carbon taxes, financial development, and environmental policies on carbon neutrality. The cross-sectional-ARDL, the Common correlated effect means group (CCEMG), and the Augmented mean group (AMG) cutting-edge model have been employed. Quantile regression has been employed for robustness. The study results demonstrate that biofuel and other renewable energy (RE) sources, carbon taxes, environmental policy, and eco-innovation decrease greenhouse gas emissions (CO2 emissions). Meanwhile, financial development, and natural resource dependence positively impact carbon neutrality. The robustness result also verifies the findings from CS-ARDL, AMG, and CCEMG methods. The empirical findings are used to infer policy implications for G7 economies.

Abbreviations: **CN**, Carbon neutrality; **EI**, eco-innovation; **RE**, Renewable energy; **FD**, Financial development; **BF**, Biofuel; **CT**, carbon taxes; **EP**, environmental policy; **NRD**, Natural resources dependence; **CO_{2e}**, carbon dioxide emission; **EIA**, energy information administration; **WDI**, World development indicators; **OECD**, Organization for economic cooperation; **GHG**, Greenhouse gas emission; **PM2.5**, Particular matter; **EKC**, Environmental Kuznets Curve; **SDG**, Sustainable development goals; **CS-ARDL**, cross-sectional autoregressive distributive lag; **CCEMG**, Common correlated effect means group; **AMG**, Augmented mean group; **MMQR**, Method of Moment Quantile Regression; **CSD**, cross sectional dependence.

* Corresponding author.
** Corresponding author.
E-mail addresses: wenzejiang@smail.nju.edu.cn (W. Jiang), 201098094@smail.nju.edu.cn (S. Chen), Peibei.Tang21@student.xjtlu.edu.cn (P. Tang), 835371986@qq.com (Y. Hu), muyaoliunju@163.com (M. Liu), qs17843316369@163.com (S. Qiu), Mujahidiqbal117@gmail.com (M. Iqbal).

https://doi.org/10.1016/j.heliyon.2024.e33526
Received 16 February 2024; Received in revised form 29 May 2024; Accepted 23 June 2024
Available online 24 June 2024
2405-8440/

1. Introduction

The environment in which humans inhale and operate is essential to both social advancement and financial growth. Ecological factors impact the well-being of both humans and the organisms that inhabit the same ecosystem as humans. Humans in a clean and healthy environment maintain good health and vitality, allowing them to engage in social interactions actively. Organisms having good health and other valuable NRD are utilized in present financial processes and facilitate the implementation of SDG. However, both naturally occurring and human-induced polluting factors harm the value of NRD and the country's development. Carbon dioxide (CO_2) emissions are considered one of the most detrimental causes of environmental pollution [1]. CO_2 emissions contribute to Climate change which ultimately leads to global warming and disrupt the climate equilibrium, damaging living organisms, including humans and the atmosphere. Carbon dioxide ($CO_{2)}$ emissions function as a layer in the atmosphere, enveloping the Earth and contributing to the heating of the atmosphere, thus raising the planet's overall temperature. This leads to an increase in the Earth's average warmth on a worldwide scale. Global warming is caused by releasing carbon dioxide (CO_2) into the atmosphere, which disrupts environmental conditions, weather patterns, and water supplies, food and sea levels [2]. As a result, The level of excellence or superiority in natural resources decreases, and the health of living beings, including humans, deteriorates. Therefore, the public and economic progress of country, which relies on a conducive environment, including natural resources such as land, water, and human resources, is in jeopardy. The potential danger can be mitigated by decreasing the amount of CO_2 emissions [3].

Undoubtedly, natural resources continue to be the primary catalyst for economic growth and development. Humans and the air ecology are reliant on natural resources for economic and survival purposes. Essential resources, including natural gas, oil, coal, sand, metals, and stones, are crucial for economic and non-economic human endeavors. Key natural resources that are essential for global sustainability include sunshine, water, soil, and air. Although there are compelling disputes on the importance of natural resources, they continue to pose the most difficult challenges in the present period for three specific reasons. The environmental challenges posed by natural resources exacerbate the ecological system, causing worldwide economic uncertainty on its sustainability [4]. Furthermore, the increase in dangerous illnesses cannot be separated from the subsequent negative consequences of the depletion of natural resources [5]. Natural resources continue to be a significant concern for states, regional, and international organizations. This was particularly evident at the latest Conference of the Parties held in the UK in November 2021 (COP26) [6]. The need to propose effective answers to the ongoing ecological problems caused by the decreasing availability of natural resources highlights the importance of the sustainability agenda.

Furthermore, the primary factors contributing to CO_2 emissions, aside from population growth, include the decay of faunae and florae, transportation activities, expansion of domestic technological infrastructure, and increased business activities dependent on nonrenewable energy sources such as oil, coal, natural gas, petroleum, and Orimulsion [7]. Controlling the causes of CO_2 emissions and implementing green practices such as eco-innovations, RE production or consumption, and environmental taxes can effectively reduce CO2 emissions. In order to achieve environment free of CO_2 emissions in the environment, it is essential to utilize ecologically friendly supplies of renewable energy such as solar, wind, biomass, hydro and geothermal energy [8,9]. Renewable energy is the term used to describe the energy obtained from sources like geothermal heat, sunlight, airstream, waves, rain, and other natural phenomena that have a minimal negative influence on the environment [10]. RE is commonly utilized to fuel four distinct sectors: transportation, air, electricity generation and water cooling or heating, and rural energy [11]. The utilization of RE resources, which are environmentally friendly sources of energy, in various business operations such as infrastructure development, manufacturing processes, and transportation, does not result in the emission of CO_2. These sources are derived from organic materials that absorb heat or CO_2 to generate energy. Furthermore, the generation of sustainable energy sources such as biomass and biofuel involve utilizing crops, plants, wood, and agricultural and forestry waste [12]. These resources harness solar heat and absorb CO_2 from the atmosphere throughout their growth. Therefore, the heightened generation of RE diminishes the preexisting CO_2 in the atmosphere [13]. Furthermore, the inclination towards utilizing renewable energy sources such as solar, wind, biomass, hydro and geothermal energy reduces reliance on imported nonrenewable energy. RE is more cost-effective and therefore more desirable compared to nonrenewable energy, which tends to be significantly costly. Decreasing the burning of fossil fuels leads to a reduction in CO_2 emissions [14–16].

Given the global recognition of environmental sustainability, governments and authorities are currently implementing significant measures to mitigate pollution and counterbalance the adverse effects of CO_2 emissions on the environment. Governments implement various regulatory strategies, such as environmental levies, to effectively mitigate carbon emissions [17,18]. An "environmental-related tax" refers to a tax that is based on a physical unit or an estimate of a physical unit, which represents anything that has a confirmed and specific harmful impact on the environment [19,20]. Carbon taxation schemes, commonly referred to as price mechanisms for greenhouse gas (GHG) emissions, are an effective technique for reducing CO_2 emissions [21,22]. The imposition of environmental taxes leads to an increase in fossil fuel prices, making them costly for both producers and consumers. This in term affect individual financial decisions and reduce the use of costly non-RE, so helping to protect the environment from CO_2 emissions and their negative effects [23]. These taxes incentivize industrial and manufacturing sectors to prioritize the production of environmentally sustainable products and methods, thereby decreasing reliance on fossil fuels and mitigating CO_2 emissions. In addition, environmental taxes serve to boost the use of RE sources instead of nonrenewable energy, hence reducing carbon dioxide emissions and enhancing the ecosystem [24]. Environmental taxes also function as a means of allocating financial resources to local authorities and governments. The government can utilize these resources to implement and engage in environmentally-friendly measures aimed at reducing CO_2 emissions [25]. Given these circumstances, the primary focus of this study is to inspect the correlation between carbon neutrality and dependence on natural resources in the G7 economies, considering the integration of eco-innovation, green energy, carbon taxes, and conservation policies.

This research has four main benefits. To begin with, it guides environmental problems by filling in gaps in empirical data and policy insights concerning the ongoing spike in GHG emissions, especially in G7 economies. Secondly, the research provides a broader framework for evaluating carbon neutrality by adding CO_2 emissions and PM2.5 air pollution to the list of possible outcomes. The third point is that it brings up the topic of how well carbon and environmental restrictions have worked to curb increasing GHG emissions from the government. Finally, considering the combined effects of reliance on natural resources, eco-invention, green energy, carbon pricing, and conservation legislation, it is the first empirical strategy to tackle the rising greenhouse gas emissions in G7 economies [26]. Our study's inclusion of numerous G7 nations allows for comparison analysis, revealing distinct methods and successful strategies. This international viewpoint provides a comprehensive view, letting countries study each other's triumphs and tribulations. At a time when international collaboration is more critical than ever, our research adds to the conversation surrounding environmental diplomacy. The G7 can use these findings to encourage cooperation, standardize policy, and tackle the pressing global need for carbon reductions as a group [27]. Observing how the G7 countries balance reducing emissions with increasing their economies can teach industries and investors a thing or two about environmental sustainability. Our findings point to promising openings and new directions for development in this field. Finally, the study's methodological approach boosts the robustness and relevance of its contributions. It includes cross-sectional autoregressive distributed lag, robustness tests, and multiple regression procedures.

Hence, the arrangement of this work is as follows: after the introduction, while, part 2 comprises the literature review, part 3 outlines the methodology, part 4 gives the empirical analysis, and final part 5 concludes the research and discusses its consequences.

2. Review of literature

2.1. Theoretical literature

The hypothesis that pertains to our investigation is the EKC theory, derived from the argument put forth by Grossman and Krueger et al. [28]. According to the EKC theory, a non-linear relationship exists between environmental quality and actual productivity, characterized by an upward curve followed by a downward curve. In their study, Yu et al. [29] observed that there is a positive relationship between economic activity, as measured by GDP, and environmental degradation up to a certain threshold. According to Naqvi et al. [30], further economic growth depends on decreasing ecological harm. The EKC thesis suggests that environmental catastrophes caused by CO_2 follow a quadratic relationship with monetary expansion, symbolizing productive activities that require energy consumption [31].

The EKC offers a conceptual comprehension of the competition to achieve carbon neutrality by embracing environmental technology, RE, and innovation through agricultural output economic development and fossil fuel. According to the premise of the EKC, the first increase in ecological pollution caused by the excessive emission of CO_2 can be attributed to fossil fuel energy, agricultural production, and total economic growth measured by GDP. Usman et al. [32] and Jiang et al. [33] have found that the usage of fossil fuels leads to the carbon emissions into the atmosphere, which has a detrimental impact on the quality of the environment. Khan et al. [34] also highlighted the significant presence of carbon in fossil fuels. When these fossil fuels undergo combustion, carbon atoms combine with oxygen to form CO_2, releasing energy.

The EKC posited that there is an inverse relationship between environmental contamination and long-term economic productivity growth. Wan et al. [35] observed that integrating RE, environmental technology, and innovation into production processes at this level reduces pollution by promoting energy and carbon efficiency. In addition, Sun et al. [36] suggested that technical innovation can mitigate adverse environmental conditions resulting from production operations. Furthermore, the research done by Ahmad et al. [37] and Azam et al. [38] substantiates the contribution of renewable energy utilization in reducing carbon emissions. Hence, by integrating RE and ecological technology and innovation based on the EKC argument, we can better assess the importance of utilizing RE. Ecological technology and innovation in G7 promote carbon neutrality by reducing fossil fuel energy use, increasing renewable energy, carbon taxes, economic innovation and fostering GDP growth.

2.2. Empirical literature

The ongoing flow of worldwide greenhouse gas (GHG) emissions has fueled an in-depth exploration of conservational science. Primarily, this research aims to address the uncertainties surrounding the sustainability of the worldwide economy.

2.2.1. Natural resources and carbon neutrality

The EKC hypothesis was tested using an empirical model spanning 208 economies from 1990 to 2018 by Kahia et al. [39] and found that Natural resource rent was a moderating influence on CO_2 emissions. This employ the Fully Modified Ordinary Least Squares (FMOLS) estimator and the GMM estimator to account for the correlation between RE, human capital, and trade openness. The outcomes support the EKC hypothesis, which demonstrates that normal supply rents meaningfully contribute to the rise in CO_2 emissions for the economies included in the sample [40]. Although economic growth follows an "inverted U-shaped" curve, carbon emissions are also induced by trade openness and economic expansion. Instead, RE helps slow the increase in global emissions. The increasing trend in CO_2 emissions in a piece of 24 chosen markets from 2001 to 2020 is the subject of this study, which isolates the effects of three crucial natural resource indicators: oil, coal and natural gas. Nuclear power, alternative energy sources, and GDP expansion are all factored into the data. Based on the findings, nuclear power and renewable energy sources are good policy choices for fostering sustainable development since they considerably reduce CO_2 emissions, driven by the three components of natural resources [41].

Researchers examine the G7 nations' environmental quality from 1990 to 2020 and how economic success, resource dependency, and price volatility impacted it. The study uses panel quantile regression to validate its empirical model, which includes second-generation methodologies [42]. According to the results, economic performance and commodity pricing of natural resources have a harmful effect on quality of environment, as seen by their effects on carbon emissions across different quantiles. Renewable energy, oil rents, and R&D can provide better environmental quality by diminishing carbon dioxide emissions.

Continuing with the climate change feedback from COP26, Zhao et al. [22] looks at how a panel of G20 nations fared in carbon neutrality between 2001 and 2019 due to their reliance on natural resources. Applying the GMM and FMOLS estimators to test its assumptions, the study also explains the roles of vitality ingesting and trade openness in the model. The study's outcomes show that RE, exports, and gas rents moderate the effect of imports, oil rents, and coal rents on the rise of carbon emissions [43]. conducts research into technological progress, renewable energy, and natural resource price volatility on China's ecological economy. This study tests its hypothesis using yearly time series data from 1990 to 2017 and several estimators, such as FMOLS, DOLS, and CCR. The results showed that natural resources and technological advancement are two positive forces driving environmental degradation (ecological footprint).

Wang et al. (2023) looked at 35 BRI nations from 1985 to 2019 to see the interdependencies between carbon emissions, economic development, RE use, and natural resources. RE and carbon dioxide drive economic expansion, whereas natural resources slow it, according to results from ordinary least squares (OLS), fixed effect, extended technique of instants, and disparate relapse models. Although natural resource extraction and economic expansion have a beneficial influence on CO_2 emissions, the use of RE sources considerably lowers emissions. Usage of RE increased due to economic development, but carbon dioxide and natural resource usage decreased. This study's results on the effects of wealth disparity and natural resource scarcity on the interplay between RE use, economic growth, and CO_2 emissions have important policy implications for BRI nations.

The study by Ref. [26] examined the effects of remittances, natural possessions, technical innovation, economic expansion, and management of energy intake and development on CO_2 emissions from 1990 to 2019, in Pakistan. In a combined integration test, the Bayer and Hanck model found that remittances, natural resources, technical advancements, economic growth, and CO_2 emissions are interdependent. Furthermore, the ARDL model suggested a long-term positive correlation between remittances and CO_2 emissions, suggesting that an uptick in remittances is terrible for Pakistan's environmental performance. According to Huang et al. [45], natural resources reduce carbon dioxide emissions, whereas technological development, economic growth, energy use, and urbanization contribute to higher emissions. Furthermore, the findings of ARDL estimations were consistent with the robustness checks conducted using OLS and FMOLS estimators. Various factors, including normal incomes, technical novelty, financial growth, energy use, development, remittances, and the findings of frequency causality tests, cause carbon dioxide emissions.

Borojo et al. (2023) used yearly time series data from 1970 to 2016 to inspect the backdrop of Pakistan and the dynamic linkages between carbon-fossil GHG emissions, WEF resources and growth-specific factors. A country's water footprint in greenhouse gas emissions is increased by chemicals employed in manufacturing, according to results from a simultaneous GMM estimator, which in turn is affected by industry value added and fossil fuel burning. The association between it is an inverted U-shaped carbon footprint for water and food in terms of fossil fuel GHG emissions. With a per capita income turning point of US$1120, US$1170, US$1250, and US $1140, respectively. The carbon-fossil-GHG footprints of energy and water's proportion in fossil fuels support the U-shaped EKC. In contrast, per capita income and water's proportion in GHG emissions establish monotonic increasing functions. The Pollution Haven Hypothesis (PHH) holds true for water's contribution to carbon emissions. In contrast, the IPAT hypothesis is supported by a carbon footprint associated with water, a carbon footprint associated with food, and a carbon footprint associated with electricity.

2.2.2. *Green energy and carbon neutrality nexus*

Renewable energy sources and their significance to environmental research are growing as greenhouse gas (GHG) emissions continue to rise despite attempts to reduce their harmful effects. Evaluative research is developing as a continuous effort to improve the ecosystem's sustainability in response to this challenge. For example, Zhang et al. [47] looks at 63 developed and developing nations from 1990 to 2020 and uses carbon footprints to determine whether nonrenewable energy, green energy, financial development, and economic development help or hurt carbon neutrality [26]. Estimated model results show that renewable energy foundations adversely influence carbon footprint, lending credence to the carbon neutrality movement. According to the study, nonrenewable energy sources increase the carbon footprint, whereas financial development significantly decreases it. Also, Zhong et al. [48] looks at 18 developed nations from 1990 to 2019 and how RE has helped them reduce their CO_2 emissions. Nonlinear autoregressive distributed lag and pooled mean groups are also used in this study to analyze the mediating effects of technological innovation. The research shows that renewable energy and technological innovation have positive shocks that lower CO_2 emissions and that these indicators have adverse shocks that cause CO_2 emissions to spike.

L. N. Hao et al. (2021) investigated how renewable energy does, in fact, help the E7 economies' emission curves flatten and either support or disprove the EKC theory. This research uses CS-ARDL techniques and AMG to examine secondary data collected annually from 1995 to 1999. Results from the E7 economies add credence to the EKC hypothesis, which postulates that procedural invention and renewable energy sources will moderate the emission increase. Rising economic activity is a significant factor in the rise of CO_2 emissions. Determining how much renewable energy mitigates the environmental impact in a worldwide sample of 120 economies is the study's primary goal [50]. By expanding its scope to include the association between nonrenewable energy and economic development in the model, the study by Guo et al. [51] adds to the existing body of knowledge. The calculated models' feedback shows that RE is the key to reducing carbon footprints while raising economic growth rates. While increasing economic growth is desirable, it is worth noting that the environment suffers when nonrenewable energy sources are combined with it. From 1990 to 2017, Huan et al. [52] similarly proved that RE moderated CO_2 emissions for 147 nations. The report emphasizes biofuels' importance in delivering economic and environmental benefits. It identifies the top five nations for biomass energy demand as India, followed by China, Brazil, the US, and Germany. Using yearly data from 1970 to 2016, the study examines the connections among CO_2 emissions and biomass energy in these countries, considering the effects of monetary liberalization, economic expansion, and urbanization. The results show that biomass does leave an environmental impact [39].

In recent decades, environmental degradation has been steadily increasing in speed [53]. Because of the influence it has on billions of human lives, ecological pollution has been the focus of studies around the world. Little worldwide agreement on cutting energy consumption and carbon emissions has been reached despite the rising need for fossil fuels in developing economies [54]. On the other hand, several nations are working to meet the 2015 Paris Climate Agreement's requirements. While most studies [55,56] find positive social and economic effects from international commerce, there are many [57,58] who argue that it really has the opposite effect, leading to reduction of natural resources and environmental deterioration.

Sun et al. [59] investigated how changes in renewable energy, population density, life expectancy, income, and other demographic factors influenced the ecological footprint of eight developing nations in South and Southeast Asia over a 25-year period from 1990 to 2015. The utilization of the CS-ARDL methodology produced results that suggest a non-linear relationship between income and ecological footprint, following an N-shaped pattern. The long-term results further emphasized the necessity of embracing low-pollution energy choices. Furthermore, the study demonstrated that greater adoption of renewable energies reduced the environmental footprint of the region. Fareed et al. [60] used the CS-ARDL model to argue that the use of renewable energies and the development of ecologically focused technical advances contribute to the promotion of environmental sustainability.

2.2.3. *Eco-innovation (EI) and carbon neutrality*

Eco-innovation (EI) has been included as a new element in the growth-pollution model due to its acknowledged significance in lowering global CO_2 emissions. Scientists have emphasized the need for countries to urgently develop and implement environmental or eco-innovation in order to address the climate disaster and achieve net zero emissions by 2040. This involves reducing and removing the carbon emissions released into the atmosphere [61]. This suggests that to reduce carbon emissions and offset any leftover CO_2 emissions by absorbing an equal quantity from the atmosphere, it will be necessary to develop environmental or eco-innovations. EI relies on socially responsible investment practices and incorporating natural environmental standards into patents to enhance ecological quality [45]. Recent research has provided insight into adopting eco-innovation and its ability to facilitate sustainable development and the reduction of CO_2 emissions towards achieving net zero. In their study, Shang et al. [62] observe the determinants of carbon neutrality in the US and provide evidence that EI can effectively decrease CO_2 emissions. Therefore, it is critical to prioritize the advancement and availability of sustainable EI to achieve carbon neutrality. Petrychenkoet al. [63] proposed that EI technologies serve as the primary means to discourage the utilization of fossil fuels and promote the adoption of environmentally friendly and RE sources, hence mitigating carbon emissions. As said by Kuang et al. [64], eco-innovation enhances energy efficiency, decreasing the use of polluting energy sources and contributing to the attainment of environmental sustainability. Deng et al. [65] highlighted that eco-innovation has offered a favorable approach for European companies to reduce their direct and indirect CO_2 emissions. This suggests that EI enhances environmental quality without impeding economic operations. Abu Houran et al. [66] states that implementing policies that promote sustainable technologies will effectively cut CO_2 emissions without the need for ecological fees and regulations. Ghosh et al. [67] demonstrate that EI is crucial in reducing CO_2 emissions and PM2.5 in the US economy. According to Almasri et al. [68], there is a claim that the implementation of energy efficiency and eco-innovations in G7 countries results in higher energy consumption and emissions due to the rebound effect. Pata et al. [69] emphasize the necessity of aggressive measures to mitigate the rebound effect of residential eco-innovation. Zhou et al. (2023) emphasize that EI can reduce CO_2 emissions in OECD countries but also lead to a rebound effect. In their study, Kahia et al. (2023) found that eco-innovation has a long-term impact on reducing CO_2 emissions. In contrast, in the near term, it causes a rise in CO_2 emissions.

Eco-innovation (EI), renewable energy, globalization, haze contamination complete PM2.5, and conservatory gas emissions were the main metrics used to assess China's natural environment's sustainability in the study by Ref. [70]. The link between the explanatory and outcome variables was examined in both the long and short term using the Quantile ARDL technique. Under various quantiles, the consequences showed that EI, renewable energy, and EI all had an undesirable and statistically noteworthy effect on CO_2 emissions in the regional China. However, only at the highest quantiles was a positive and statistically significant association among globalization and CO_2 emissions noted. In addition, the long-term estimate demonstrated that ERTech, renewable energy, and EI may substantially contribute to reducing PM2.5 haze pollution in China. In addition, QARDL verifies the negative and long-term estimate among EI, RE, and ERTech; in contrast, globalization is increasing GHG emissions in China, leading to a slew of sustainability problems. As a result, we may say that globalization raises carbon emissions while efficient innovation, use of renewable vitality, and environmental fees diminution them.

A study by Ref. [71], has studied the relationship between political risk index, RE and non-RE consumption, EI, and renewable energy R&D while taking data from seven OECD countries. Fiscal decentralization was also considered as a potential new determinant. The robustness is checked using a CCEMG test, the short-run and long-run analyses are conducted using a CS-ARDL technique, and the empirical analysis uses the test for cointegration suggested by Ref. [72]. The results supported earlier studies that found fiscal decentralization and eco-innovation to be associated with higher rates of RE consumption and lower rates of non-RE consumption. An improved political risk index and more investment in RE R&D have led to a shift in energy ingesting away from non-renewable foundations. In terms of policy implications, this study suggests that devolving power to local governments will lead to even greater improvements in energy efficiency and a shift towards more sustainable energy sources in these nations' energy mixes.

2.3. Research gap

A significant void in the current body of research has been revealed by the thorough examination of the papers covered above. In particular, the G7 economies' efforts to achieve carbon neutrality have not been examined in light of the interconnected impacts of green vitality, reliance on natural resources, EI, carbon taxes, and environmental policies. In this study, novel methods of estimations (CS-ARDL, CCEMG, and AMG) along with multiple empirical test like cross sectional dependence test, slop homogeneity test and unit root tests have been used to get robust results. This work intends to fill this knowledge gap and make a significant role to this important area of research. The study main objective to shed light on the complex dynamics impacting the G7 economies' pursuit of carbon impartiality by investigating these interrelated elements.

3. Data and methodology

3.1. Data

This research looks at the G7 countries' reactions to the CO_2 emissions boom from 1999 to 2021 through viewed through the prisms of economic development, carbon pricing, renewable energy, ecological innovation, dependence on natural resources, and green legislation. The countries in question are the UK, Canada, France, Germany, Italy, USA, and Japan. All of the variables listed above are determined by external forces; however, carbon neutrality, as dignified by CO_2 emissions, is an internal variable [73]. The concept of carbon neutrality is a relatively new approach to solving the pervasive problems impacting the long-term viability of the world economy. An economy is said to be moving toward a carbon-neutral environment if its CO_2 emission curve flattens, whereas the reverse is suggested by an economy whose emissions are carbon-inducing. Although there are many reasons given in the introduction to choose the G7 frugalities as the focus of the review, there are three main reasons why the timeframe from 1999 to 2021 was chosen. The selection of 1999 as the baseline year was made possible by the availability of balanced national data for PM2.5 air pollution for all of the years that were required. Second, 2021 was chosen as the destination year because 2022 did not have any data on carbon taxes, biofuels, environmental regulations, or CO_2 emissions [74]. The study's variables were culled from three authoritative sources. The variables used in this study are carbon neutrality (CN), renewable energy (RE), and total natural resource dependence (NRD). The former is represented by CO_2 emissions (MM tones CO_2), while the latter is a proxy for renewable electricity connected volume (million kW) and is derived from the Energy Material Management (Emm). Additionally, the World Development Indicator (WDI) provides data on financial development (FD), which is calculated as domestic credit to the private sector as a percentage of GDP, and P.M2.5 air pollution, which is the percentage of the population exposed to levels exceeding the WHO Interim Target-1 value, as a percentage of the total. The following metrics are derived from the OECD: eco-innovation (EI), biofuels (BF), carbon tax (CT), environmental policy (EP), and financial development (FD). The variables acronyms, measurement and sources are given in Table 1.

Traditional economic theory serves as the foundation for the model and the theories that support it [75]. The research makes some educated guesses about the connections between the G7 economies' carbon neutrality and a number of other variables. Since RE is known to decrease emissions, it is predicted that there is an inverse association between RE and CO_2 emissions. The moderating influence of eco-innovation on emission levels is shown in the predicted undesirable connection among eco-invention and CO_2 emissions. Drawing on research supporting the moderating effects of carbon prices on emissions, the study also expects an inverse connection between carbon taxes and CO_2 emissions. As a reflection of the ecological effects of resource depletion, it is believed that natural resource dependency is positively associated with CO_2 emissions. Since biofuels moderate emissions of greenhouse gases, the study predicts that there would be an undesirable association among biofuels and CO_2 emissions. Empirical evidence indicating the efficacy of strict environmental regulations in lowering emissions leads one to assume a converse connection between the environmental policy and CO_2 emissions [49]. Both good and negative impacts on carbon dioxide emissions are expected as a result of financial development. In order to shed light on the quest for ecologically friendly behaviors, the study intends to investigate the intricate relationship between these factors and how they affect carbon impartiality in the G7 nations.

Table 1
Description of variables.

Variables	Acronyms	Measurement	Sources
Carbon dioxide emission	CO_2	CO_2 emissions (metric tons per capita)	WDI
PM2.5 Air pollution	PM2.5	Percentage of the population exposed to levels exceeding the WHO Interim Target-1 value, as a percentage of the total	WDI
Eco-innovation	EI	Number of patents, with country fractional value	OECD
Natural resource dependence	NRD	Total natural resources rents (% of GDP)	
Renewable energy	RE	Renewable electricity installed capacity (million kW)	EIA
Biofuels	BF	Number of patents, with country fractional value	
Carbon tax	CT	Environmental related tax revenue	OECD
Environmental policy	EP	Environmental Policy Stringency Index	OECD
Financial development	FD	Domestic credit to the private sector as a percentage of GDP	WDI

3.2. Empirical modeling

Newly published research informs the model that lays out the assumptions and evaluates the possessions of reliance on usual incomes, eco-innovation, and renewable energy on the G7 markets' achievement of carbon impartiality. These relationships can be expressed mathematically in the following:

$$CN_{it} = \sigma_0 + \sigma_1 GE_{it} + \sigma_2 EI_{it} + \sigma_3 CT_{it} + \sigma_4 EP_{it} + \sigma_5 FD_{it} + \alpha_{it} \tag{1}$$

Carbon neutrality (CN) is a vector that includes two outcome variables, P.M2.5 air effluence and CO_2 emissions. Green energy, or GE, refers to sources of renewable power and biofuels. EI denotes eco-innovation, whereas CT stands for carbon tax. In addition, EP stands for environmentally stringent policies and FD for financial development. The following is an expansion of Equation (1) that considers green energy components, as well as two pointers of carbon impartiality in Equations (2) and (3).

$$CO2_{it} = \sigma_0 + \sigma_1 BF_{it} + \sigma_2 RE_{it} + \sigma_3 EI_{it} + \sigma_4 CT_{it} + \sigma_5 EP_{it} + \sigma_6 FD_{it} + \alpha_{it} \tag{2}$$

$$PM2.5_{it} = \sigma_0 + \sigma_1 BF_{it} + \sigma_2 RE_{it} + \sigma_3 EI_{it} + \sigma_4 CT_{it} + \sigma_5 EP_{it} + \sigma_6 FD_{it} + \alpha_{it} \tag{3}$$

in this context, α stands for the stochastic term, and t represents the research period that begins in 1999 and ends in 2021. In order for any variable to be tested scientifically, it must first be transformed using the natural logarithm.

3.3. Estimation strategy

When conducting empirical validation, it is essential to first ensure that the slope coefficients and cross-sectional dependencies are consistent in order to determine the dataset's features. We then learn what kinds of statistical tests are available and whether there are any cointegration relationships. Regression analysis verifies the extent to which endogenous and exogenous elements interact with one another. Examining the correlations between indicators allows us to draw conclusions about policy.

3.3.1. Cross-sectional dependence and homogeneity tests

It should be stressed that cross-sectional data might be negatively affected by interference among cross-sectional units. It is possible that the panel model experienced an interruption that caused this problem. It is essential to thoroughly observe cross-sectional dependence before moving forward with empirical analysis when generating panel regression models. Predictions of conflicting measurements may be erroneous if this basic issue is ignored. This investigation makes use of the cross-sectional dependence tests proposed by Pesaran [76] and Pesaran [77]. Slope homogeneity testing is essential, in addition to checking for common component problems, because CSD might vary between units. The slope similarity test is used for this purpose. You can use this test on balanced or unbalanced panel data, to estimate strong or weak exogenous regressors, CSD, and serially correlated errors. Based on its relative accuracy, this test uses the cross-sectional deviation of each slope. Since it only takes into account external, non-normally distributed regressors, the homogeneous slope test is also dependable [78]. Slope homogeneity test standard models are represented by the following symbols (See Eqs. (4) and (5)).

$$\widetilde{\Delta}_{SH} = (N)^{\frac{1}{2}}(2k)^{-\frac{1}{2}}\left(\frac{1}{N}\widetilde{S} - k\right)\widetilde{\Delta} = \Bigg(N\,1\Bigg(2k(T-k-1) - 2(\widetilde{1}S - 2k) \tag{4}$$

$$\widetilde{\Delta}_{ASH} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1}{T+1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}\widetilde{S} - 2k\right) \tag{5}$$

3.3.2. Panel unit roots test

After the SH and CSD tests are passed, the next important step is to run a panel stationarity test. When cross-sectional dependence (CSD) is apparent, second-generation testing is the way to go [79]. Assuming that the series is not stationary, this methodology is legitimate. The following equations (Eq. 6) represent the CIPS test statistic obtained by being around each CADF.

$$\widehat{\mathrm{CIPS}} = \frac{1}{\mathrm{N}}\sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{CADF_i} \tag{6}$$

3.3.3. Long-run nexus test

Confirming a panel regression requires three steps, the third of which is panel cointegration. This second-generation panel long-run nexus is based on Westerlund's [80] work. Its ability to mitigate issues brought about by slope heterogeneity and CSD is a notable strength. Evidence from empirical studies [81], suggests that this resilient technique is useful for analyzing cointegration, which refers to the long-run links among endogenous and exogenous variables. Remember that in this case, refusing the null theory would imply that, in the end, carbon neutrality is connected to outside factors. Following Westerlund's [80] approach, the cointegration nexus can be expressed as follows (See Eq. (7)&8):

$$\alpha i(L)\Delta y_{it} = y2_{it} + \beta_i(y_{it} - 1 - \acute{\alpha}_i \mathrm{x_{it}}) + \lambda_i(\mathrm{L})\mathrm{v_{it}} + \eta_i \tag{7}$$

$$\delta_{1i} = \beta_i(1)\widehat{\vartheta}_{21} - \beta_i\lambda_{1i} + \beta_i\widehat{\vartheta}2_i\text{and}y2_i = -\beta_i\lambda 2_i \tag{8}$$

here are the two standard test statistics that were used to examine Equation (9-12):

$$G_t = \frac{1}{N}\sum_{i-1}^{N}\frac{\acute{\alpha}_i}{SE(\acute{\alpha}_i)} \tag{9}$$

$$G_\alpha = \frac{1}{N}\sum_{i-1}^{N}\frac{\mathrm{T}\acute{\alpha}_i}{\acute{\alpha}_i(1)} \tag{10}$$

$$P_T = \frac{\acute{\alpha}}{SE(\acute{\alpha})} \tag{11}$$

$$P_\alpha = \mathrm{T}\acute{\alpha} \tag{12}$$

3.3.4. Panel long-run estimation

In this analysis, panel reversion examination is mostly used in the fourth step of the estimating technique. When doing empirical verification, it is significant to pay devotion to the qualities of the supporting dataset to avoid misunderstanding the relevance and validity of the expected regression results. When dealing with different slope parameters, for example, Traditional methods of estimation, such as those involving fixed and random effects, may yield contradictory findings. Previous estimators have used the assumption that the slope coefficients of the aggregate cross-sectional units follow a distribution that is normally distributed. In general, this work adheres to the CS-ARDL that was proposed by Ref. [82]. Furthermore, it is consistent with the empirical research that was conducted in the past by Refs. [41,73]. There are three interconnected econometric problems that the CS-ARDL intends to tackle. These problems are heterogeneous slope coefficients, convergent endogeneity, and CSD. This is the simplest way to describe the model (See Eq. (13)):

$$CN_{it} = \beta_0 + \sum_{j=1}^{q}\pi_{it}CN_{i,t} + \sum_{j=0}^{q}\theta_{i1}^{t}X_{i,t-j} + \sum_{j=0}^{q}\varphi_{i1}^{t}\gamma_{i,t-1}\overline{Z}_{i,t-j} + e_{it} \tag{13}$$

Three additional estimators, namely the panel quantile regression model, the augmented mean group, and the mutual connected possessions mean group, are examined to guarantee the CS-ARDL's resilience. According to heterogeneity is used in the research to determine the direction of causality [40]. This study employs a country-level analysis based on a completely modified ordinary least squares model to tackle the inherent heterogeneity of the cross-sectional units.

4. Results and discussions

This study explores the nature of the indicators using three standard approaches to identify the properties of the carbon neutrality hypothesis in G7 economies. Descriptive statistics are used to aggregate a number of characteristics of the variables that have been chosen. You can find more details on the distribution of the dataset in Table 2, which also contains descriptive analysis. As a proxy for environmental pollution, carbon dioxide emissions average 6.72 percent across the G7 economies, as shown by the averages computed from the summary numbers. When one considers the rapid monetary development that contributes to air effluence in these parsimonies, this result is in line with expectations. The G7 economies' average CO_2 emissions from PM2.5 air pollution are 4.05 percent, making them the biggest contributor to global warming. This finding is consistent with empirical observations that demonstrate CO_2 emissions are a major component of greenhouse gas emissions [11].

Green energy typically comes from renewable sources (approximately 3.56 % of the total) and biofuels (about 2.72 %). With an average value of −1.62 % for reliance on natural resources, the G7's commitments to attain carbon neutrality are strengthened [46]. As a result of their serious commitments and hard work, the G7 countries have been recognized as pioneers in the transition to a more sustainable energy future [83]. With an average significance of 7.33 percent, the G7 nations' commitment to enhancing their

Table 2
Descriptive statistics.

Variables	LCO_2e	LPM2.5	LBF	LRE	LNRDP	LEI	LCT	LEP	LFD
Mean	3.36	1.975	1.36	1.78	−0.81	3.665	0.78	0.40	2.385
Median	3.18	2.245	1.41	1.82	−0.965	3.565	0.785	0.49	2.395
Maximum	4.35	2.3	3.035	2.785	0.805	4.63	0.84	0.675	2.69
Minimum	2.905	−0.16	−0.345	0.195	−2.27	2.58	0.705	−0.22	2.05
Std. Dev.	0.435	0.575	0.645	0.535	0.825	0.59	0.035	0.225	0.17
Skewness	0.655	−1.125	−0.08	0.385	0.06	0.06	−0.08	−0.42	−0.03
Kurtosis	1.77	3.82	1.825	1.78	0.945	0.87	0.965	1.37	0.935
Jarque- Bera	24.16	140	1.79	9.025	4.37	5.5	4.21	9.755	4.37
Probability	0.00	0.00	0.15	0.00	0.01	0.00	0.01	0.00	0.01

technological standing is evident. The high-tech performance is not unexpected given the extensively industrialized nature of these economies. Carbon taxes are 1.56 % on average, but environmental regulations are 0.80 % stricter [84] reports that the financial sectors of the G7 nations have progressed somewhat, with a growth rate of 4.77 percent on average.

In Table 3 the correlation matrix of the variables has been shown and in Table 4 the slop homogeneity and cross-sectional dependence has been shown. For slop homogeneity the technique suggested by Pesaran et al. [76] and Pesaran et al. [85] has been employed. Both tests are confirmed by the results. As a result, we discovery indication in favor of the alternative hypothesis, which states that the cross-sectional units are dependent on one another. Results from the CSD tests are further supported by the strong correlation coefficient values, which range from 60 % to 99 %. Also, both are statistically significant, therefore we can't accept the null hypothesis. The current situation in the sample of G7 economies can be better understood with the help of these findings (see Table 5).

Table 5. Summarizes the findings from panel unit root tests, namely the CIPS (2007) and Cross-Sectionally Augmented IPS (CIPS) (2003) estimators. Conferring to the conclusions, all of the variables show unit roots at the level, but they all become stationary at first difference, indicating an integrated order of I. The series is inveterate to be stationary at the first difference, given the empirical feasibility of carrying out long-run tests with the method chosen to address cross-sectional dependence by Ref. [22].

In Table 6, the results from westerlund co-integration has been presented. Significant panel statistics (Pt and Pa) and group statistics (Gt and Ga) point to the presence of a long-term nexus. Thus, one thing that stands out among the G7 economies is the strong link between carbon neutrality, financial development, environmental legislation, reliance on renewable energy, eco-innovation, carbon pricing, and renewable energy.

4.1. Research findings in the long term

Here you may find the main results as well as the assessments of the robustness checks. The key findings are offered below based on the research that used CO_2 emissions as the outcome variables and were estimated using CS-ARDL, CCEMG, and AMG. Meanwhile, the results related to robustness checks center on P-estimates that utilize country-specific studies and other chosen estimators. The outcome variable in this case is M2.5 air pollution.

4.2. Main results

Table 7 presents the findings from the CSARDL long-term association analysis between the dependent and explanatory variables. Realizing carbon impartiality in the G7 frugalities appears to be dependent on green energy, as evidenced by the considerable environmental benefits of biofuel and RE in lowering CO_2 emissions. To be clear, renewable energy is important in the short- and Long-terms, while biofuel energy is only relevant in the long term. It seems sense to us that a percentage increase in RE sources will result in a proportional reduction in CO_2 emissions. As demonstrated by the optimistic and statistically significant possessions on CO_2 emissions, Table 7 also makes it clear that the G7 economies' ability to achieve carbon impartiality is inhibited by their reliance on natural resources. The findings suggest that there is a direct and indirect relationship between the percentage increase in reliance on natural resources and the rise in CO_2 emissions as time goes on. The primary empirical findings show that environmentally related innovation influences CO_2 emissions negatively and statistically significantly over the long term, indicating that it supports the G7 countries' efforts to become carbon neutral.

Furthermore, we examine the robustness of our results with the addition of a new outcome variable by measuring the probability that the G7 economies will reach carbon neutrality. This investigation's main goal is to determine whether changes in environmental quality indicators, like CO_2 emissions and PM2.5. The selected exogenous indicators, such as PM2.5 air pollution, show either consistent or divergent responses. We choose P for this analysis. The endogenous variable in Table 8 is PM2.5 air pollution. Tiny airborne particles that are known to sternly decrease discernibility and produce hazy air are referred to as fine particulate matter (PM2.5). Additionally, PM2.5 significantly endangers the public's health. As can be seen from Table 8's results, P is considerably reduced when green energy—which includes biofuel and renewable energy—is used. Air pollution caused by M2.5 in the G7 countries. Biofuel and renewable energy have these mitigating effects on P.M.5 Both short-term and long-term analyses show that PM2.5 air effluence is still there. Similarly, the escalation of P is greatly influenced by the reliance on natural resources and financial development. Air pollution caused by PM2.5, having a significant and favorable impact. Thus, a rise in PM2.5 is correlated with an increase in reliance on natural resources. Remaining statistically significant are the mitigating effects of environmental policy, carbon taxation,

Table 3
Correlation matrix.

Variables	LCO_2e	LPM2.5	LBF	LRE	LNRDP	LEI	LCT	LEP	LFD
LCO2e	1								
LPM2.5	0.115	1							
LBF	−0.305	−0.09	1						
LRE	−0.235	−0.265	0.27	1					
LNRDP	0.055	0.24	0.025	0.1	1				
LEI	−0.25	−0.03	0.24	0.215	−0.185	1			
LCT	−0.235	−0.12	0.195	0.105	0.09	0.215	1		
LEP	−0.085	−0.015	0.22	0.16	−0.055	0.135	0.025	1	
LFD	0.29	0.115	0.245	0.105	0.085	0.315	0.5	0.02	1

Table 4
Tests of homogeneity and cross-sectional dependency.

Indicators	Pesaran (2004)	Pesaran (2015)	Correlation
LCO2e	3.778***	3.478***	0.433
LPM2.5	3.061***	3.7715***	0.295
LBF	5.6725***	5.7995**	0.4575
LRE	7.5275***	7.5175**	0.4275
LNRDP	8.2775***	7.9825**	0.4625
LEI	3.0675***	3.0275***	0.2825
LCT	6.61***	6.4925***	0.4475
LEP	8.5475***	8.514***	0.4925
LFD	4.676**	4.5075**	0.34405

Note: For 1 %, 5 %, and 10 % significance levels, the conventional criteria are ***, **, and *.

Table 5
Tests for panel stationarity and long-run outcomes.

CIPS (2007) CIPS (2003)				
Variable	Level	First difference	Level	First difference
LCO2e	−0.9975	−2.6125***	−0.522	−2.0325***
LPM2.5	−1.0275	−2.079***	−1.033	−2.0575***
LBF	−1.047	−2.1175***	−0.6165	−2.5045***
LRE	−0.9425	−2.5575***	−0.9155	−2.156***
LNRDP	−1.112	−1.9975**	−0.666	−2.466**
LEI	−1.33	−2.5325***	−0.5275	−2.062**
LCT	−1.4565	−2.216***	−0.9435	−1.6575**
LEP	−0.4575	−2.506**	−1.0075	−2.9545**
LFD	−0.778	−1.4275**	−0.504	−1.956**

Table 6
Westerlund cointegration results.

Statistic	Value	Z-value	P-value
Gt	−4.079***	−0.6115	0.0024
Ga	−5.0385***	−2.3915	0
Pt	−4.5165***	−1.778	0.0002
Pa	−2.527*	1.281	0.0128

Table 7
Short and long-run outcomes. Dependent variable: CO_2 emissions.

	CS-ARDL			
Variables	Short-run	Long-run	CCEMG	AMG
LBF	−0.049 (0.029)	−0.178*** (0.049)	−0.029** (0.016)	−0.55*** (0.28)
LRE	−0.039* (0.034)	−0.140*** (0.040)	0.060 (0.028)	0.059 (0.037)
LNRDP	0.094*** (0.017)	0.059*** (0.020)	0.049*** (0.030)	0.069** (0.023)
LEI	−0.298*** (0.059)	−0.399*** (0.079)	−0.130*** (0.048)	−0.212*** (0.058)
LCT	−0.079** (0.029)	−0.098*** (0.037)	−0.040 (0.034)	−0.043 (0.023)
LEP	−0.049** (0.028)	−0.069** (0.035)	−0.076 (0.050)	−0.078 (0.043)
LFD	0.097*** (0.026)	1.049*** (0.198)	0.499** (0.169)	0.788** (0.543)
ect (−1)	−0.498*** (0.130)			
Observations	163	163	169	169

Note: The ***, **, and * criteria are the standard for 1 %, 5 %, and 10 % level of significance, respectively.

and eco-innovation when PM2.5 is the one. The study results are sported by Refs. [67,75]. The variables relationship has been shown in Fig. 1.

4.3. *Verification of robustness via country-level analysis*

Time series estimations are carried out separately for respectively of the G7 frugalities in this study to add to the current dialogue

Table 8
Short and long-run outcomes. Dependent variable: P.M2.5 air pollution.

CS-ARDL CCEMG AMG				
Variables Short-run Long-run				
LBF	−0.075*** (0.030)	−0.145*** (0.021)	−0.045 (0.032)	−0.056*** (0.026)
LRE	−0.044*** (0.025)	−0.176*** (0.012)	0.098*** (0.014)	0.064*** (0.028)
LNRDP	0.131** (0.046)	0.168*** (0.027)	0.125*** (0.087)	0.017 (0.032)
LEI	−0.067*** (0.017)	−0.312*** (0.027)	−0.176*** (0.031)	−0.143*** (0.029)
LCT	−0.148** (0.069)	−0.138** (0.026)	−0.132*** (0.076)	−0.087 (−0.076)
LEP	−0.065 (0.056)	−0.076** (0.021)	−0.090** (0.028)	−0.176*** (0.019)
LFD	0.087** (0.076)	0.067** (0.087)	0.127 (0.021)	0.225** (0.068)
ECT (−1)	−0.376*** (0.087)			
Observations	163	163	169	169

Note: The conventional standards for level of significance are *** for 1 %, ** for 5 %, and * for 10 %.

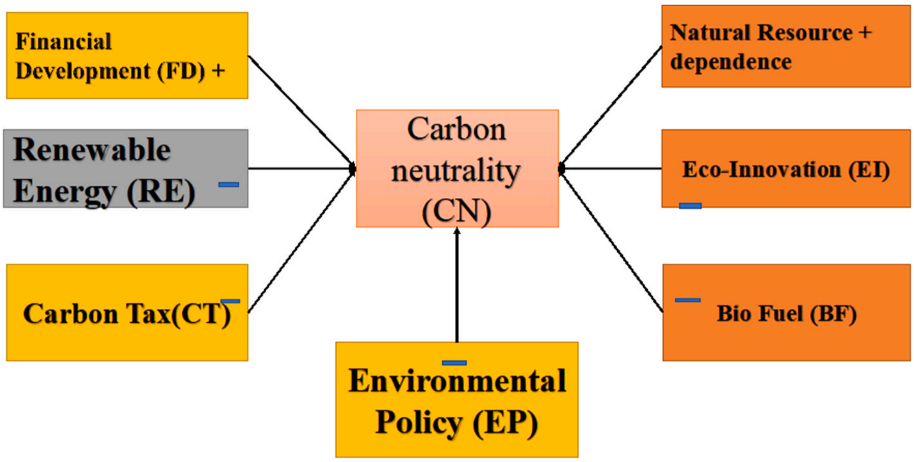

Fig. 1. Variables impact on Carbon neutrality.

about the relationship between reliance on natural capitals and carbon neutrality. For two main reasons, the robustness check at the national level is crucial. First, heterogeneous slopes in the model are indicated by the slope homogeneity test results, which calls for a study of slope differences using estimations at the national level.

Table 9
The results of the empirical research conducted at the country level.

Variables/ coefficient	United States	United Kingdom	Japan	Italy	Germany	France	Canada
LBF	−0.121*** (0.024)	−0.076** (0.042)	−0.132*** (0.054)	−0.085*** (0.021)	−0.074*** (0.053)	−0.045** (0.016)	−0.092*** (0.007)
LRE	−0.134*** (0.076)	−0.187*** (0.029)	−0.065 (0.087)	−0.087 (0.005)	−0.112*** (0.067)	−0.087** (0.034)	−0.154*** (0.036)
LNRDP	0.267*** (0.058)	0.386*** (0.043)	0.123** (0.076)	0.098*** (0.043)	0.065*** (0.013)	0.199*** (0.091)	−0.134** (0.065)
LEI	−0.235*** (0.087)	−0.075** (0.029)	−0.865*** (0.197)	−0.654** (0.153)	−0.433** (0.176)	−0.495*** (0.175)	−0.132 (0.076)
LCT	−0.643*** (0.167)	−0.554*** (0.153)	−0.386*** (0.087)	−0.397*** (0.097)	−0.185*** (0.054)	−0.074*** (0.084)	−0.196*** (0.021)
LEP	−0.386*** (0.088)	−0.228*** (0.045)	−0.122*** (0.046)	−0.115*** (0.044)	−0.125*** (0.036)	−0.223*** (0.066)	−0.133** (0.062)
LFD	0.465*** (0.026)	0.653*** (0.199)	0.275 (0.128)	0.679*** (0.066)	0.185*** (0.025)	0.396*** (0.154)	0.215 (0.076)
C	1.155** (0.266)	2.663 (3.235)	1.744*** (0.317)	3.724*** (0.376)	2.025*** (0.198)	2.277*** (0.875)	−1.015 (1.075)
R-squared	0.987	0.753	0.789	0.865	0.934	0.765	0.986
Adjusted R-squared	0.991	0.876	0.901	0.960	0.887	0.904	0.802

Note: The conventional standards for level of significance are *** for 1 %, ** for 5 %, and * for 10 %.

Table 10
Empirical results based on the panel quantile regression estimator.

Indicators	LOW			MEDIUM			HIGH		
	10_{th}	20_{th}	30_{th}	40_{th}	50_{th}	60_{th}	70_{th}	80_{th}	90_{th}
LBF	−0.055 (0.039)	−0.023 (0.051)	−0.083 (0.057)	−0.133** (0.064)	−0.146** (0.064)	−0.178*** (0.067)	−0.187** (0.065)	−0.195** (0.076)	−0.208** (0.084)
LRE	−0.001 (0.03)	−0.05 (0.04)	−0.066 (0.045)	−0.116** (0.05)	−0.183*** (0.052)	−0.099* (0.052)	−0.143*** (0.051)	−0.184*** (0.062)	−0.202*** (0.063)
LNRDP	0.154*** (0.026)	0.135*** (0.035)	0.163*** (0.039)	0.187*** (0.043)	0.195*** (0.043)	0.177*** (0.045)	0.187*** (0.044)	0.101* (0.052)	0.084 (0.054)
LEI	−0.613*** (0.058)	−0.518*** (0.075)	−0.451*** (0.085)	−0.409*** (0.094)	−0.442*** (0.095)	−0.394*** (0.099)	−0.506*** (0.096)	−0.417*** (0.113)	−0.397*** (0.118)
LCT	−0.258*** (0.072)	−0.775*** (0.192)	−0.965** (0.349)	−0.288** (0.135)	−0.751*** (0.191)	−0.896*** (0.216)	−0.849** (0.348)	−0.763*** (0.211)	−0.855*** (0.195)
LEP	−0.479*** (0.063)	−0.496*** (0.082)	−0.491*** (0.092)	−572*** (0.103)	−0.603*** (0.103)	−762*** (0.108)	−974*** (0.104)	−0.058*** (0.123)	−1.09*** (0.129)
LFD	0.138** (0.089)	0.177*** (0.068)	0.199*** (0.052)	0.528*** (0.159)	0.544*** (0.101)	0.692*** (0.253)	0.503*** (0.134)	0.894*** (0.229)	0.876** (0.303)
CONS	4.064*** (0.587)	3.467*** (0.692)	2.164*** (8.623)	63.381*** (9.628)	63.97*** (9.658)	58.326*** (10.065)	49.857*** (9.746)	41.705*** (11.504)	38.207*** (12.076)
Observations	161	161	161	161	161	161	161	161	161

Note: For 1 %, 5 %, and 10 %, respectively, the standard criteria selected for level of significance are ***, **, and *.

The second purpose of the country-specific analysis is to evaluate the stability and degree to which the panel examination's results can be repeated among the G7 countries. In order to ascertain long-term effects, this study uses FMOLS, and Table 9 presents the findings. Green energy considerably reduces CO_2 emissions in all G7 economies, as shown by the results in Table 9. In terms of renewable energy, the results for the US, the UK, Germany, France, Japan, Italy, and Canada show the mitigating effects. Given the significant reliance of these nations on fossil fuels, it makes sense that natural resource dependence influences CO_2 emissions positively across all G7 economies. Furthermore, all G7 nations—aside from Canada—find that eco-innovation greatly lowers carbon emissions. Across the G7 economies, environmental policies and carbon taxes have a major moderating effect on CO_2 emissions [42,53].

This study purposes to empirically confirm the influence of natural resources on the G7 countries' carbon neutrality agenda while considering the factors that impact renewable energy, ecological innovation, environmental legislation, carbon pricing, and economic growth. Looking at the mechanisms of green energy reveals that renewable energy and biofuel counterbalance the anticipated rise in CO_2 emissions, which is the reverse of what was expected. More specifically, it has been found that biofuel energy doesn't matter in the short term but is effective in lowering CO_2 emissions over time. On the other hand, from a short- and long-term perspective, renewable energy greatly lowers CO_2 emissions. These results have the economic consequence of showing that green energy is a useful instrument for influencing the trajectory of emissions in G7 nations. A significant amount of empirical research backs up the controlling effects of green energy on conservatory gas emissions [44]. Therefore, by its justifying possessions on CO_2 emissions, we conclude that green energy empirically contributes to the G7 economies' pursuit of carbon impartiality. Additionally, the empirical results show that ecological challenges are made worse by the G7 countries' heavy dependence on natural capitals. The growing effect of reliance on natural resources on CO_2 emissions points to a major roadblock in the way of the G7 countries' goalmouth of becoming carbon neutral. The outcomes of this study are consistent with earlier studies like [86,87].

The consequences of the experiential study display that the favorable result of monetary growth on CO_2 emissions can be explained by the widespread practice of financial institutions endorsing investments in fossil fuels, which are seen as less hazardous and more profitable, frequently at the expenditure of renewable energy investments. Empirical evidence supports the beneficial belongings of monetary development on CO_2 emissions in the literature Usman & Associates. Both the CCEMG and AMG estimates have produced results that agree with the empirical data that has been given. Additionally, while taking PM2.5 into consideration, the robustness checks are performed [88]. Under the circumstances in which CO_2 emissions were the primary indicator of results, PM2.5 air pollution offers compelling evidence for the experiential consistency of the estimations that were achieved. The study outcomes are consistent with [34,89].

4.4. Robustness test

The panel quantile regression estimator is used in this investigation. Because of its reliability in capturing the correlation between endogenous and exogenous variables even when cross-sectional dependency is present, the panel quantile regression estimator is deemed an empirically essential tool in panel analysis [90]. If we want to see how different exogenous variables affect distributions, we can divide quantiles into nine groups, from the 10th to the 90th quantiles. There are three other types of quantiles: low (10th to 30th), medium (40th to 60th), and high (70th to 90th). Green energy mostly moderates CO_2 emissions between the medium and high quantiles, according to the panel quantile regression results shown in Table 10. This proposes that the early adoption of renewable energy sources might not be totally successful in mitigating spikes in carbon emissions. Still, a consistent and growing use of renewable energy becomes significant in mitigating spikes in carbon emissions, supporting the G7 economies' goal of becoming carbon neutral. Dependency on natural resources consistently reduces spikes in carbon emissions at different quantiles. Furthermore, a reduction in CO_2 emissions across quantiles is demonstrated by stricter environmental policies and carbon taxes. The study results are in line with

Table 11
Results of DH causality test.

Model	W-stat	Z-stat	Decision
BF → CO_2	7.014***	2.915	Bidirectional
CO_2 → BF	8.003***	3.814	Bidirectional
RN → CO_2	8.982***	3.822	Bidirectional
CO2 →RE	7.987***	3.322	Bidirectional
BF → PM2.5	6.076***	3.432	Bidirectional
PM2.5 → BF	9.675***	2.454	Bidirectional
RE → PM2.5	8.675***	3.768	Bidirectional
PM2.5 →RE	7.232***	2.987	Bidirectional
NRDP → CO_2	10.973**	4.829	Unidirectional
CO_2 → NRDP	4.005	2.972	Unidirectional
EI → CO_2	4.962*	2.985	Bidirectional
CO_2 →EI	7.978***	3.952	Bidirectional
CT → CO_2	2.815*	2.005	Bidirectional
CO_2 → CT	11.939***	4.834	Bidirectional
EP → CO_2	13.945***	7.985	Bidirectional
CO_2 → EP	12.915***	6.012	Bidirectional
FD → CO_2	5.001*	1.995	Unidirectional
CO_2 →FD	5.989	3.021	Unidirectional

The conventional standards for level of significance are *** for 1 %, ** for 5 %, and * for 10 %.

the previous studies [91–93].

4.5. Panel granger causality effects

The findings of the Granger Causality Test [43] are summarized in Table 11. The study results demonstrate a bidirectional causal relationship between G7 carbon emissions and green energy, which encompasses biofuel and renewable power. According to this, policies that increase the investment, production, and consumption of green energy may be able to reduce carbon emissions and significantly improve the environment, which would make it easier to transition to a carbon-free environment over time. On the other hand, among the ways to achieve emission reduction, policies meant to lower carbon emissions may require more investment in green energy. Upon closer inspection, it is clear that there is a one-way causal relationship between the use of natural resources and CO_2 emissions. Because of the potential for increased CO_2 emissions associated with the depletion of natural resources, policy changes aimed at increasing revenue from resource extraction may interfere with the goal of becoming carbon neutral. Eco-innovation and CO_2 emissions have a clear causal relationship, indicating that changing one variable through policy would likely have a major influence on the other [73]. Carbon emissions and the strictness of environmental regulations are causally related to each other in both directions. This suggests that the policy initiatives were concentrated on refining the efficiency of the carbon tax and implementing.

Following accepted scientific practices, the study starts with the dataset being validated using summary statistics, bivariate correlation analysis, and normality tests. After validation, the dataset is put through initial testing and diagnostics, which include a cross-sectional correlation, slope homogeneity, and Cross-sectional dependence assessment. There is a combined rejection of the theories claiming homogeneity of slopes and no cross-sectional dependence. Consequently, the analysis confirms that the estimated model contains a long-term association. Panel quantile regression, augmented mean group, common connected properties mean group, and cross-sectional ARDL are among the estimators used in the panel analyses. Taken together, these estimators help provide a thorough grasp of the relationships that are being studied. To further improve the granularity of insights into the observed phenomena, the study also performs analyses specific to each country.

5. Conclusions

This study investigates the effects of green energy (biofuels and renewable energy), environmental technology, carbon price, environmental policy, and financial development on achieving carbon neutrality goals in G7 economies from 1999 to 2021. The study examines various second-generation estimate approaches, including the CSD test, slope homogeneity, cross-sectionally dependent IPS unit root, and Westerlund cointegration tests. The study's objectives are evaluated using cross-sectional ARDL, CCE mean group, AMG, and method of moment quantile regression. The (Dumitrescu & Hurlin 2012) panel Granger causality test provides more evidence to support the findings. The response indicates that the G7 economies' reliance on natural resources is impeding their progress towards achieving carbon neutrality, primarily due to its adverse effects on CO2 emissions. This result demonstrates that the ongoing exhaustion of natural resources has significant adverse impacts on the long-term viability of the G7 environment for both present and future generations. In addition, implementing carbon prices and environmental policies in G7 countries contributes to advancing the carbon neutrality goal by effectively reducing the increase in CO2 emissions. Specifically, higher tax rates on items and services with a significant carbon footprint and stricter environmental policies can accelerate progress toward achieving the G7's carbon neutrality goals. In addition, biofuels and renewable energy significantly decrease CO2 emissions, promoting carbon neutrality in the G7. The advancement of financial systems has a direct and substantial impact on the increase in carbon dioxide (CO2) emissions, which hinders achieving carbon neutrality in the economies of the G7 countries. The findings of the MMQR estimator from various distribution locations reinforce the previous results. In addition, the causality tests conducted by Dumitrescu and Hurlin (2012) reveal the importance of unidirectional and bidirectional causal relationships in the analyzed model.

5.1. Policy recommendations

1) The adverse impact of natural resources on the economy of the G7 countries is unsatisfactory, particularly when it comes to the dilemma of choosing between economic advancement and environmental sustainability. Therefore, it is advisable for the government to use the revenue generated from natural resource rents towards environmentally sustainable initiatives in order to mitigate the adverse effects of natural resource depletion
2) Collaborations between public and commercial entities in eco-innovation efforts have the capacity to enhance the effectiveness of environmental technologies in reducing carbon emissions. The G7 nations have a strong technological foundation that may be used to protect the natural environment. This is achieved through investments in innovative projects, scientific discoveries, technological breakthroughs, and research and development.
3) The utilization of renewable energy offers promising opportunities for G7 economies to achieve their net zero emissions objectives. Therefore, it is imperative for the government to encourage investment in renewable energy in order to strengthen the ability of G7 nations to generate sustainable energy. Furthermore, the government ought to decrease subsidies on fossil fuels in order to promote investment in renewable energy sources. Green energy, which includes biofuel and renewable sources, has made a substantial contribution to society and is crucial in tackling the ongoing problem of rising emissions. Investments in biofuels and renewable energy sources should be strongly encouraged by governments. The government should also think about subsidizing the costs of biofuels and renewable energy sources in order to lessen the significant financial burden on final consumers.

4) Environmental taxes have proven to be highly effective in reducing the harmful impacts of carbon footprints. Therefore, the government can efficiently utilize this method to discourage the production and use of carbon-intensive goods and services.
5) The environmental strategy effectively offers a long-term solution to reduce the carbon footprint of the G7 nations. Given the results, it is crucial for the government to prioritize the implementation of programs that consistently reduce the carbon footprint. Moreover, the implementation of strict laws is crucial in order to protect the environment.

5.2. Future research opportunities and limitations

The progress made toward the G7's carbon neutrality blueprint has received strong empirical support from the current analysis. Still, there are some unanswered questions about the current body of work. The topic of carbon neutrality as determined by CO_2 emissions and P. is the effort of the current study. Interesting and thought-provoking is M2.5 air pollution. Nevertheless, there is ongoing debate regarding how well the chosen repressors can account for differences in other environmental contaminants such as sulfur, methane, and ecological impact. Future research can therefore consider these subjects. Furthermore, extending the present is necessary from a methodological perspective. For example, research on in order to achieve carbon neutrality, it is possible to do research into the unequal effects of depending on natural resources in order to gain a holistic perspective and useful policy recommendations.

Research support

This research received no external financial and non-financial support.

Relationship

There are no additional relationships to disclose.

Patents and intellectual property

There are no patents to disclose.

Other activities

There is no any kind of relation exists.

Ethical approval and consent to participate

The authors declare that they have no known competing financial interests or personal relationships that seem to affect the work reported in this article. We declare that we have no human participants, human data or human tissues.

Consent for publication

N/A.

Availability of data and materials

The data can be available on request.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Wenze Jiang: Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Songrui Chen:** Software, Resources, Project administration, Methodology, Investigation. **Peibei Tang:** Supervision, Software, Resources, Project administration, Methodology. **Yuhang Hu:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision. **Muyao Liu:** Software, Resources, Project administration, Methodology, Investigation. **Shi Qiu:** Writing – review & editing, Writing – original draft, Visualization, Validation. **Mujahid Iqbal:** Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis.

Declaration of competing interest

The authors declare no conflict of interest.

References

[1] F. Mngumi, S. Shaorong, F. Shair, M. Waqas, Does green finance mitigate the effects of climate variability: role of renewable energy investment and infrastructure, Environ. Sci. Pollut. Res. 1 (2022) 1–13, https://doi.org/10.1007/s11356-022-19839-y.
[2] L. Du, A. Razzaq, M. Waqas, The impact of COVID - 19 on small - and medium - sized enterprises (SMEs): empirical evidence for green economic implications, Environ. Sci. Pollut. Res. (2022), https://doi.org/10.1007/s11356-022-22221-7.
[3] D. Zhao, M. Sibt e-Ali, M. Omer Chaudhry, B. Ayub, M. Waqas, I. Ullah, Modeling the Nexus between geopolitical risk, oil price volatility and renewable energy investment; evidence from Chinese listed firms, Renew. Energy 225 (2024) 120309, https://doi.org/10.1016/J.RENENE.2024.120309.
[4] Q. Quan, W. Liang, D. Yan, J. Lei, Influences of joint action of natural and social factors on atmospheric process of hydrological cycle in Inner Mongolia, China, Urban Clim. 41 (2022) 101043, https://doi.org/10.1016/j.uclim.2021.101043.
[5] F. Ze, W. Yu, A. Ali, S.S. Hishan, I. Muda, K. Khudoykulov, Influence of natural resources, ICT, and financial globalization on economic growth: evidence from G10 countries, Resour. Pol. (2023), https://doi.org/10.1016/j.resourpol.2022.103254.
[6] F. Shaheen, M.S. Lodhi, J. Rosak-Szyrocka, K. Zaman, U. Awan, M. Asif, W. Ahmed, M. Siddique, Cleaner technology and natural resource management: an environmental sustainability perspective from China, Cleanroom Technol. 4 (2022) 584–606, https://doi.org/10.3390/CLEANTECHNOL4030036.
[7] L. Zhou, Z. Ke, M. Waqas, Beyond the Arena: how sports economics is advancing China's sustainable development goals, Heliyon (2023) e18074, https://doi.org/10.1016/J.HELIYON.2023.E18074.
[8] M.H. Nasir, J. Wen, A.A. Nassani, M. Haffar, A.E. Igharo, H.O. Musibau, M. Waqas, Energy security and energy poverty in emerging economies: a step towards sustainable energy efficiency, Front. Energy Res. 10 (2022) 1–12, https://doi.org/10.3389/fenrg.2022.834614.
[9] M. Li, M. Yao-Ping Peng, R. Nazar, B. Ngozi Adeleye, M. Shang, M. Waqas, How does energy efficiency mitigate carbon emissions without reducing economic growth in post COVID-19 era, Front. Energy Res. 10 (2022) 1–14, https://doi.org/10.3389/fenrg.2022.832189.
[10] L. Hai Ming, L. Gang, H. Hua, M. Waqas, Modeling the influencing factors of electronic word-of-mouth about CSR on social networking sites, Environ. Sci. Pollut. Res. (2022) 1–18, https://doi.org/10.1007/s11356-022-20476-8.
[11] W. Ameer, M.S.e. Ali, F. Farooq, B. Ayub, M. Waqas, Renewable energy electricity, environmental taxes, and sustainable development: empirical evidence from E7 economies, Environ. Sci. Pollut. Res. (2023) 1–16, https://doi.org/10.1007/S11356-023-26930-5/METRICS.
[12] Y.M. Tang, K.Y. Chau, A. Fatima, M. Waqas, Industry 4.0 technology and circular economy practices: business management strategies for environmental sustainability, Environ. Sci. Pollut. Res. 29 (2022) 49752–49769, https://doi.org/10.1007/S11356-022-19081-6/METRICS.
[13] Z. Hailiang, K.Y. Chau, M. Waqas, Does green finance and renewable energy promote tourism for sustainable development: empirical evidence from China, Renew. Energy 207 (2023) 660–671, https://doi.org/10.1016/j.renene.2023.03.032.
[14] Z. You, L. Li, M. Waqas, How do information and communication technology, human capital and renewable energy affect CO2 emission; new insights from BRI countries, Heliyon (2024) e26481, https://doi.org/10.1016/J.HELIYON.2024.E26481, 0.
[15] S.A.R. Shah, S.A.A. Naqvi, S. Anwar, A.A. Shah, A.M. Nadeem, Socio-economic impact assessment of environmental degradation in Pakistan: fresh evidence from the Markov switching equilibrium correction model, Environ. Dev. Sustain. (2022) 1–31, https://doi.org/10.1007/s10668-021-02013-8.
[16] S.A.R. Shah, Q. Zhang, J. Abbas, D. Balsalobre-Lorente, L. Pilař, Technology, urbanization and natural gas supply matter for carbon neutrality: a new evidence of environmental sustainability under the prism of COP26, Resour. Pol. 82 (2023) 103465, https://doi.org/10.1016/J.RESOURPOL.2023.103465.
[17] H. Li, M.S.e. Ali, B. Ayub, I. Ullah, Analysing the impact of geopolitical risk and economic policy uncertainty on the environmental sustainability: evidence from BRICS countries, Environ. Sci. Pollut. Res. 2023 (2023) 1–15, https://doi.org/10.1007/S11356-023-26553-W.
[18] E. Ntom Udemba, N.U. Khan, S.A. Raza Shah, Demographic change effect on ecological footprint: a tripartite study of urbanization, aging population, and environmental mitigation technology, J. Clean. Prod. 437 (2024), https://doi.org/10.1016/J.JCLEPRO.2023.140406.
[19] N. Ahmed, Z. Hamid, F. Mahboob, K.U. Rehman, M.S.e. Ali, P. Senkus, A. Wysokińska-Senkus, P. Siemiński, A. Skrzypek, Causal linkage among agricultural insurance, air pollution, and agricultural green total factor productivity in United States: pairwise granger causality approach, Agric. For. 12 (2022) 1320, https://doi.org/10.3390/AGRICULTURE12091320.
[20] S. Wang, J. Abbas, K.I. Al-Sulati, S.A.R. Shah, The impact of economic corridor and tourism on local community's quality of life under one belt one road context, Eval. Rev. (2023), https://doi.org/10.1177/0193841X231182749/ASSET/IMAGES/LARGE/10.1177_0193841X231182749-IMG01.JPEG.
[21] X. Ma, R. Akhtar, A. Akhtar, R.A. Hashim, M. Sibt-e-Ali, Mediation effect of environmental performance in the relationship between green supply chain management practices, institutional pressures, and financial performance, Front. Environ. Sci. 10 (2022) 1196, https://doi.org/10.3389/FENVS.2022.972555/BIBTEX.
[22] J. Zhao, S. ur Rahman, S. Afshan, M.S.E. Ali, H. Ashfaq, S. Idrees, Green investment, institutional quality, and environmental performance: evidence from G-7 countries using panel NARDL approach, Environ. Sci. Pollut. Res. 30 (2023) 100845–100860, https://doi.org/10.1007/s11356-023-29332-9.
[23] Z. Weimin, M. Sibt-e-Ali, M. Tariq, V. Dagar, M.K. Khan, Globalization toward environmental sustainability and electricity consumption to environmental degradation: does EKC inverted U-shaped hypothesis exist between squared economic growth and CO2 emissions in top globalized economies, Environ. Sci. Pollut. Res. 29 (2022) 59974–59984, https://doi.org/10.1007/S11356-022-20192-3/METRICS.
[24] N. Ahmed, F. Mahboob, Z. Hamid, A.A. Sheikh, M.S.e. Ali, W. Glabiszewski, A. Wysokińska-Senkus, P. Senkus, S. Cyfert, Nexus between nuclear energy consumption and carbon footprint in Asia pacific region: policy toward environmental sustainability, Energies 15 (2022) 6956, https://doi.org/10.3390/EN15196956.
[25] C. Li, S. Asim, W. Khalid, M. Sibt E. Ali, What influences the climate entrepreneurship? Chinese-based evidence, Front. Environ. Sci. 10 (2023) 2560, https://doi.org/10.3389/FENVS.2022.1051992/BIBTEX.
[26] Z. Wenlong, N.H. Tien, A. Sibghatullah, D. Asih, M. Soelton, Y. Ramli, Impact of energy efficiency, technology innovation, institutional quality, and trade openness on greenhouse gas emissions in ten Asian economies, Environ. Sci. Pollut. Res. 30 (2023) 43024–43039, https://doi.org/10.1007/s11356-022-20079-3.
[27] N. Saqib, M. Radulescu, M. Usman, D. Balsalobre-Lorente, T. Cilan, Environmental technology, economic complexity, renewable electricity, environmental taxes and CO2 emissions: implications for low-carbon future in G-10 bloc, Heliyon 9 (2023) e16457, https://doi.org/10.1016/j.heliyon.2023.e16457.
[28] G.M. Grossman, A.B. Krueger, Economic growth and the environment, Q. J. Econ. 110 (1995) 353–377, https://doi.org/10.2307/2118443.
[29] C. Yu, M. Moslehpour, T.K. Tran, L.M. Trung, J.P. Ou, N.H. Tien, Impact of non-renewable energy and natural resources on economic recovery: empirical evidence from selected developing economies, Resour. Pol. 80 (2023) 103221, https://doi.org/10.1016/J.RESOURPOL.2022.103221.
[30] S.A.A. Naqvi, B. Hussain, S. Ali, Evaluating the influence of biofuel and waste energy production on environmental degradation in APEC: role of natural resources and financial development, J. Clean. Prod. 386 (2023) 135790, https://doi.org/10.1016/J.JCLEPRO.2022.135790.
[31] C. Zheng, S. Wu, Y.P. Teng, S. Wu, Z. Wang, Natural resources, tourism resources and economic growth: a new direction to natural resources perspective and investment, Resour. Pol. 86 (2023) 104134, https://doi.org/10.1016/J.RESOURPOL.2023.104134.
[32] M. Usman, D. Balsalobre-Lorente, Environmental concern in the era of industrialization: can financial development, renewable energy and natural resources alleviate some load? Energy Pol. 162 (2022) 112780 https://doi.org/10.1016/j.enpol.2022.112780.
[33] Q. Jiang, Z.U. Rahman, X. Zhang, Z. Guo, Q. Xie, An assessment of the impact of natural resources, energy, institutional quality, and financial development on CO2 emissions: evidence from the B&R nations, Resour. Pol. (2022), https://doi.org/10.1016/j.resourpol.2022.102716.
[34] H. Khan, L. Weili, I. Khan, J. Zhang, The nexus between natural resources, renewable energy consumption, economic growth, and carbon dioxide emission in BRI countries, Environ. Sci. Pollut. Res. 30 (2023) 36692–36709, https://doi.org/10.1007/S11356-022-24193-0/TABLES/9.

[35] Q. Wan, X. Miao, S. Afshan, Dynamic effects of natural resource abundance, green financing, and government environmental concerns toward the sustainable environment in China, Resour. Pol. 79 (2022) 102954, https://doi.org/10.1016/J.RESOURPOL.2022.102954.
[36] Y. Sun, H. Chang, D.G. Vasbieva, Z. Andlib, Economic performance, investment in energy resources, foreign trade, and natural resources volatility nexus: evidence from China's provincial data, Resour. Pol. 78 (2022) 102913, https://doi.org/10.1016/J.RESOURPOL.2022.102913.
[37] F. Ahmad, M.U. Draz, A.A. Chandio, M. Ahmad, L. Su, F. Shahzad, M. Jia, Natural resources and environmental quality: exploring the regional variations among Chinese provinces with a novel approach, Resour. Pol. 77 (2022) 102745, https://doi.org/10.1016/J.RESOURPOL.2022.102745.
[38] A. Azam, M. Ateeq, M. Shafique, M. Rafiq, J. Yuan, Primary energy consumption-growth nexus: the role of natural resources, quality of government, and fixed capital formation, Energy 263 (2023) 125570, https://doi.org/10.1016/J.ENERGY.2022.125570.
[39] M. Kahia, B. Jarraya, B. Kahouli, A. Omri, Do environmental innovation and green energy matter for environmental sustainability? Evidence from Saudi arabia (1990–2018), Energies 16 (2023), https://doi.org/10.3390/en16031376.
[40] U. Shahzad, M. Radulescu, S. Rahim, C. Isik, Z. Yousaf, S.A. Ionescu, Do environment-related policy instruments and technologies facilitate renewable energy generation? Exploring the contextual evidence from developed economies, Energies 14 (2021), https://doi.org/10.3390/en14030690.
[41] Z. Khan, S. Ali, M. Umar, D. Kirikkaleli, Z. Jiao, Consumption-based carbon emissions and International trade in G7 countries: the role of Environmental innovation and Renewable energy, Sci. Total Environ. 730 (2020), https://doi.org/10.1016/j.scitotenv.2020.138945.
[42] X. Meng, T. Li, M. Ahmad, G. Qiao, Y. Bai, Capital Formation, green innovation, renewable energy consumption and environmental quality: do environmental regulations matter? Int. J. Environ. Res. Publ. Health 19 (2022) https://doi.org/10.3390/ijerph192013562.
[43] M. Aydin, P. Koc, K.I. Sahpaz, Investigating the EKC hypothesis with nanotechnology, renewable energy consumption, economic growth and ecological footprint in G7 countries: panel data analyses with structural breaks, Energy Sources, Part B Econ. Plan, Policy 18 (2023), https://doi.org/10.1080/15567249.2022.2163724.
[44] Q. Wang, Z. Sun, J. Guo, R. Li, The more effective option to combat environmental degradation: energy efficiency vs. renewable energy vs. natural gas? Energy 283 (2023) 128512 https://doi.org/10.1016/j.energy.2023.128512.
[45] Y. Huang, M. Ahmad, S. Ali, D. Kirikkaleli, Does eco-innovation promote cleaner energy? Analyzing the role of energy price and human capital, Energy 239 (2022) 122268, https://doi.org/10.1016/J.ENERGY.2021.122268.
[46] D.G. Borojo, J. Yushi, Z. Hongyu, L. Xiao, M. Miao, A pathway to the green revolution in emerging economies: how does green technological innovation affect green growth and ecological sustainability? Econ. Res. Istraz. . 36 (2023) https://doi.org/10.1080/1331677X.2023.2167223.
[47] W. Zhang, G. Li, Environmental decentralization, environmental protection investment, and green technology innovation, Environ. Sci. Pollut. Res. 29 (2022) 12740–12755, https://doi.org/10.1007/s11356-020-09849-z.
[48] M. Zhong, G. Huang, R. He, The technological innovation efficiency of China's lithium-ion battery listed enterprises: evidence from a three-stage DEA model and micro-data, Energy 246 (2022) 123331, https://doi.org/10.1016/j.energy.2022.123331.
[49] L.N. Hao, M. Umar, Z. Khan, W. Ali, Green growth and low carbon emission in G7 countries: how critical the network of environmental taxes, renewable energy and human capital is? Sci. Total Environ. 752 (2021) 141853 https://doi.org/10.1016/j.scitotenv.2020.141853.
[50] R. Kutieshat, P. Farmanesh, The impact of new human resource management practices on innovation performance during the covid 19 crisis: a new perception on enhancing the educational sector, Sustain. Times 14 (2022) 2872, https://doi.org/10.3390/SU14052872.
[51] B. Guo, Y. Feng, F. Hu, Have carbon emission trading pilot policy improved urban innovation capacity? Evidence from a quasi-natural experiment in China, Environ. Sci. Pollut. Res. (2023) 1–14, https://doi.org/10.1007/S11356-023-25699-X/METRICS.
[52] Y. Huan, M. Qamruzzaman, Innovation-led FDI sustainability: clarifying the nexus between financial innovation, technological innovation, environmental innovation, and FDI in the BRIC nations, Sustain. Times 14 (2022) 15732, https://doi.org/10.3390/SU142315732.
[53] A. Jahanger, I. Ozturk, J.C. Onwe, S.O. Ogwu, M.R. Hossain, A. Awoad Abdallah, Do pro-environmental interventions matter in restoring environmental sustainability? Gondwana Res. (2023) https://doi.org/10.1016/j.gr.2023.07.010.
[54] B. Li, J. Chang, J. Guo, C. Zhou, X. Ren, J. Liu, Do green innovation, I.C.T., and economic complexity matter for sustainable development of B.R.I. economies: moderating role of higher education, Environ. Sci. Pollut. Res. (2023), https://doi.org/10.1007/S11356-023-26405-7.
[55] N.P. Nguyen, H.A. Vien, The Relationship Among Corporate Social Responsibility, Network Cooperation, Green Innovation, Environmental Performance and Firm Performance: Evidences in Viet Nam, 2023, pp. 329–351, https://doi.org/10.1007/978-981-19-7489-2_17.
[56] A. Sharif, N. Saqib, K. Dong, S.A.R. Khan, Nexus between green technology innovation, green financing, and CO2 emissions in the G7 countries: the moderating role of social globalisation, Sustain. Dev. 30 (2022) 1934–1946, https://doi.org/10.1002/SD.2360.
[57] Á.L. Dias, I. Cunha, L. Pereira, R.L. Costa, R. Gonçalves, Revisiting small- and medium-sized enterprises' innovation and resilience during COVID-19: the tourism sector, J. Open Innov. Technol. Mark. Complex 8 (2022) 11, https://doi.org/10.3390/JOITMC8010011.
[58] T.S. Adebayo, S.D. Oladipupo, I. Adeshola, H. Rjoub, Wavelet analysis of impact of renewable energy consumption and technological innovation on CO2 emissions: evidence from Portugal, Environ. Sci. Pollut. Res. 29 (2022) 23887–23904, https://doi.org/10.1007/s11356-021-17708-8.
[59] Y. Sun, W. Ding, G. Yang, Green innovation efficiency of China's tourism industry from the perspective of shared inputs: dynamic evolution and combination improvement paths, Ecol. Indicat. 138 (2022), https://doi.org/10.1016/j.ecolind.2022.108824.
[60] Z. Fareed, M.A. Rehman, T.S. Adebayo, Y. Wang, M. Ahmad, F. Shahzad, Financial inclusion and the environmental deterioration in Eurozone: the moderating role of innovation activity, Technol. Soc. 69 (2022) 101961, https://doi.org/10.1016/j.techsoc.2022.101961.
[61] S. Jafarinejad, R.R. Hernandez, S. Bigham, B.S. Beckingham, The intertwined renewable energy–water–environment (rewe) nexus challenges and opportunities: a case study of California, Sustain. Times 15 (2023) 10672, https://doi.org/10.3390/SU151310672.
[62] Y. Shang, L. Zhu, F. Qian, Y. Xie, Role of green finance in renewable energy development in the tourism sector, Renew. Energy 206 (2023) 890–896, https://doi.org/10.1016/J.RENENE.2023.02.124.
[63] O. Petrychenko, M. Levinskyi, S. Goolak, V. Lukoševičius, Solar energy: revolutionizing shipping industry towards sustainability and environmental stewardship. https://doi.org/10.20944/PREPRINTS202402.0154.V1, 2024.
[64] H. Kuang, Z. Akmal, F. Li, Measuring the effects of green technology innovations and renewable energy investment for reducing carbon emissions in China, Renew. Energy 197 (2022) 1–10, https://doi.org/10.1016/J.RENENE.2022.06.091.
[65] Z. Deng, J. Liu, S. Sohail, Green economy design in BRICS: dynamic relationship between financial inflow, renewable energy consumption, and environmental quality, Environ. Sci. Pollut. Res. 29 (2022) 22505–22514, https://doi.org/10.1007/S11356-021-17376-8/METRICS.
[66] M. Abou Houran, U. Mehmood, How institutional quality and renewable energy interact with ecological footprints: do the human capital and economic complexity matter in the Next Eleven nations? Environ. Sci. Pollut. Res. 1 (2023) 1–13, https://doi.org/10.1007/S11356-023-26744-5/TABLES/7.
[67] S. Ghosh, T.S. Adebayo, S. Abbas, B. Doğan, S.A. Sarkodie, Harnessing the roles of renewable energy, high tech industries, and financial globalization for environmental sustainability: evidence from newly industrialized economies, Nat. Resour. Forum (2023) 1–22, https://doi.org/10.1111/1477-8947.12356.
[68] R.A. Almasri, N.H. Abu-Hamdeh, N. Al-Tamimi, A state-of-the-art review of energy-efficient and renewable energy systems in higher education facilities, Front. Energy Res. 11 (2023) 1344216, https://doi.org/10.3389/FENRG.2023.1344216/BIBTEX.
[69] U.K. Pata, Q. Wang, M.T. Kartal, A. Sharif, The role of disaggregated renewable energy consumption on income and load capacity factor: a novel inclusive sustainable growth approach, Geosci. Front. 15 (2024) 101693, https://doi.org/10.1016/J.GSF.2023.101693.
[70] H. Zhou, A.A. Awosusi, V. Dagar, G. Zhu, S. Abbas, Unleashing the asymmetric effect of natural resources abundance on carbon emissions in regional comprehensive economic partnership: what role do economic globalization and disaggregating energy play? Resour. Pol. 85 (2023) 103914 https://doi.org/10.1016/j.resourpol.2023.103914.
[71] M. Manjang, X. Hao, M.A. Husnain, Examining the impact of environmental technologies, environmental taxes, energy consumption, and natural resources on GHG emissions in G-7 economies, Environ. Sci. Pollut. Res. 30 (2023) 106611–106624, https://doi.org/10.1007/s11356-023-29885-9.
[72] M.A. Khalil, K. Nimmanunta, Conventional versus green investments: advancing innovation for better financial and environmental prospects, J. Sustain. Financ. Invest. 13 (2023) 1153–1180, https://doi.org/10.1080/20430795.2021.1952822.

[73] O.S. Ojekemi, H. Rjoub, A.A. Awosusi, E.B. Agyekum, Toward a sustainable environment and economic growth in BRICS economies: do innovation and globalization matter? Environ. Sci. Pollut. Res. 1 (2022) 1–18, https://doi.org/10.1007/s11356-022-19742-6.

[74] A. Anwar, A.R. Chaudhary, S. Malik, M. Bassim, Modelling the macroeconomic determinants of carbon dioxide emissions in the G-7 countries: the roles of technological innovation and institutional quality improvement, Global Bus. Rev. (2021), https://doi.org/10.1177/09721509211039392.

[75] M.E. Hossain, S. Rej, M.R. Hossain, A. Bandyopadhyay, R.A.Z. Tama, A. Ullah, Energy mix with technological innovation to abate carbon emission: fresh evidence from Mexico applying wavelet tools and spectral causality, Environ. Sci. Pollut. Res. 30 (2023) 5825–5846, https://doi.org/10.1007/s11356-022-22555-2.

[76] M.H. Pesaran, General diagnostic tests for cross section dependence in panels, SSRN Electron. J. (2004), https://doi.org/10.2139/SSRN.572504.

[77] M.H. Pesaran, Testing weak cross-sectional dependence in large panels, Econom. Rev. 34 (2015) 1089–1117, https://doi.org/10.1080/07474938.2014.956623.

[78] B. Oğuztürk, F. Özbay, The relationship between green innovation, CO2 emissions, gross domestic product, and renewable energy supply: a panel data analysis for BRICS countries and Turkey, Istanbul Bus. Res (2022), https://doi.org/10.26650/ibr.2022.51.969130, 0–0.

[79] M.H. Pesaran, A simple panel unit root test in the presence of cross-section dependence, J. Appl. Econom. 22 (2007) 265–312.

[80] J. Westerlund, Testing for error correction in panel data, Oxf. Bull. Econ. Stat. 69 (2007) 709–748, https://doi.org/10.1111/J.1468-0084.2007.00477.X.

[81] S. Ruan, G. Wan, X. Le, S. Zhang, C. Yu, Combining the role of the banking sector and natural resource utilization on green economic development: evidence from China, Resour. Pol. 83 (2023) 103671, https://doi.org/10.1016/J.RESOURPOL.2023.103671.

[82] T.S. Adebayo, A. Samour, A.A. Alola, S. Abbas, M. Ağa, The potency of natural resources and trade globalisation in the ecological sustainability target for the BRICS economies, Heliyon 9 (2023) e15734, https://doi.org/10.1016/j.heliyon.2023.e15734.

[83] S.A.R. Khan, Z. Yu, I.L. Ridwan, A. ur R. Irshad, P. Ponce, M. Tanveer, Energy efficiency, carbon neutrality and technological innovation: a strategic move towards green economy, Econ. Res. Istraz. . 36 (2023), https://doi.org/10.1080/1331677X.2022.2140306.

[84] A.A. Awosusi, T.S. Adebayo, D. Kirikkaleli, M. Altuntaş, Role of technological innovation and globalization in BRICS economies: policy towards environmental sustainability, Int. J. Sustain. Dev. World Ecol. (2022) 1–18, https://doi.org/10.1080/13504509.2022.2059032.

[85] M.H. Pesaran, Testing weak cross-sectional dependence in large panels, Econom. Rev. 34 (2015) 1089–1117, https://doi.org/10.1080/07474938.2014.956623.

[86] Y. Li, M. Tariq, S. Khan, H. Rjoub, A. Azhar, Natural resources rents, capital formation and economic performance: evaluating the role of globalization, Resour. Pol. 78 (2022) 102817, https://doi.org/10.1016/J.RESOURPOL.2022.102817.

[87] X. Lei, Y. Yang, M. Alharthi, F. Rasul, S.M. Faraz Raza, Immense reliance on natural resources and environmental challenges in G-20 economies through the lens of COP-26 targets, Resour. Pol. 79 (2022) 103101, https://doi.org/10.1016/J.RESOURPOL.2022.103101.

[88] L. JinRu, M. Qamruzzaman, Nexus between environmental innovation, energy efficiency, and environmental sustainability in G7: what is the role of institutional quality? Front. Environ. Sci. 10 (2022) 68–83, https://doi.org/10.3389/fenvs.2022.860244.

[89] M.S.A. Makhdum, M. Usman, R. Kousar, J. Cifuentes-Faura, M. Radulescu, D. Balsalobre-Lorente, How do institutional quality, natural resources, renewable energy, and financial development reduce ecological footprint without hindering economic growth trajectory? Evidence from China, Sustain. Times 14 (2022) 13910, https://doi.org/10.3390/SU142113910.

[90] W. Hao, F. Rasul, Z. Bhatti, M.S. Hassan, I. Ahmed, N. Asghar, A technological innovation and economic progress enhancement: an assessment of sustainable economic and environmental management, Environ. Sci. Pollut. Res. 28 (2021) 28585–28597, https://doi.org/10.1007/s11356-021-12559-9.

[91] A.E. Caglar, E. Yavuz, M. Mert, E. Kilic, The ecological footprint facing asymmetric natural resources challenges: evidence from the USA, Environ. Sci. Pollut. Res. 29 (2022) 10521–10534, https://doi.org/10.1007/S11356-021-16406-9/FIGURES/6.

[92] A. Raihan, Nexus between economic growth, natural resources rents, trade globalization, financial development, and carbon emissions toward environmental sustainability in Uruguay, Electron. J. Educ. Soc. Econ. Technol. (2023), https://doi.org/10.33122/ejeset.v4i2.102.

[93] A.E. Caglar, B. Guloglu, A. Gedikli, Moving towards sustainable environmental development for BRICS: investigating the asymmetric effect of natural resources on CO2, Sustain. Dev. 30 (2022) 1313–1325, https://doi.org/10.1002/SD.2318.