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The effect of natural capital, regional development, FDI, and natural resource rent on environmental performance: The Mediating role of green innovation

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ABSTRACT

In recent years, numerous studies have investigated the relationships between natural resource rents, FDI, and their impact on economic growth in both developed and emerging economies. However, the existing studies have overlooked the effects of natural capital and regional development on environmental performance in resource-exporting economies. Therefore, this study contributes to the existing literature by examining the effect of natural capital, regional development, foreign direct investment, and natural resource rent on the environmental performance of resource-exporting economies over the period from 2002 to 2022. Furthermore, the analysis is extended by analyzing the mediating role of green technological innovation. The study used panel unit root, cointegration test and augmented mean group (AMG) estimators for long-run and short-run relationships between study variables. Our preliminary findings confirm the existence of cross-sectional dependency, slope heterogeneity, and cointegration among the study variables. The long run empirical results obtained using the AMG estimator indicate that regional development, green innovation, natural capital, and natural resource rent contribute positively to environmental performance, while FDI has negative effect. In the short run, regional development and natural capital have negative impacts on environmental performance. Furthermore, green innovation plays a mediating role in enhancing environmental performance in resource-exporting economies. Based on the empirical findings of our study, the paper presents several policy implications for policymakers. Resource-exporting countries should implement effective policies that prioritize the restoration of environmental quality and emphasize green technological innovation to achieve their sustainable development goals.

1. Introduction

Over the last two decades, the utilization and conservation of natural resources have emerged as a pivotal global issue, with particular attention directed toward the resource-rich exporting economies as they grapple with numerous challenges Sheikhzeinoddin et al. (2022). The utilization of natural resources is steadily expanding and diversifying, giving rise to a multitude of environmental consequences. Resources are essential at every stage of a product's lifecycle, from extraction and processing to manufacturing and consumption and waste to disposal (Ibrahim et al., 2022). Thus, unsustainable consumption and production practices in resource exporting economies lead to natural resource depletion and various environmental challenges, including carbon emissions and climate change (Belaïd, 2022). In response to the persistent challenges of climate change and other global issues, the international community and global leaders are actively and passionately committed to combat the global challenges and achieve 17 sustainable development goals. The United Nations (UN) integrated framework for Sustainable Development Goals (SDGs) addresses global challenges across three major dimensions: the economy, the environment, and society. More specifically, the Sustainable Development Goals (SDGs) put emphasis on the reduction of poverty and addressing various types of

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deprivation. These objectives are also aligned with initiatives aimed at improving healthcare and education, reducing inequality, fostering economic growth, mitigating climate change, and preserving forests and oceans (UN, 2019). SDGs 13 (addressing climate change) and SDGs 11& 12 (tackling air pollution) are closely interrelated to control both air pollution and the effects of climate change. Achieving these objectives requires a combined commitment from both collective and individual efforts, coupled with a comprehensive identification of the key factors that must be addressed to effectively tackle environmental challenges, particularly greenhouse gasses.

A growing body of scientific literature and research has comprehensively illustrated that industrialization, globalization, financial development, trade liberalization, and urbanization contribute to various adverse externalities and environmental damage (Ahmed and Wang, 2019; Chandio et al., 2023). Particularly, less-developed countries, facing significant environmental challenges stemming from their heavy reliance on natural resources (Feng et al., 2023; Wang et al., 2023b), as well as issues related to natural resource mismanagement (Wencong et al., 2023). The implementation and adoption of environmentally friendly technologies are consider key pillar to mitigate environmental challenges while maintaining a sustainable economy (Luo et al., 2023; Wang, 2023). Although, technological innovation is considered the most effective response for sustaining current standards of living and addressing serious environmental concerns. Cainelli et al. (2020) also argued that innovation adaptation and diffusion by firms are key pillars for the resource efficiency and development of circular economy. Although, the transition to a circular economy (CE) is increasingly viewed as essential to decouple economic growth from natural resources. The proponents of the circular economy (Cainelli et al., 2020; De Jesus et al., 2018; Kirchherr et al., 2017) emphasize that technological innovation facilitate a shift from current linear systems of production and consumption, which are currently unsustainable due to limited stocks of non-renewable resources. Hence, technical innovation has been underscored as a pivotal catalyst for change in the shift towards sustainability. It is defined as innovation in all its forms (product, process, marketing, organizational), yielding both ecological and economic benefits (Cainelli et al., 2020). In essence, this concept has been acknowledged as a crucial element that enable "environmental benefits, " such as increased efficiency in the consumption and utilization of resources (Ul-Durar et al., 2023). In the policy realm, innovation has been referred to as "a catalyst" for a circular economy and a key component in the transition from a linear to a circular system of production and consumption (Le et al., 2023).

Another important factors that influence environmental quality is trade and follow of foreign investment (Liu et al., 2018; Xu et al., 2023). In several resource-rich countries, environmental regulations are insufficient to protect environmental quality. As a result, developed countries are increasingly redirecting their investments towards developing countries. Hence, the abundance of natural resource including gas, oil and minerals attract the foreign investment resulting increase resource consumption and it has negative impact on host economies. Previous literature shows that resource rich economies, particularly, oil resource are main driving force to attract foreign investors (Ullah et al., 2023; Yue et al., 2023). Shah et al. (2023) argued that natural resources have a crucial role in discouraging the use of highly polluting fossil fuels by reducing the need for their importation and providing a viable alternative in the form of cleaner energy sources such as natural gas. These evidences are also support by Bashir et al. (2023), argued that natural resources have played a pivotal role in mitigating environmental damage in the United States, and analogous results have been observed across the resource rich countries (Abbas et al., 2022; Kostakis et al., 2023). Conversely, Ulucak and Baloch (2023) argued that the abundance of natural resources can have adverse environmental consequences due to mining activities that degrade the environment. When a country heavily relies on abundant yet highly pollutant low-cost fossil fuels, it becomes less likely to leveraging the environmental advantages offered by its natural resources. In parallel, Sarkodie and Adams (2018) demonstrated similar findings, emphasizing that deforestation, mining, and chainsaw operations are notable contributors to environmental pollution and the depletion of natural habitats.

Other than these factors, diverse social, economic and country contexts have differential impacts on national climate adaptation and environment (Hua and Wang, 2023). Although, linkages between social, economic and other factors with environment are broadly accepted and each of these factors play major role (Kobeissi et al., 2023; Mabin and Harrison, 2023), but there has been limited systematic scientific investigation in relation to regional development, natural capital and green technological nexus in resource -exporting economies. Therefore, drawing from the aforementioned context, the main aim of this paper is to investigate the relationship between foreign direct investment (FDI), natural resource rent (NNR), green innovation (GI), natural capital (NCAP), and environmental performance (EPI) in the group of 22 resource-exporting economies. Furthermore, the current study investigates the mediating role of green innovation. The novelty of this study will be demonstrated by the investigation of the following questions within the framework of environmental sustainability in resource-abundant economies; a. What is the contribution of FDI to environmental performance in the short and long run? B. Does natural resources rent in resource-rich countries exert a significant impact on its environmental sustainability? c. What impact does green innovation have on environmental performance? D. How does the regional economic development and natural capital affect its progress towards sustainable environment?

This study makes significant contributions to the current body of literature in multiple aspects. Firstly, to the best of our knowledge, this study is optimistic that it pioneers the investigation of variables such as regional development, natural capital, green innovation, natural resource rent, foreign direct investment, and environmental performance in resource-rich economies. The inclusion of RED and NCAP sheds new light on the factors influencing the environmental performance across the resource rich economies. Secondly, we employed advanced second-generation panel econometric techniques, which encompass "Westerlund cointegration, cross-sectional augmented autoregressive distributed lag (CS-ARDL), and augmented pooled mean group (AMG) estimators." These methodologies have been specifically designed to tackle challenges associated with cross-sectional interdependence and structural factors. By utilizing these robust techniques, we not only bolstered the reliability of our findings but also heightened the precision of our conclusions. Thirdly, this study holds significant relevance for policymakers and government officials in resource-rich economies. Therefore, "the results of this study offer valuable insights into the factors that impact environmental performance," thereby contributing to the formulation of efficient policies aimed at promoting environmental sustainability.

The remainder of the study is structured into five key sections: Section 2 looks into a review of prior research, and section 3 presents the theoretical model employed in our analysis. In Section 4, we outline the estimation methodology, while section 5 is devoted to presenting empirical findings and discussion. Lastly, section 6 offers a conclusion and the policy implications arising from our study.

2. Review of literature

This section analyzes the prior research work on the effect of foreign direct investment, technological green innovation, natural resource rent, regional development and natural capital on environmental performance. The relevant literature presents a variety of research findings, each of which is carefully reviewed to identify the causal and dynamic linkages and their effects on environmental performance. We categorize previous empirical studies into four distinct sections. The first section encompasses research that investigates the link between FDI and EPI. Section two encompasses research focused on linkages between NNR and EPI. The third section is reviewing studies that specifically examine the link between GTI and EPI. The fourth and final section comprises studies on RED and NCAP in relation to EPI, respectively.

2.1. Foreign direct investment and environmental performance

In the existing literature, FDI is recognized as a macroeconomic factor with the potential to influence the environment. This suggests that the relationship between environmental quality and FDI may be positive, leading to investments in low-carbon intensity industries or the adoption of environmentally friendly technologies (Ali et al., 2022, 2023; Wang et al., 2022). On the other hand, a number of researchers argued that the ongoing influx of FDI can have an adverse effect on environmental quality (Adeel-Farooq et al., 2021; Neequaye and Oladi, 2015; Rahman et al., 2023). These studies assert that lax environmental regulations in many emerging economies have led to a compromise in the environmental ecosystem. This compromise results from the widespread adoption of emission-intensive manufacturing techniques by foreign investors who are driven by a desire to maximize their investments.

The study backed by Xu et al. (2019) examined the linkages between FDI, Growth of economy, consumption of energy, and environment in China from 1980 to 2014. They utilized a variety of analytical tools, such as ARDL, VECM, and "Granger causality methods, to investigate the connection between the independent and dependent variables." The findings of this research study indicated a substantial and persistent relationship between said variables. The data presented in this study pose a challenge the Environmental Kuznets Curve (EKC) hypothesis's viability in relation to environmental quality in China. This challenge is particularly significant when considering the impact of foreign direct investment on economic growth. In contrast, the research conducted by Zhuang et al. (2022) aimed to examine the dynamic relationships among FDI, China's economy, and environment from 1980 to 2017. They found that FDI inflow significantly influences environment and serving as the Granger cause.

Ren et al. (2022) They conducted an extensive analysis covering data from 1990 to 2013, spanning fifteen developing nations in Asia. Their research examined both short-term and long-term implications of fossil fuel usage, economic development, and FDI on CO2 emissions. Utilizing the "autoregressive distributed lag model (ARDL)," their study affirmed the idea that FDI significantly contributes to CO2 emissions. Likewise, Liu et al. (2021) conducted a study on the linkages between CO2 emission and FDI from 1990 to 2015. The researchers "reached the conclusion that the idea of a pollution haven is valid" in the context of the regions such as Middle East and countries of North African under examination. It was found that FDI shown an important factor contributing to the emissions of CO2. In contrast to these findings, Kamal et al. (2023) presented a divergent perspective by revealing that there is no significant linkages between FDI and emissions of CO2 in G20 countries. Hence, we test the following hypothesis.

Hypothesis 1. Higher levels of foreign direct investment positively associated with environmental performance in resource rich countries.

2.2. Natural resource rent and environmental performance

It has been investigated by several current empirical research studies that the linkages between environment and natural resource rent. numerous studies concentrating on the transitional development of economies, while others have centered their research on developed countries. For instance, Baloch et al. (2019) examining South Africa, Umar et al. (2020) investigating into China, Zafar et al. (2021) exploring Asian countries, Kwakwa et al. (2020) scrutinizing Ghana, Joshua and Bekun (2020) studying South Africa, Nathaniel et al. (2021) exploring economies of Latin America and Caribbean regions, and Mahmood and Furqan (2021) focusing on "Gulf Cooperation Council countries". The findings of studies revealed that having abundant in natural resource; have consistently played a pivotal role in the factors of production. However, it is worth noting that their abundance can potentially lead to a detrimental long-term economic phenomenon which is acknowledged as the "resource curse" (Apergis and Katsaiti, 2018; Chang et al., 2023). Most of the countries grapple with environmental challenges stemming from carbon emissions across multiple phases, spanning from the initial extraction to the natural resources' ultimate utilization. Therefore, it is imperative to mitigate the rising trend in emission of carbon dioxide (CO2) that arise from the exploitation of resources (Gao et al., 2023). The economic growth process has been then stimulated by the industrial development, hence increasing the natural resources' importance. However, the unsustainable usage of natural resources has an adverse effect on the environment (Ahmad et al., 2022; Guo et al., 2023; Mushtaq et al., 2022).

Ulucak and Ozcan (2020) studied environmental impact of various drivers of economic activities in OECD countries spanning from 1980 to 2016. Their findings reveal a positive and statistically significant association and one-way causality that originates from natural resource rents and leads to environmental quality. In particular, Khan et al. (2021) conducted an extensive examination of the 10 highest ranked manufacturing countries. They employed an approach of econometrics to explain the effect of natural resources, urbanization, and manufacturing value-added on environmental performance. By scrutinizing linkages between urbanization, value addition in manufacturing sector and the environment for the period 1970 to 2016, the study unveiled that there is a crucial role played by natural resources in shaping the quality of environment. Interestingly, it also revealed that protection of natural resources can pose a hindrance to economic growth. Additional research conducted by Nathaniel and Khan (2020) and Balsalobre-Lorente et al. (2023) verified these findings and recognized a substantial reduction of the effect of natural resource rents for BRICS and EU-5 countries, respectively.

Altinoz and Dogan (2021) have studied the same discourse by applying quantile regression approach by using data for the time period 1990 to from 82 nations. Their analysis yielded noteworthy results, indicating that natural resource has a significant mitigating effect in these countries on lower quantiles of CO2 emissions, while showing a positive effect for nations with middle- and high-quantile on CO2 emissions. Additionally, Razzaq et al. (2022) provided insights into country-specific cases concerning quality of environment and its relationship with natural resources in Pakistan and United States of America USA, respectively. They discovered that the environmental quality in Pakistan was not statistically significant and no causal impact by natural resource rents. The recent study backed by Singh et al. (2023), the authors explore the impact of natural resource rents on the association between CO2 and economic growth. They employ the specifications of Environmental Kuznets Curve (EKC) and analyzed data spanning from 1970 to 2016. The study's findings highlight how economic Dependence on natural resources can disrupt the EKC's theoretical explanation. More precisely, the research offers empirical proof demonstrating that natural resource rents amplify the influence of affluence on the increase in CO2 emissions during the early stages of development while diminishing the benefits of an environment associated with increased level of income. Therefore, this study designed the following hypothesis.

Hypothesis 2. Higher natural resource rent is associated with higher environmental performance.

2.3. Green technological innovation and environmental performance

Economic growth relies heavily on technological innovation, and the idea that prosperity is linked to innovation enjoys broad acceptance and substantial support across economics and various other fields. Technological innovations lead to increased productivity in various sectors of the economy (Chandio et al., 2021; Wang et al., 2019). When new technologies are introduced, they often automate or streamline processes, reducing the amount of labor and resources required for the production of goods and services. Countries invest in and adopt cutting-edge technologies gain a competitive advantage. Technological advancements enable firms to produce higher-quality products at lower costs, making them more competitive in domestic and international markets (Li et al., 2023). This can result not only increase market share and revenue but also improve the environmental quality (Lin and Ma, 2022). However, over the last two decades, the worldwide community is increasingly focused on green technology innovation due to a growing global concern for the environment and related issues. Li et al. (2019) argued that foster green growth on a global scale, it is imperative to prioritize the worldwide implementation and continuous enhancement of green technology innovations. The most potent tools at the disposal of all economies for achieving sustainable development encompass environmental regulations and advancements in green technology. In most recent studies Wang et al. (2023a) and Sharif et al. (2023) claimed that countries implementing green technologies to combat ecological degeneration, with a focus on reducing air, water, and soil contamination. Moreover, direct environmental regulations, such as the imposition of taxes on pollution reduction, subsidies, or investments in research and development, invariably compel polluting industries to implement and improve conventional green technologies to maintain a competitive edge in the international market. Similarly, Fang (2023) also claimed that green technological innovation promotes conservation of resource, enhances the efficiency of energy, and aids in controlling pollution prevention, ultimately boosting environmental performance. A lack in GTI associates with lower environmental performance, impacting both individual well-being and public health. This scenario often triggers government intervention through regulatory measures aimed at limiting pollutant emissions. In response, businesses tend to prioritize the adoption of GTI as a cost-effective means of mitigating environmental penalties.

Jiakui et al. (2023) have studied the linkages between technological innovation and environmental quality in Malaysia for the period of time 1985 and 2012. They used auto regressive distributed lag model to analyze both short and long-term effects and found that while technological innovation seemed to reduce CO2 emissions, this effect was not statistically significant. Liao and Li (2022) conducted an analysis using data from 2000 to 2014 to evaluate how CO_2 emissions are affected by green technology innovation. Their study revealed that countries investing in research and development have succeeded in reducing their CO2 emissions. Employing GMM techniques, they found a significant and negative correlation between GTI and CO2 emissions. Moreover, Wu et al. (2022) asserted a one-way causal link between GTI and renewable energy, noting a negative association with CO2 emissions. However, conflicting findings exist in other research regarding the environmental implications of GTI. For instance, Li et al. (2023) examined the benefits of GTI and optimal pollution control, revealing that both reduces CO2 emissions. The welfare gains from optimal pollution control, however, are higher than the welfare gains from GTI, according to the empirical findings. Additionally, the spurred innovation only partially offsets the effects of energy conservation policies, reducing just the per capita income decline. (Abbas et al., 2022; Huang et al., 2023).

Hypothesis 3. Increased green technological innovation positively influences environmental performance.

2.4. Regional development and environmental performance

The existing body of literature explores the relationship between the environment and regional development, with a particular emphasis on per capita income and pollution as key variables. Numerous empirical studies have highlighted that rapid development has significant environmental consequences, impacting both local and global ecosystems. In most recent study, Fakher et al. (2023) asserts that the preliminary phases of developing economies are categorized by low environmental performance, but this is expected to improve as economic growth progresses is called EKC.

Previous studies have also identified a U-shaped relationship between the environment and GDP per capita, as demonstrated by Akbostancı et al. (2009) and Khan et al. (2017). These scholars investigated the association between CO2 emissions and GDP in 16 countries from 1950 to 1993, employing both the "fixed-effect model and cross-section ordinary least squares (OLS) methodology." They observed "N-shaped Environmental Kuznets Curve" (EKC), incorporating structural transition as a factor. Their findings suggested that neither U-shaped nor N-shaped relationships between level of income and CO2 emission. Contrary to these findings, Adediyan et al. (2020) also investigated both the inverted U and N-shaped EKC models. Altıntaş and Kassouri (2020) also explored the relationship between public spending, per capita income, renewable energy sources, and greenhouse gas emissions across twenty-eight OECD countries from 1993 to 2010. They showed that public spending and investments in renewable energy have a favorable impact on the improvement of environmental quality.

In the context of environmental degradation in Myanmar from 2000 to 2014, the empirical study by Awan and Azam (2022) that looked at the relationship between GDP and CO2 emissions found a strong and substantial association over the short and long runs. They used the autoregressive distributed lag (ARDL) method and took into account factors including GDP, trade, financial development, urbanization, and greenhouse gases (CO2, N2O, CH4). Similarly, Balsalobre et al. (2015) explore the linkages between economic development and CO2 emissions in the five "EU-5 nations of Germany, France, Italy, Spain, and the UK" from 1985 to 2016. They discovered an N-shaped connection between environmental change and GDP growth. Contrary to this, Hao et al. (2020) found no "evidence of the EKC in the panel of Non-OECD countries". Khan et al. (2019) examined the nexus between emissions and GDP growth for China from 1977 to 2013. Using the FMOLS method, they found that EKC was insufficient to account for China's total CO2 emissions. The study backed by Baloch et al. (2020) revealed Turkey's N-shaped Kuznets curve between 1980 and 2017 after investigating the relationship between GDP growth and pollution. To demonstrate there is no proof of "N-shaped EKC in Turkey, they used quantile regression and ARDL approaches."

Hypothesis 4. Initial stages of regional development negatively impact on short-term environmental performance.

2.5. Natural capital and environment

Natural capital is critical to overall economy due to its role in providing essential goods such as food, energy, and water, as well as invaluable services like climate regulation and cultural enrichment. Hence, natural capital play important role toward achieving Sustainable Development Goals (SDG) including environmental quality, "lowering greenhouse gas (GHG) emissions, safeguarding ecosystems and biodiversity," and recognizing the importance of culture and society (Acosta et al., 2020). Kurniawan et al. (2021) also emphasized that the most essential type of capital, which provides the necessities for human existence, is natural capital, which includes water, land, forests, and minerals. Additionally, natural capital includes ecological services provided by nature in addition to the resources used in manufacturing processes (Acosta et al., 2020; Maes et al., 2020; Wielgus et al., 2023).

Kurniawan et al. (2021) explored the nexus between environmental quality and economic growth in the context of sustainability. They "used a pooled mean group estimator analysis to accomplish this goal," which covered 140 nations from 1990 to 2014. The study uses the "natural capital portion of inclusive wealth as a proxy for environmental" quality. Agricultural, fisheries, forestry, fossil fuels, and mineral resources are all included in this component. The results of the cointegration analysis showed that population density and economic expansion had substantial long-term effects on natural capital. The extraction of natural resources is continually under pressure due to population expansion, while the impact of economic growth on environmental quality follows a nonlinear trend. Notably, the results point to an advantageous effect of economic structure and a technical influence within the economy that effectively uncouples environmental degradation from the trajectory of economic expansion.

Hypothesis 5. Higher levels of natural capital positively influence environmental quality.

3. Theoretical framework

This "section explains the theoretical framework" that examines the relationship between FDI, natural resource rent, green technological innovation, and their combined effect on environmental performance. The hypothesis of Environmental Kuznets Curve (EKC) a widely used concept in recent literature, is employed to assess the environmental effects that arise on account of economic growth. The EKC hypothesis uses the lenses of scale effect, composition effect, and technical to demonstrate various scenarios' effects (Pata et al., 2023). The first dimension under consideration relates to the scale effect, which refers to an expansion in production levels without any changes to technological or economic structures (Ulucak and Ozcan, 2020). As a result, in this particular stage, there is a tendency for economic growth to have an adverse effect on environmental performance (Zafar et al., 2021). This is due to the higher production requirements, which in turn lead to a greater demand for raw materials and natural resources. Consequently, this heightened economic activity results in an increase of waste and pollution levels (Hao et al., 2020). The second channel is the composition effect, which elucidates how pollution levels and the substances used in manufacturing processes are influenced by the industrial composition of a specific economy (Liao and Li, 2022). As burgeoning economies frequently undergo structural transformations, transitioning from agriculture to industry and ultimately toward the service sector, the impact of this composition effect plays a pivotal role in diminishing material consumption and alleviating the environmental challenges associated with rapid economic growth (Liu et al., 2021). Furthermore, the 3rd channel under scrutiny is the technical effect, which contributes to enhanced productivity and the adoption of advanced, clean technologies (Guo et al., 2023). These technological advancements play a pivotal role in mitigating the multifaceted threats posed by environmental degradation (Fakher et al., 2023). Subsequently, there has been a remarkable flow in scholarly interest in empirical research on the Environmental Kuznets Curve (EKC). Initially, the majority of academics focused on investigating the link between environmental degradation and economic growth. For instance, Shafik and Bandyopadhyay (1992) conducted a comprehensive analysis of the association between environmental indicators and per capita income, revealing an inverted U-shaped relationship specifically for Sulphur dioxide (SO2) and per capita income. Jiakui et al. (2023) extended this inquiry by examining emissions of various pollutants in Sweden and observed a similar inverted U-shaped pattern in emissions for carbon dioxide (CO2) a d Sulphur dioxide (SO2).

There are two opposing viewpoints on the relationship between foreign direct investment (FDI) and environmental quality: the pollution haven hypothesis and the pollution halo theory. The original version of the "pollution haven hypothesis," made by Walter and Ugelow (1979), implies that capital will flow from areas with strict environmental standards to others with more lax rules in an open economy because of differences in environmental regulations. As a result, this capital mobility causes pollution and environmental deterioration. in the host country. Accordingly, different countries have different environmental standards because they are at different stages of development and have different goals. As the incomes of developed countries keep going up, environmental standards are getting stricter, and the level of cleanliness of production is always getting better. Because of this, FDI in high-polluting industries has moved to developing countries, turning them into a polluted paradise. Several studies proved this hypothesis through the empirical analysis that foreign direct investment worsen the host country environmental quality. For instance, Ali et al. (2022) and Li et al. (2023) came to the same conclusion that FDI will cause the environment in the host country to get worse. Guo et al. (2023) using information from "One Belt, One Road" countries as a sample, researchers discovered that developing nations like South Africa and Malaysia are still "polluted paradises." Similarly, Khan et al. (2019) examined panel data from 1995 to 2012 and discovered that, on a national scale, the pollution haven hypothesis is correct. Wang et al. (2019) examined how FDI and international trade impacted the transfer of polluting industries using an interprovincial panel. They discovered that the transfer of pollution-intensive businesses increased in proportion to the amount of FDI that China's provincial administrative regions attracted. As a result, China continues to be a "pollution paradise" for FDI.

The pollution hallo hypothesis, in contrast to the pollution haven idea, explains the linkages between FDI and environmental quality. According to this hypothesis, FDI could provide the host nation with advanced environmental practices, clean manufacturing technologies, and strong environmental performance management skills, all of which increase environmental quality. According to (Khan et al., 2023), FDI from industrialized countries has a good effect on the overall environment of emerging economies. Kamal et al. (2023) constructed a panel smooth transfer (PSTR) model of foreign direct investment (FDI) and environmental pollution using economic growth and FDI accumulation as conversion variables. They thought that foreign direct investment boosts the advancement of environmental protection technologies via the "demonstration impact," "spillover effect," and "competition effect," hence validating the "pollution halo" idea. Thus, FDI has a wide range of complex and multidimensional effect on pollution (Hong et al., 2019). As a result, FDI has a variety of environmental effects on the host nation, such as size effects, structural effects, and technology effects. These three effects—which can be either positive or negative—show the overall impact of FDI on pollution when combined together. Wang and Zhou (2021) empirically examined the link between FDI and pollution emissions using a structural econometric model and generalized moment estimation approach. They found that the positive technical impact associated with foreign direct investment, which is beneficial to lowering the pollution emissions. Contrary to it, Chen et al. (2023) examined the influence of foreign investment on three dimensions including water pollution, industrial structure and global and regional relative technical improvement. They argued that foreign investment has no substantial influence on technology promotion when it promotes the shift of industrial structure to polluting sectors, which has a detrimental effect on overall environmental status. Similarly, endogenous growth theory supports the idea that countries can achieve long-term economic growth without compromising environmental integrity through the utilization of technical advancements.

4. Material and methods

4.1. Data source and sample selection

This study employed a balanced panel dataset covering 22 countries abundant in both oil and non-oil resources. The sample selection process involved a two-step procedure. In the initial round, 38 oil and non-oil resource-rich exporting countries were chosen, and in the subsequent round, we eliminated countries with missing values, resulting in a final selection of 22 countries from five regions as shown in Appendix Table A1. The identification of resource-rich countries was based on the 2018 OECD report on resource flows. In alignment with the study's objectives and a comprehensive review of theoretical and empirical literature, this research includes six key variables: foreign direct investment, natural resource rent, regional development, green innovation, natural capital, and the environmental performance index, spanning the period from 2002 to 2022. The data utilized in this study was sourced from various reputable databases, including the World Development Indicators (2022), the OECD database, and the Yale University.

4.2. Variables definition and measurement

4.2.1. Environmental performance index

The Environmental Performance Index (EPI) serves as our primary dependent variable, measuring and ranking countries' environmental performance. It offers a quantitative analysis of diverse environmental indicators, enabling comparisons and assessments of countries' efforts towards environmental sustainability (Papadimitriou et al., 2020). The EPI encompasses a broad spectrum of indicators, including forty performance indicators across eleven environmental issues such as air quality, water resources, biodiversity, and climate change. The source and description of variable shown in Table 1.

4.2.2. Foreign direct investment

Foreign direct investment (FDI) refers to the investment made by a country or individuals' firm from one country into a business located in another country. The country inflow of FDI play central role toward environmental outcomes. The most recent literature shows the complex both positive and negative relation between environmental performance and FDI. Uche et al. (2023) argued that FDI have positive impact through the technological transfers from the developed countries to least developed countries. The foreign investment has help to improve environmental management practices and more sustainable production process. While some studies (Udemba, 2023; Wang et al., 2023c) indicate that FDI can sometimes results in environmental degradation, particularly in industries with weak environmental regulation. Hence, FDI can promote social and environmental inequality without adequate consideration for sustainable development. This study used the inflow of FDI (%GDP). The source and description of variable shown in Table 1.

4.2.3. Natural resource rent

Natural Resource Rent (NRR) is crucial for a sustainable economy, as highlighted by Shittu et al. (2021), and is considered an incentive for developing countries. NRR is defined as the sum of income or profit generated from the use of natural resources, such as minerals, oil, gas, timber, and other renewable and non-renewable resource. The data for NRR has been taken from the world development indicators of World Bank. The detailed source and description shown in Table 1.

Table 1
Data details and variable names.

Variable	Description of variables	Measurement	Source
EPI	Environmental performance index	Overall EPI ranking score	Yale University
FDI	Foreign Direct Investment	Net inflow of foreign direct investment (% GDP)	WDI
NRR	Natural Resource Rent	Total natural resource rent (% GDP)	WDI
RED	Regional Development	GDP growth (Annual %)	WDI
GTI	Green technology innovation	% of all technologies	OECD
NCAP	Natural Capital	Sum of renewable, nonrenewable resource including minerals, land, forest and protected areas.	World Bank report on the changing wealth of nations 2021

Note: In the dataset, the values for certain years were entirely missing. To address this data gap, we applied the interpolation method to calculate and fill the missing values.

4.2.4. Regional development

Regional development (RED) refers to the economic, social and infrastructure progress within a specific geographical region. RED involves initiatives and strategies aimed at improving living standards, promoting economic growth, and address regional disparities (Ghisetti and Quatraro, 2013). Its overall aim to improves and enhances the well-being of communities through the economic opportunities, and creating favorable environment for the sustainable development. Hence, the RED and environment are interconnected and can influence each other in several ways. For instance, under the regional development investment in regional infrastructure including renewable energy infrastructure and green transportation, which aligned with sustainable practices and can contribute to the transition toward more environmentally friendly industries and practices (Cao et al., 2021). This study used the regional economic growth as proxy variable for the regional development. The data has been taken from the WDI for the period 2002–2022.

4.2.5. Green technology innovation

Green technological innovation (GTI) encompasses the development and implementation of new or improved technological solutions toward sustainable development (Aydin and Bozatli, 2023). Its primary objective is to eliminate or minimize the environmental externalities, aiming for mutual progress in ecological environmental protection and socio-economic development (Cao et al., 2021). The present study assessed green technological innovation (GTI) by quantifying the number of environmentally-related technologies as a percentage of all domestic innovations. The data were sourced from the Patent Technology Development dataset of the OECD.

4.2.6. Natural capital

Natural capital (NCAP) refers to the stock of natural resources and ecosystem that provide valuable goods and services to human as well as overall society (Shittu et al., 2021). NCAP encompass the earth natural assets, such as forest, wetlands, minerals, water resources and biodiversity (Acosta et al., 2020). NCAP provide wide range of benefits to the sustainable environment. There is direct relationship between NCAP and environment. This study used the sum of renewable, nonrenewable resource including minerals, land, forest and protected areas as proxy variable for the NCAP. The data has been taken from the World Bank report on the changing wealth of nations 2021. The detailed source and description shown in Table 1.

4.3. Empirical model

In order to "achieve the main objective of current study, we constructed environmental pollution-model based on Grossman and Krueger (1995) framework. The Grossman and Krueger (1995) environmental-pollution model is based on scale effect, technical effect and structural effect. (1)

$$EP = f(FDI, NNR, GTI, RED, NCAP) \tag{1}$$

Where EP denote the environmental performance indicator and shows the pollution level in a particular area. Earlier research (Awan and Azam, 2022; Khan et al., 2019; Kurniawan et al., 2021) has employed environmental performance index to serve as a proxy for environmental indicator. FDI denote the follow of foreign direct investment. NNR represents natural resource rent. The term technical effects are represented as GTI, that improving production, promoting energy efficiency, upgrading pollution treatment equipment, and mitigating pollution levels. The use of green technology serves as an effective means to facilitate the efficient exploitation of resources and mitigate environmental degradation (Abbas et al., 2022). To account for technological effects, we incorporated green environmental technologies into our model, as demonstrated by Wang et al. (2019) and Pata et al. (2023).

The variables RED and NCAP signify regional economic development and natural capital, respectively, encompassing the concept of scale effects that explain the "relationship between economic expansion and the utilization of fossil fuels, ultimately leading to long-term pollution escalation." In simpler terms, an upsurge in economic growth often corresponds to a direct increase in energy consumption and pollution. Earlier academic works (Kurniawan et al., 2021; Neequaye and Oladi, 2015) have verified the role of economic development in advancing environmental sustainability. Hence, this study considers regional economic development as a governing factor for the scale effects explained in the environmental pollution model by Grossman and Krueger (1995).

To improve the empirical estimation of Equation (1), we employ a logarithmic transformation on the model's variables. This transformation effectively reduces data variability and enhances the distributional properties of these variables. The utilization of a natural logarithmic transformation serves to address issues related to autocorrelation and heteroskedasticity present in the dataset. The log-linear form of augmented environmental performance is as per following;

$$ln\ (EPI)_{it} = \alpha_0 + \beta_1 (FDI)_{it} + \beta_2\ ln\ (NRR)_{it} + \beta_3\ Ln\ (GTI)_{it} + \beta_4\ ln\ (RED)_{it} + \beta_5\ ln\ (NCAP)_{it} + \delta_i + \eta_t + \varepsilon_{it} \quad (2)$$

Where *ln*, *i* and *t* denote "natural logarithms, cross-section and time period," respectively. $\beta_1, \beta_2, \ldots \beta_5$ are coefficients of FDI, natural resource resent, green technological innovation, regional development and natural capital, respectively. α_0 represent intercept, δ_i, η_t and ε_{it} are country-fixed effects, time-effect and error term, respectively. It is widely held that countries are pursuing the liberalization of trade and investment policies to attain economic stability. Conversely, certain developed economies are endeavoring to shift their investments towards resource-rich developing nations, in an effort to mitigate the associated high environmental costs (Behera et al., 2023). Consequently, foreign investment has both direct and indirect impacts on environmental quality. In this regard, there are two concepts: Frist, carbon-intensive FDI contribute negatively to host countries. Secondly, less carbon-intensive foreign investment positively contributes to the environment (Cai et al., 2023). Hence, this argument led to following two outcomes.

$$\beta_1 = \frac{Ln(EPI)}{Ln(FDI)} < 0, \beta_1 = \frac{Ln(NNR)}{Ln(NNR)} > 0$$

Furthermore, the process of economic growth stimulates the development of industries, hence increasing the importance of natural resources. It is argued that unsustainable usage of natural resources has detrimental impacts on the environment (Guo et al., 2023). Hence, this argument evidence that natural resource rent is negatively related with environmental outcomes.

$$\beta_2 = \frac{Ln(EPI)}{Ln(NNR)} < 0$$

Technological innovation is essential for economic growth and prosperity is a widely accepted. Technological innovations lead to increased productivity in various sectors of the economy (Wang et al., 2019). Hence, green technological innovation increases the efficiency of production and contribute to environmental sustainability.

$$\beta_3 = \frac{Ln(EPI)}{Ln(GI)} > 0$$

Similarly, the regional development affecting both local and global environment. Fakher et al. (2023) argued that the initial phases of economic development are characterized by low environmental performance, but this is expected to improve as economic growth progresses. Hence, these arguments make the following two outcomes.

$$\beta_4 = \frac{Ln(EPI)}{Ln(RED)} < 0, \beta_4 = \frac{Ln(EPI)}{Ln(RED)} > 0$$

The natural capital play important role toward achieving Sustainable Development Goals (SDG) including "environmental quality, reduction of greenhouse gas (GHG) emissions, protection of ecosystems and biodiversity," and the recognition of cultural and social value (Acosta et al., 2020).

$$\beta_5 = \frac{Ln(EPI)}{Ln(NCAP)} > 0$$

4.4. Estimation strategy

To achieve the main objective of study, the current study used the standard econometric approach (see Fig. 1). Our study includes 22 countries from five different regions including "Europe & Central Asia, East Asia & Pacific, Latin America & Caribbean, Middle East & North Africa, and Sub-Saharan Africa" for the time period 2002 to 2022. Hence, in this case, (N < T), conventional techniques like fixed and random effect models are preferable but we not only rely on conventional panel econometric methodology. Thus, we used both first- and second-generation panel econometric methodology because five regions examined in this study are closely connected economically. Due to the panel data nature and diagnostic assessments, these five "cross-sectional regions may exhibit cross-sectional dependence, slope heterogeneity," and a mixed order of integration" (comprising both I (0) and I (1)). Fig. 2 shown the methodological road map.

The current study used the following four step econometric procedure to estimate the coefficients of variables.

4.4.1. slope homogeneity and cross-sectional dependency test

In panel data analysis, the cross-section dependence test assumes importance, particularly when the sample countries share similar "economic characteristics, such as developing nations, emerging economies, and transition countries." Furthermore, in the context of hyper-globalization, financial integration, and the internationalization of production, economies exhibit cross-sectional interdependence, rendering them vulnerable to shocks in one country that can propagate to affect others. Therefore, the analysis of cross-sectional dependency finds consistent application in empirical research utilizing panel data. Within the current literature, numerous cross-sectional dependency tests have evolved and are employed to identify common dynamics among the countries in the sample. For instance, Breusch and Pagan (1980) proposed the following LM_{BP} test:

$$y_{it} = \alpha_i + \beta_i x_{it} + u_{it} \quad (3)$$

$$i = 1, \ldots .N\ t = 1$$

Where y_{it} and x_{it} shows "dependent and independent variables," respectively. i and t represents cross sections and time period. In the case of large cross-sectional units LM_{BP} test unable to capture the common characteristics. In order "to overcome these issues, Pesaran (2007) proposed the following CD test" for examining cross-sectional dependency."

$$CD = \sqrt{\frac{2T}{N(N-1)}} \sum_{I=1}^{N-1} \sum_{j=i+1}^{N} (\widehat{\rho_{ij}}) \quad (4)$$

Where "CD denoted cross-sectional dependence", with T representing the time period, N is panel "cross-sections, and $\widehat{\rho_{ij}}$ representing the estimated cross-sectional association of errors between i and j." Furthermore, Pesaran (2015) improved the CD test and known as bias-adjusted LM test. The test statistics can be written as following.

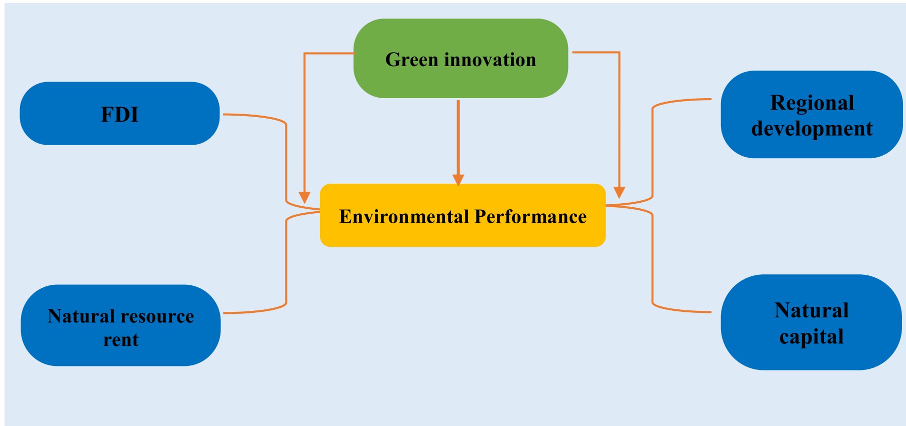

Fig. 1. Theoretical framework of a transmission mechanism.

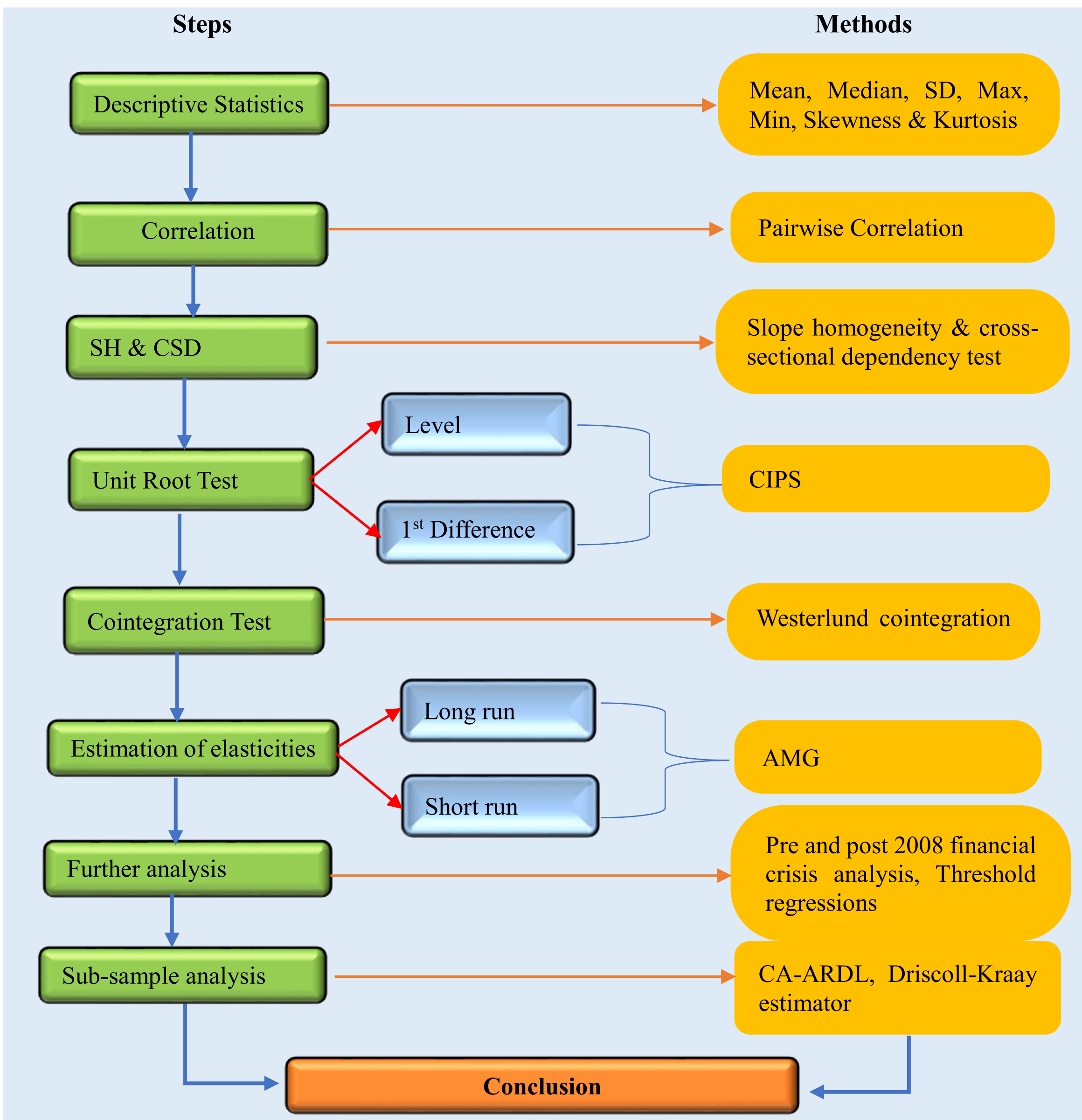

Fig. 2. Road map to research methodology.

$$CD_{LM} = \sqrt{\frac{2T}{N(N-1)}} \sum_{I=1}^{N-1} \sum_{j=i+1}^{N} \left(\frac{(T-K)\widehat{\rho_{ij}}^2 - \mu_{Tij}}{v_{Tij}^2} \right) \quad (5)$$

Where k refers to the number of regresses, μ_{Tij} and v_{Tij}^2 and mean and variances of $(T-K)\widehat{\rho_{ij}}^2$, respectively. Moreover, the potential for slope homogeneity, arising from country-specific effects within the sample countries, cannot be overlooked. "To assess slope homogeneity before determining the integration order of the variables, the current research employed" the approach introduced by Pesaran and Yamagata (2008), which is based on the delta (△) and biased adjusted delta (△adj). The empirical model for this test is as follows:

$$\Delta = \sqrt[2]{(N)}\,(2K)^{-\frac{1}{2}} \left(\frac{1}{N} S^{\sim} - K \right) \quad (6)$$

$$\Delta_{adj} = \sqrt[2]{(N)} \left(\frac{2k(T-k-1)}{T+1} \right)^{-\frac{1}{2}} \left(\frac{1}{N} S^{\sim} - K \right) \quad (7)$$

4.4.2. panel unit root test

In empirical estimation, the identification of variable properties is considered a crucial step, especially in panel data analysis. To determine the stationary properties of the data, previous studies have predominantly relied on first-generation unit root tests, including the ones proposed by "Maddala and Wu (1999), Levin et al. (2002), and Im et al. (2003)." However, the first-generation panel unit root tests do not account for cross-sectional dependency (CSD), leading researchers to favor "second-generation panel unit tests such as the Cross-sectional Augmented Dickey-Fuller (CADF) and Cross-sectional Augmented Im, Pesaran, and Shin (CIPS) tests," as formulated by Pesaran (2015). Consequently, the current study incorporates both first and second-generation panel unit root tests. Thus, the model for the CIPS test is presented as follows:

$$\Delta C_{i,t} = \mu_i + \mu_i X_{i,t-1} + \mu_i \overline{X}_{t-1} + \sum_{m=0}^{n} \mu_{im} \Delta \overline{Y}_{t-1} + \sum_{m=0}^{n} \mu_{im} \Delta Y_{i,t-1} + \vartheta_{it} \quad (8)$$

Where $\overline{Y}$ is the average cross-section. Pesaran (2007) CIPS test statistics are expressed as:

$$\widehat{CIPS} = N^{-1} \sum_{i=1}^{n} CADF_i \quad (9)$$

Where "CADF stands for Cross-Sectionally Augmented Dickey-Fuller."

4.4.3. panel Co-integration test

Once the stationarity of the variables has been assessed, the subsequent step involves evaluating the long-run cointegration relationship among the selected variables. Due to our concerns regarding cross-sectional dependence (CSD) and heterogeneity, it is imperative to employ "second-generation panel cointegration tests that offer precise and reliable insights into the long-run cointegration relationships across variables under various circumstances." To address the issues of CSD and heterogeneity, we employed the cross-sectional augmented Westerlund (2005) error correction-based cointegration method. "The error correction-based cointegration test generates two sets of results: two group test statistics (G_T & G_a) and two panel test statistics (P_T & P_a)." The advantage of employing the Westerlund cointegration test over other methods in the literature is its simplicity, as it does not necessitate the correction for temporal data dependency. Additionally, it demonstrates robustness in the aspect of cross-sectional dependence and panel heterogeneity, as indicated by Dogan et al. (2020). The results of the group statistics can be derived as follows:

$$G_T = \frac{1}{N} \sum_{i-1}^{N} \frac{\varnothing_i}{SE\varnothing_i}, G_a = \frac{1}{N} \sum_{i-1}^{N} \frac{T\varnothing_i}{\varnothing_i(1)} \quad (11)$$

$$P_T = \frac{\varnothing_i}{SE\varnothing_i}, P_a = T\varnothing_i \quad (12)$$

Where G_t and G_a represent the group mean statistics, P_t and P_a represents panel statistics.

4.4.4. estimation of short and long-run coefficients

To analyze "both short-term and long-term relationships among the study variables, we utilize the Augmented Mean Group (AMG) estimator, a methodology initially developed by Eberhardt and Bond (2009)" and subsequently refined by Bond and Eberhardt (2013). This estimator is particularly well-suited for producing precise "estimates in the presence of cross-sectional dependence and country-specific heterogeneity." The "AMG estimator incorporates a shared dynamic process that reveals unobservable common factors within the core model. This estimation method involves a two-step procedure." In the initial stage, we estimate differenced data, which includes $T-1$ period dummies denoted as ΔDt, using the traditional Ordinary Least Squares (OLS) estimator. In the subsequent stage, we derive the long-run parameter by accounting for cross-sectional dependence (CSD) and other common factors.

$$\begin{aligned}\Delta EPI_{it} &= \beta_1 \Delta FDI_{it} + \beta_2 \Delta NNR_{it} + \beta_3 \Delta GTI + \beta_4 \Delta RED + \beta_5 \Delta NCAP \\ &+ \beta_6 FDI_{it} + \beta_7 NNR_{it} + \beta_8 GTI + \beta_9 RED + \beta_{10} NCAP + \sum_{t=2}^{T} c_t \Delta D_t + \varepsilon_{it}\end{aligned} \quad (13)$$

Where Δ denote "the first difference operator and c_t represent unobserved common factors that provide constructed variable $\widehat{\varphi}$ for the second stage of AMG estimation to calculate" long-run coefficient.

$$y_{it} = \delta_i + \beta_i x_{it} + c_t + d_i \widehat{\varphi}_t + \varepsilon_{it} \quad (14)$$

$$\Delta \widehat{\beta}_{AMG} = N^{-1} \sum_i \widehat{\beta}_i$$

The "estimation procedure in Equation (14) is used to derive cointegration parameters and, consequently, long-run relationships by taking into account "cross-sectional dependence among panel sections via common factors." In addition, to assess the robustness of AMG estimator results, CS-ARDL was employed as an alternative method in the present investigation. The CS-ARDL offers a conclusive solution because it is resistant to endogeneity and non-stationarity concerns, and it addresses CSD and" heterogeneity issues (Zhou et al., 2023).

5. Empirical results and discussion

5.1. Primarily results

Table 2 presents the estimated results of descriptive statistics and pairwise correlation for the sample from 2002 to 2022. For each series, estimated means, medians, standard deviations, minimum, Maximum Skewness and Kurtosis. We have summarized the descriptive information of six variables including environmental performance index (EPI), foreign direct investment (FDI), regional development (RED), green innovation (GTI), natural resource rent (NRR), and natural capital (NCAP). The standard deviations of the variables range from 0.990 for NRR to 1.791 for NCAP, while the estimated averages are ranging from 1.460 for FDI to 26.058 for NCAP. We have also reported the minimum and maximum of the variables with minimum of −4.309 for FDI and Maximum for GTI. We found a greater dispersion around the mean in Foreign direct investment in all selected countries.

Panel (b) of Table 1 presents the linear relationships among the variables. Notably, it demonstrates a robust and positive correlation of 0.73 between green innovation (GTI) and natural capital (NCAP). Conversely, negative correlations are observed between several pairs of variables, including NCAP and RED, NCAP and NRR, GTI and RED, GTI

Table 2
Summary statistics and pairwise correlation.

(a) Summary statistics

Variables	Mean	SD	Min	Max	Skewness	Kurtosis
EPI	4.260	1.165	1.089	5.122	−3.066	11.390
FDI	1.460	1.482	−4.309	4.702	−0.872	3.809
NRR	3.486	0.990	0.024	5.059	−1.865	7.239
RED	1.618	1.118	−2.563	2.757	−2.170	7.666
GTI	26.051	1.774	22.595	29.839	0.233	2.215
NCAP	26.058	1.791	22.498	29.605	0.236	2.008

(b) Pairwise correlation

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
(1) EPI	1.000					
(2) FDI	−0.054*	1.000				
(3) NNR	0.015*	−0.008*	1.000			
(4) RED	−0.017*	0.16*	0.319*	1.000		
(5) GTI	0.271*	−0.78*	−0.16*	−0.018	1.000	
(6) NCAP	0.233*	−0.89*	−0.02*	−0.09*	0.073*	1.000

Source: Authors' calculation based on the data of 22 oil and non-oil resource exporting countries. ***p < 0.01, **p < 0.05, *p < 0.1

and FDI, GTI and NRR, GTI and RED, EPI and RED, FDI and EPI, NRR and FDI, and RED and FDI. On the other hand, positive correlations are evident in the relationships between RED and FDI, RED and NRR, as well as GTI and EPI.

5.2. Benchmark regression results

Our empirical analysis began with estimating baseline panel data regression methods employing a fixed effect model. The estimated results are presented in Table 3. The F-statistics and Hausman test suggested that the fixed effect model is preferred; thus, we rely on the fixed effect model in further analysis for reference. The estimation results confirm that regional development (RED) is significantly inversely related to environmental performance. This indicates that as economic development expands, environmental quality deteriorates in resource-rich economies. In contrast, green technological innovation (GTI), natural capital (NCAP), FDI, and natural resource rent are positively related to environmental performance. This suggests that green innovation, natural capital, FDI inflow, and resource rent are essential in promoting environmental sustainability. Hence, creating additional incentives for green technological innovation can significantly improve its prospects of

Table 3
Benchmark regression results.

EPI	1	2	3	4	5
RED	−0.245	−0.317	−0.146	−0.103	−0.021
	(0.538)	(0.538)	(0.529)	(0.530)	(0.526)
GTI		0.555***	0.067**	0.063*	0.066*
		(0.090)	(0.037)	(0.038)	(0.037)
NCAP			0.080***	0.079***	0.079***
			(0.018)	(0.018)	(0.018)
FDI				0.097	0.107*
				(0.080)	(0.080)
NRR					0.117***
					(0.043)
Constant	2.573	3.070**	4.100***	3.180**	3.834**
	(1.781)	(1.784)	(1.712)	(1.787)	(1.858)
Country time effects	Yes	Yes	Yes	Yes	Yes
Country specific effects	Yes	Yes	Yes	Yes	Yes
Adj R	0.50	0.50	0.52	0.52	0.53
F-statistics	165.41	155.56	188.80	175.34	126.35
Hausman test	45.23***	39.47***	46.21***	36.48***	57.32***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observation	462	462	462	462	462
No of countries	22	22	22	22	22

***p < 0.01, **p < 0.05, *p < 0.1.

reaching net-zero emission objectives in resource-rich economies. Our empirical results align more closely with recent studies (Chen et al., 2022; Zhang et al., 2022), where they argue that green technological innovation and foreign direct investment (FDI) exert a significant impact on environmental performance. These studies emphasize that advancements in green energy technologies have facilitated the widespread adoption of renewable energy sources, including solar, wind, and hydropower, leading to a reduction in carbon emissions from the energy sector.

Furthermore, the empirical results presented in Table 3, derived from fixed effect method is subject to several limitations and critical assumptions. Firstly, fixed effect method may eliminate the effects of time-invariant factors that might not fully explain the observed results. Moreover, while allowing for the assessment of the net impact of determinants on an outcome variable, this approach may not adequately control for the correlation between the error term and control variables. Therefore, we rely on the second-generation econometric methods including slope homogeneity, cross sectional dependency test, cointegration test and panel cointegration. In addition, we used the AMG and CS-ARDL estimator for the long run and short run estimates.

5.3. Main findings

In the panel data analysis, the most important test is examination of cross-sectional dependence and slope homogeneity, the subsequent stage involves evaluating the stationarity of the panel data. The test results of slope homogeneity and cross-sectional dependence shown in Appendix (Table A1 &A2). The test results of slope homogeneity indicate that the probability values for delta "are statistically significant at the 1% significance level. Consequently, we reject the null hypothesis of slope" homogeneity, leading to conclude that the slopes are heterogeneous. This finding is consistent with the core objective of this study, which is to address and account for heterogeneity in these interconnected dynamics. Furthermore, the Pesaran CD-test results also shows the presence of cross-sectional dependencies within the study data. Based on these results, we categorically "reject the null hypothesis of cross-sectional independence in all countries." These findings clearly signify that within the panel data, the presence of cross-sectional dependence has economic implications: a shock in any of the resource-rich countries can ripple through to other member states due to their closely intertwined economic connections. Shocks in one country can reverberate through other member nations.

Consequently, it becomes evident that the data exhibit heterogeneity issues, justifying the use of a second-generation unit root test to evaluate the stationarity properties of the variables and effectively address this concern within the panel dataset. To assess data stationarity, this study employed the Cross-Sectionally Augmented Test of Unit Root (CIPS). In these tests, "the null hypothesis posits the presence of a unit root, while the alternative hypothesis suggests that the data is stationary." The test results shown in Appendix (Table A3). We reject the null hypothesis of a unit root for all the variables. This indicates that all the variables exhibit stationarity at first difference. Furthermore, subsequent to the assessment of data stationarity, the study proceeds to examine cointegration among dependent and independent variables. To investigate long-term cointegration, the Westerlund (2008) test is employed, as shown in Appendix (Table A4). The results strongly rejected the "null hypothesis of no cointegration at 1%, 5%, and 10% significance level, respectively." In other words, these findings provide compelling evidence of a long-run associations between EPI, FDI, RED, GTI, NRR, and NCAP.

Tables 4 and 5 present the outcomes of the long-run and short-run coefficients, respectively. We employing the AMG technique for long-run analysis across all model specifications, it is evident that FDI, NRR, and RED are negatively associated with environmental performance, whereas GTI and NCAP are positively related with environmental performance. This indicates that green innovation and natural capital play a pivotal role in promoting environmental sustainability

Table 4
Results of AMG: Long run coefficients.

EPI	1	2	3	4	5	6	7	8
RED	0.0776***	0.0793***	0.0879***	0.0547***	0.1093***	0.2983***	0.1306***	0.1409***
	(0.0326)	(0.0329)	(0.0418)	(0.0235)	(0.0370)	(0.1118)	(0.0384)	(0.0387)
GTI	0.0382	0.0428***	0.0306***	0.0970***	0.0482***	0.0536***	0.0435*	0.0393***
	(0.1073)	(0.0162)	(0.0164)	(0.0246)	(0.0235)	(0.0200)	(0.0269)	(0.0176)
NCAP	0.2052**	0.0545***	0.2426***	0.0105	0.3479***	0.3186***	0.2557**	0.2291
	(0.1183)	(0.0195)	(0.1277)	(0.1231)	(0.1202)	(0.1200)	(0.1247)	(0.1659)
FDI		−0.0510**						
		(0.0262)						
NRR		0.0962***						
		(0.0319)						
RED × FDI			0.0484***					
			(0.0211)					
GTI × FDI				0.0467***				
				(0.0152)				
NCAP × FDI					−0.1170***			
					(0.0228)			
RED × NRR						−0.0662***		
						(0.0311)		
GI × NRR							0.0427***	
							(0.0191)	
NCAP × NNR								0.0602***
								(0.0277)
Constant	−0.2796***	0.6868***	2.9499***	2.9557***	−2.8079***	0.9782***	0.9029***	4.3247***
	(0.0507)	(0.1050)	(0.5320)	(0.3790)	(0.3945)	(0.1431)	(0.1341)	(0.5599)
Country time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country specific effects	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes

Note: standard error values are reported in parenthesis, ***p < 0.01, **p < 0.05, *p < 0.1.

Table 5
Results of AMG: Short run coefficients.

ΔEPI	1	2	3	4	5	6	7	8
ECT-1	−0.5228***	−0.4743***	−0.4249***	−0.4617***	−0.4371***	−0.4788***	−0.4654***	−0.4612***
	(0.0626)	(0.0611)	(0.0784)	(0.0608)	(0.0646)	(0.0695)	(0.0609)	(0.0600)
Δ RED	−0.0117***	−0.0370***	−0.0534***	−0.0538***	−0.0532***	−0.5540***	−0.4654***	−0.0534***
	(0.0096)	(0.0181)	(0.0166)	(0.0199)	(0.0193)	(0.2661)	(0.0609)	(0.0160)
ΔGTI	1.9769***	2.3756***	2.4681**	2.5184***	2.0228***	1.3164***	0.0322*	1.7664
	(0.9941)	(1.1587)	(1.3120)	(1.2606)	(1.1613)	(0.6794)	(0.0188)	(1.1908)
ΔNCAP	−0.9751***	−0.9028***	−0.6599***	−1.5265	−1.4047***	−0.9646***	2.2817***	−1.1551***
	(0.3821)	(0.2040)	(0.1230)	(1.2666)	(0.6800)	(0.3604)	(1.1337)	(0.6497)
ΔFDI		0.0862***						
		(0.0201)						
ΔNRR		0.0846***						
		(0.0406)						
Δ (RED × FDI)			0.0887***					
			(0.0247)					
Δ (GTI × FDI)				0.0498***				
				(0.0167)				
Δ (NCAP × FDI)					0.0508***			
					(0.0225)			
Δ (RED × NRR)						0.1357**		
						(0.0719)		
Δ (GTI × NRR)							1.0366***	
							(0.0140)	
Δ (GTI × NNR)								0.4290***
								(0.1729)

Note: standard error values are reported in parenthesis, ***p < 0.01, **p < 0.05, *p < 0.1.

across the resource rich countries. These findings aligns with previous studies conducted by Fang (2023); (Kwakwa et al., 2020) and Sharif et al. (2023), which also reported a negative relationship between green technological innovation, natural capital and environment.

In column 2, the coefficient for FDI is −0.0510, indicating that FDI reduces EPI by 5.10% in the long run. Furthermore, in column 3, we introduced an interaction term (RED × FDI), and the coefficient suggests that both RED and FDI jointly have a positive and significant impact on EPI. Similarly, in column 4, the coefficient for the interaction term (GTI × FDI) is 0.0467, indicating that both variables jointly increase EPI, with a "positive and statistically significant impact." Additionally, the coefficients for the interaction terms (NCAP × FDI) in column 5 and (RED × NRR) in Model 6 are −0.1170 and −0.0662, respectively, implying that both interaction terms reduce EPI by 11% and 6.6% in the long run. These interactions have a jointly negative and significant impact on EPI in the long run. On the other hand, in column 7, the coefficient for the interaction term (GTI × NRR) is 0.0427, and in column 8, the coefficient for (NCAP × NNR) is 0.0602. These coefficients indicate that both interaction terms jointly have a positive and statistically significant impact on EPI in the long run. Our findings are more consistent with current studies (Wang et al., 2023a; Zhou et al., 2023).

The short run results are reported in Table 5. In column 2, the coefficient of ECT-1 is −0.4743 and to explain its economic interpretation we used the formula $\frac{1}{\beta ECT-1}$ that is $\frac{1}{-0.4743} = -2.184$, meaning that the equilibrium reaches to its long run path in 2.18 years with a 47% speed of adjustment. The negative coefficients in all column shows there is stable short and long run relationship between study variables. The coefficients for ΔRED and ΔNCAP consistently exhibit negative values across all columns, signifying that, in the short run, both variables have a negative impact on EPI. Conversely, GTI and FDI exhibit positive and statistically significant impacts on EPI in the short run. Furthermore, in column 3, the coefficient for the interaction term Δ (RED × FDI) is 0.0887, and it is statistically significant. This implies that both RED and FDI jointly contribute to an increase in EPI in the short run. Similarly, the coefficients for the interaction terms Δ (GTI × FDI) in column 4, Δ (NCAP × FDI) in column 5, Δ (RED × NRR) in column 6, Δ (GTI × NRR) in column 7, and Δ (NCAP × NNR) in column 8 are 0.0498, 0.0508, 0.1357, 1.0366, and 0.4290, respectively. These values indicate that EPI increases by 4.9%, 5.0%, 13%, and 42% in the short run, respectively, for these interaction terms. In all these cases, the joint impact on EPI is positive and statistically significant in the short run.

These findings are more consistent with recent studies (Chen et al., 2023; Khan et al., 2023). They found that an increase in, FDI, natural resource rent and per capita income is associated with higher carbon dioxide emissions. In summary, our analysis leads us to the conclusion that green innovation and natural capital has a more significant impact on environment in both short and long run.

5.4. Further analysis

In recent empirical studies, the Environmental Performance Index (EPI) has been criticized by many scholars because of the sensitivity of its results depending on the choice of weights (Papadimitriou et al., 2020; Pinar, 2022). To delve deeper into this issue, the present study complements the EPI index with alternative dependent variables that specifically address environmental aspects, such as CO2 emissions and changes in forest area.

Table 5 shows the estimation results featuring alternative dependent variables, namely, CO2 emissions and changes in forest area. Panel (a) of Table 6 presents the long-run coefficient estimates, while Panel (b) provides the short-run coefficient estimates. In the long run, the coefficients associated with RED (presumably regional development), GTI (green technological innovation), and NCAP (natural capital) exhibit a statistically significant negative relationship with carbon emissions and changes in forest area. This implies that, over an extended period, an increase in regional development, green technological innovation, and natural capital is associated with a reduction in carbon emissions and a decrease in the extent of forest area. Conversely, in the short run, the coefficients of RED, NCAP, and FDI are positively correlated with both carbon emissions and changes in forest area. While FDI does not have a significant impact on changes in forest area in the long run, NNR has a significant positive impact on both CO2 emissions and changes in forest area. Furthermore, the coefficient of the error correction term (ECT-1) is negative and significant, indicating a long-run as well as short-run association between the study variables. These results are more align with the recent studies (Bergougui, 2024; Fang et al., 2024). They argued that consistent and effective utilization of foreign investment play a significant role in reducing carbon emissions within the context of carbon peaking and carbon neutrality strategies. In addition, the upgrading of green technology innovation act as intermediary mechanisms through which the stability of FDI contributes to a reduction in carbon emissions.

5.4.1. Non-linear relationships and threshold effects

In recent studies, various aspects support the existence of a non-linear relationship between regressors and environmental performance (Alola and Rahko, 2024; Gao et al., 2024). On one hand, the impact of natural resource rent, FDI, and GTI may differ above a certain threshold compared to below it. On the other hand, several resource-dependent countries, such as certain Persian Gulf and Nordic countries, illustrate examples where natural resources, foreign direct investment inflows, and technological innovation serve as sources of economic progress. According to the Gao et al. (2024), resource rich countries heavily rely on revenue from natural resources for substantial economic advancement. Conversely, some countries experience FDI inflows and GTI as the primary sources of economic progress. This dynamic is directly and indirectly linked to the environmental performance of countries. This argument suggests that the relationship between FDI, natural resource rent, and GTI exhibits a non-linear relationship and threshold effect. However, to check threshold effect of study variables on the outcome variables, we applied the threshold effect test as shown in Appendix (Table A5). We estimate our benchmark regression model using both single and double thresholds. The resulting estimates reveal two significant thresholds, namely FDI and GTI, with the respective threshold values reported in Appendix (Table A6). The single threshold for GTI occurs at a value of 9.54, while for FDI, it is 10.4. Similarly, the double thresholds for GTI and FDI are 13.12 and 12.55 points, respectively. These findings suggests that FDI and GTI are the variables that present significant thresholds. The estimated results of threshold regression model are presented in Tables 7 and 8.

Table 7 presents the estimated results of the single threshold regression model. In Model 1, where the threshold variable is GTI, we observed a positive impact on environmental performance both before and after the threshold. However, there is a difference in intensity before and after the threshold. In Model 2, with the threshold variable set as FDI, we found a positive impact before and after the threshold. All other variables have a positive impact, except for RED, which has a negative impact on environmental quality. This implies that changes or variations in RED are associated with a detrimental effect on the environment.

Table 6
Estimation results with alternative dependent variables.

	CO2 emissions			Changes in forest area		
	Coefficient	Std. errs.	z-statistics	Coefficient	Std. errs.	z-statistics
(a) Long run coefficients						
RED	−0.0242***	0.0034	−7.1862	−0.172***	0.036	−4.841
GTI	−0.0349***	0.0130	−2.6846	−0.064***	0.031	−2.065
NCAP	−0.0585***	0.0191	−3.0628	−0.013	0.012	−1.049
FDI	0.0271***	0.0116	2.3337	0.017	0.054	0.307
NRR	0.0385***	0.0152	2.5242	0.070*	0.039	1.794
(b) Short run coefficients						
ECT-1	−0.2104***	0.0683	−3.0787	−0.165***	0.039	−4.178
ΔRED	0.0106***	0.0012	8.8667	0.056***	0.016	3.511
ΔGTI	−0.0426***	0.0143	−2.9832	−0.055***	0.016	−3.411
ΔNCAP	0.0179	0.0135	1.3259	0.062***	0.014	4.581
ΔFDI	0.0566***	0.0159	3.5580	0.025**	0.013	1.958
ΔNRR	−0.0920***	0.0150	−6.1211	−0.029**	0.017	−1.771
Constant	0.0466	0.0661	0.7047	1.885	1.241	1.519

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 7
Single Threshold model regression results.

Model 1: Threshold GTI	Coefficient	Model 2: Threshold FDI	Coefficient
GTI<9.54	0.1810*** (0.0840)	FDI<10.4	0.5310*** (0.1280)
GTI>9.54	0.2530*** (0.0110)	FDI>10.4	0.4730*** (0.0160)
RED	−0.6907*** (0.0181)		−0.5190*** (0.0120)
GTI			0.7970*** (0.0160)
FDI	0.0218*** (0.0107)		
NCAP	0.0385*** (0.0151)		0.4280*** (0.2020)
NRR	0.6246*** (0.0411)		0.5270*** (0.0120)
Constant	1.8467*** (0.1189)		1.6826*** (0.1972)
Obs.	462		462
Countries	22		22
Adjusted R	0.62		0.64

***p < 0.01, **p < 0.05, *p < 0.1.

Table 8
Double threshold model regression results.

Model 1: Threshold GTI	Coefficient	Model 2: Threshold FDI	Coefficient
GTI<9.54	0.2490*** (0.0160)	FDI<10.4	0.5410*** (0.2710)
13.12<GTI<9.54	0.5720*** (0.1840)	12.55<FDI<10.4	0.6120*** (0.2750)
GTI ≥ 9.54	0.4580*** (0.0220)	FDI ≥ 10.4	0.6270*** (0.2810)
RED	−0.5897*** (0.0271)		−0.4216 (0.2841)
GTI			0.5908 (0.0727)
FDI	0.0692** (0.0354)		
NCAP	0.4109*** (0.0341)		0.4097*** (0.0411)
NRR	0.4946*** (0.1805)		0.6202 (0.4694)
Constant	4.0622*** (2.2140)		2.9007** (1.5697)
Obs.	462		462
Countries	22		22
Adjusted R	0.59		0.61

***p < 0.01, **p < 0.05, *p < 0.1.

Similarly, the estimated results of doubled threshold regression models are reported in Table 8. The coefficients of doubled threshold GTI and FDI are same as Table 7.

5.4.2. Sensitivity analysis: pre- and Post-2008 financial crisis

Moreover, we extend our empirical results to examine the impact of the 2008 financial crisis on environmental performance in resource-rich economies. Table 9 presents the empirical results both before and after the crisis. The estimated coefficients and intensity of variables are different for both periods. The coefficient of RED is positive in the long run before the 2008 financial crisis, but it becomes significantly negative in the post-2008 financial crisis period. Similarly, the coefficient of FDI is negative before the 2008 financial crisis, while it is positive and significant after the crisis. Likewise, the short-run coefficients of RED and NNR are significantly negative before the 2008 financial crisis but turn positive and significant after the crisis. The negative and significant sign of the error correction term indicates the presence of a long-run and short-run equilibrium relationship among the study variables.

Table 9
Pre- and post-2008 financial crisis.

	Pre-2008 financial crisis			Post-2008 financial crisis		
EPI	Coefficient	Std. errs.	z-statistics	Coefficient	Std. errs.	z-statistics
(a) long run coefficients						
RED	0.177***	0.028	6.230	−0.982***	0.405	−2.425
GTI	0.031***	0.014	2.235	0.044***	0.019	2.284
NCAP	0.046***	0.019	2.426	0.054***	0.015	3.718
FDI	−0.064***	0.011	−5.722	0.717***	0.133	5.388
NRR	−0.034***	0.007	−5.124	0.078***	0.011	7.344
(b) Short run coefficients						
ETC-1	−0.215***	0.057	−3.764	−0.327***	0.112	−2.931
ΔRED	−0.033***	0.012	−2.839	0.037	0.243	0.152
ΔGTI	0.021*	0.013	1.652	0.046***	0.018	−2.477
ΔNCAP	0.031*	0.018	1.774	0.031*	0.017	1.785
ΔFDI	−0.075***	0.027	−2.820	0.023	0.151	0.150
ΔNRR	−0.077***	0.014	−5.445	0.260***	0.101	2.569
Constant	1.598***	0.659	2.427	−3.408	4.342	−0.365

***p < 0.01, **p < 0.05, *p < 0.1.

5.5. Robustness check

5.5.1. Subsample analysis

To assess the robustness of the pre-defined empirical model in explaining the relationships among the study variables, this study employed a decomposition of the entire sample into subgroups, distinguishing between oil-rich and non-oil resource-rich economies. In this robustness check, we utilized the CS-ARDL as an alternative method. The outcomes of this analysis, both in the long run and short run, are summarized in Table 10. These results are validated by the estimated results of AMG test. The long run estimates of CS-ARDL show that 1% increase in RED and FDI leads to reduce EPI by 0.3420% and 0.5371% respectively. On the other hand, in the short run RED, NCAP, and FDI have negative effect on EPI in Oil resource rich countries. Meanwhile, in non-oil rich countries only RED has negative effect on EPI in the long run, while in the short run RED and NCAP both have negative effect on EPI. The error correction mechanism of CS-ARDL shows that, in all the models we can see that it converges to its equilibrium path in the long run, because the coefficient of ECT-1 is statistically significant and negative. The findings revealed that in non-oil resource rich countries, environmental performance is far better than that of Oil resource rich countries.

The robustness results of AMG indicate similar outcome with CS-ARDL outcome. All parameters' directions are same in the long run except RED and FDI in AMG test and statistically significant. On the other hand, both RED and NCAP have negative direction in AMG and CS-ARDL models in the long run with statistically significant parameters.

5.5.2. Robustness of results using alternative method and proxies

Moreover, to ensure the robustness of our findings, the current study employed alternative methods, such as the Driscoll-Kraay estimator, and alternative proxy variables were utilized to estimate our benchmark regression model. We employed two alternative dependent variables, namely carbon emissions and the change in forest area, along with one alternative proxy for the dependent variable, the inclusive wealth index. This supplementary analysis aims to assess the consistency and reliability of our results. The estimated findings are presented in Table 11. The findings revealed that RED is positively related with carbon emissions and forest area change. The positive significant relationship between regional development, forest area changes and carbon emissions suggest that as regional development increases, so does the level of carbon emissions. This relationship attributed to several factors such as industrialization, energy consumption, transportation, land use and consumption patterns etc. While, GTI is significant negative related with carbon emission and forest area change. The negative and significant relationship between green technological innovation and carbon

Table 10
CS-ARDL Analysis (long-run and short-run results).

(A) Long -run Results						
	Whole sample countries		Oil resource rich countries		Non-oil resource rich countries	
EPI	1	2	3	4	5	6
RED	0.3559***	0.4074***	−0.3420***	−0.4257***	−0.5489***	−0.5995***
	(0.0196)	(0.2052)	(0.1222)	(0.1323)	(0.1691)	(0.2591)
GTI	0.5523***	0.3151***	0.3468***	0.6679***	0.2882***	0.7009*
	(0.2083)	(0.0270)	(0.1762)	(0.0436)	(0.1152)	(0.4418)
NCAP	0.7752***	0.4376***	0.3701***	0.7089***	0.5607*	0.3176***
	(0.0243)	(0.1324)	(0.1818)	(0.3086)	(0.3199)	(0.1215)
FDI		0.6473**		−0.5371***		0.4360***
		(0.3390)		(0.0436)		(0.0714)
NRR		0.5341***		0.7429***		0.3844***
		(0.2206)		(0.0673)		(0.1983)
(B) Short- run Results						
ECT-1	−0.8048***	−0.9702***	−0.2519***	−0.9346***	−0.8496***	−0.3764***
	(0.0996)	(0.0818)	(0.1168)	(0.1067)	(0.1744)	(0.1258)
ΔRED	−0.2439	−0.2899**	−0.4857***	−0.5088***	−0.6760**	−0.7175***
	(0.1900)	(0.1682)	(0.2263)	(0.1097)	(0.3536)	(0.3268)
Δ GTI	0.4108***	0.3780***	0.4418*	0.6561*	0.7145***	0.3450***
	(0.0790)	(0.1409)	(0.2408)	(0.3688)	(0.2466)	(0.0320)
ΔNCAP	0.6385***	0.4030***	−0.7629***	−0.8733***	−0.5950***	−0.2735***
	(0.1087)	(0.1940)	(0.1246)	(0.2571)	(0.2956)	(0.1639)
ΔFDI		0.0321***		−0.0386***		0.0768***
		(0.0125)		(0.0104)		(0.0157)
ΔNRR		0.2498***		0.0624***		0.3574***
		(0.1228)		(0.0177)		(0.2077)
CSD Statistics	**0.635**	**0.429**	**0.831**	**0.732**	**0.837**	**0.465**
	(0.3380)	**(0.9160)**	**(0.4092)**	**(0.3791)**	**(0.4181)**	**(0.2469)**

Note: standard error values are reported in parenthesis, ***p < 0.01, **p < 0.05, *p < 0.1.

Table 11
Results of Driscoll-Kraay estimator.

	CO2 emissions		Changes in forest area	
	Coefficient	std. errs.	Coefficient	std. errs.
RED	0.085***	(0.015)	0.093***	(0.037)
GTI	−0.035***	(0.017)	−0.048***	(0.019)
TW	−0.026***	(0.013)	−0.061***	(0.028)
FDI	0.078	(0.045)	0.308	(0.186)
NRR	−0.109***	(0.025)	0.321***	(0.015)
Constant	9.572***	(0.803)	2.839**	(1.444)

Notes: TW represent the Inclusive Wealth Index, which includes human and produced capitals alongside natural capital. Drisc/Kraay standard errors are reported in parenthesis. ***p < 0.01, **p < 0.05, *p < 0.1.

emissions, as well as forest area change, implies that an increase in green technological innovation is associated with a decrease in both carbon emissions and changes in forest area. This relationship reflects the positive environmental impact of adopting and implementing green technologies. Hence, negative and significant relationship underscores the potential of green technological innovation as a crucial component of sustainable development and environmental conservation efforts. The coefficient of inclusive wealth (TW) is negative in both models. The negative and significant relationship suggests that an increase in inclusive wealth is associated with a decrease in both carbon emissions and changes in forest area. This implies that inclusive wealth considers not only economic aspects but also incorporates natural and human capital. Regions or countries with a focus on inclusive wealth may adopt sustainable development practices that prioritize environmental conservation, leading to reduced carbon emissions and forest-area change. Hence, this relationship aligns with the idea that sustainable development should address economic, social, and environmental dimensions concurrently for long-term prosperity. The coefficient of FDI is positive but insignificant. The coefficient of NNR is negatively related with CO2 emissions while it significant positive with changes in forest area. A negative relationship between natural resource rent and carbon emissions suggests that as the income generated from natural resources increases, carbon emissions decrease. The coefficient of NRR is positive with changes in forest area. This implies that an increase in income from natural resources is associated with a net expansion or positive change in forested areas. The empirical findings are aligned with the recent studies (Li et al., 2024; Nkoa et al., 2024). The studies argued that there are several factors that can contribute to this positive association such as natural resource rents may allocate a portion of these revenues to conservation initiatives, substantial natural resource rents may invest in sustainable forestry practices and natural resource rents may implement policies to protect and expand forested areas.

6. Discussion and conclusion

Over the past two decades, researchers globally have conducted extensive investigations into the numerous factors contributing to environmental degradation, encompassing its causes, consequences, determinants of pollution, and the economic impacts of environmental contamination. Within the existing body of literature, numerous studies and policy reports have illuminated the relationship between energy consumption, urbanization, foreign direct investment, economic growth, trade openness, industrialization, and globalization in the context of environmental sustainability. These factors play a crucial role in environmental quality and sustainable development (Ahmed and Wang, 2019; Chandio et al., 2023). On one hand, the expansion of economic activities contributes to social and economic development; on the other hand, it directly affects the state of the environment (Ibrahim et al., 2022). However, the United Nations (UN) and the global international community are making efforts toward designing a sustainable framework for development. The United Nations Sustainable Development Goals (SDGs), specifically SDG-7 and SDG-13, emphasize addressing climate change, protecting natural resources, and promoting sustainable consumption for comprehensive development. The theoretical and empirical aspects of the linkages between the environment and growth are explained through modern theories, including the theory of ecological modernization, Karl Marx's theory of ecology, energy efficiency theory, sustainable development theory, and green growth theory. These theories aim to offer economic, social, political, and environmental solutions for the protection of the environment and sustainable development. The most recent empirical studies emphasized that technological innovation facilitate a shift from current linear systems of production and consumption(Luo et al., 2023; Wang, 2023). Similarly, trade inflows and foreign direct investment, natural resource rent, natural capital and regional development influence the environmental performance (Liu et al., 2018; Xu et al., 2023).

This study aims to explore the relationship between green innovation, natural resource rent, foreign direct investment (FDI), with the moderating roles of regional development and natural capital, in addition to their impact on environmental quality. Previous studies have often overlooked the significance of natural capital and regional development, especially in the context of resource-rich countries. To address this literature gap, our study investigates the connections between environmental performance, FDI, natural resource rent, and green innovation, considering the moderating influences of regional development and natural capital across twenty-two oil and non-oil resource rich countries, during the period 2002–2022. Data were sourced from three main databases: World Development Indicators, Yale University, and the OECD database.

In our empirical analysis, we applied standard econometric techniques. Initially, we conducted a "cross-sectional dependence test, which revealed a strong cross-sectional dependence among the variables within the sample countries. After confirming this cross-sectional dependence," we proceeded to employ the Westerlund cointegration tests. These cointegration tests yielded positive results, affirming the existence of cointegration among the selected variables. With cointegration established among the variables, we then examined the long-term relationship among them using the Augmented Pooled Mean Group (AMG) estimator. As an additional method to validate the robustness of our findings, we also employed the cross-sectional autoregessive distributed lag (CSARDL) model.

The long-run findings revealed that regional development, green technological innovation, natural capital, and natural resource rent have positive effects on environmental performance, while foreign direct investment negatively affects environmental performance. The green innovation and natural resources significantly promote environmental performance. Our empirical results are more consistent with the prior literate (Ali et al., 2022, 2023; Wang et al., 2022). The studies argued that positive environmental impact associated with the adoption and implementation of green technologies. Therefore, green technological innovation, FDI inflows and natural capital as a vital component of sustainable development and environmental conservation efforts in the long run. Conversely, regional development and natural capital are negatively related with environmental performance, while FDI has positive significant impact on environmental performance in the short run. Furthermore, non-linear threshold regression results show there is threshold effect from the green innovation and FDI. The findings are more consistent with the study of Alvarado et al. (2022). The study argued that FDI and technological innovation has threshold effects on environmental quality. In addition, the pre and post 2008 financial crisis, the effects are varying before and after crisis in term of intensity and magnitude. In addition, to check the model robustness, we used the CS-ARDL estimator and alternative proxy variables. The outcomes aligned with those obtained using AMG estimator. This study findings offers significant empirical insights into the influence of FDI, natural resource rent, green innovation, regional development and natural capital on environmental performance within the resource rich economies. The findings and policy recommendations presented in this study can offer valuable guidance to these countries in improving environmental quality and advancing environmental sustainability through the promotion of green innovation and natural capital. Drawing from the study's results, "we propose the following policy measures for governments and policymaking bodies to address environmental challenges in resource rich countries."

First, governments should proactively promote and implement green innovation strategies, fostering an environment that encourages innovative approaches at both the central and local levels. Second, invest in research and development to foster green innovation. This can be achieved through partnerships between government agencies, research institutions, and private enterprises to develop and implement eco-friendly technologies. Third, encourage foreign investors to engage in environmentally sustainable practices including investments in green technologies, renewable energy, and environmentally friendly projects. Fourth, strengthen environmental regulations and enforcement mechanisms to ensure that FDI projects adhere to sustainable practices. This includes strict emissions controls, waste management standards, and penalties for non-compliance. Fifth, collaborate with other nations to share best practices, technologies, and experiences in achieving environmental sustainability through FDI. Finally, governments should prioritize the conservation and sustainable management of their natural resources, often referred to as natural capital. This includes safeguarding forests, water sources, biodiversity, and ecosystems that contribute to a nation's long-term environmental health.

This study has some limitations; First, this study has explored the relationship between FDI, natural resource rent, green innovation, regional development, natural capital and environmental performance within the resource rich countries. Future research endeavors could extend this inquiry to diverse regions that could offer valuable insights. Secondly, due to the absence of data, we used few variables. The relationship between FDI, natural resource rent, and environmental performance may be endogenous. Further study can be extended by using instrumental variable approaches or two-stage least squares (2SLS) could be used to address potential endogeneity. Furthermore, there might be other factors affecting environmental performance that are not considered. The study can be extended by considering more variables such as green financing strategies, green bounds, green credit and environmental taxes on the environmental performance.

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CRediT authorship contribution statement

Thi Hao Nguyen: Conceptualization, Formal analysis, Investigation. **Hongbing Deng:** Supervision, Validation. **Zainab Zahra Abbas:** Software, Visualization. **Thi Thoa Lam:** Writing – review & editing. **Hussain Raza Abbas:** Software, Writing – review & editing.

Declaration of competing interest

The authors assert that they do not have any known financial interests or personal relationships that could be perceived as influencing the work reported in this paper.

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Data availability

Data will be made available on request.

Appendix-A

Table A1Results of slope homogeneity

Test	△	$△^{adj}$
Pesaran, Yamagata. (2008)	15.081*** (0.000)	21.913*** (0.000)
Blomquist, Westerlund. (2013)	13.808*** (0.000)	20.063*** (0.000)

H0: slope coefficients are homogenous, ***p < 0.01, **p < 0.05, *p < 0.1.

Table A2
Cross-sectional dependence test results

Variable	CD	p-value
EPI	3.521	0.000
FDI	2.128	0.000
NRR	31.493	0.000
RED	39.264	0.000
GTI	2.748	0.000
NCAP	81.207	0.000

Table A3
CIPS unit root test

Variable	Level		First difference		
	Intercept	Intercept & trend	Intercept	Intercept & trend	
EPI	−0.779	−1.827	−3.435***	−4.270***	I [1]
FDI	−1.575	−2.016	−3.433***	−3.753***	I [1]
NRR	−1.267	−1.356	−2.630***	−2.716***	I [1]
RED	−2.551**	−2.615**	–	–	I [0]
GTI	−1.007	−1.146	−2.124***	−2.470***	I [1]
NCAP	−1.125	−1.448	−5.019***	−5.035***	I [1]

***p < 0.01, **p < 0.05, *p < 0.1.

Table A4
Results of Westerlund panel co-integration test

Test	Test statistics	Probability
G_t	−2.618***	(0.077)
G_a	−2.732**	(0.062)
P_t	−2.683*	(0.034)
P_a	−3.735**	(0.055)

Note: (.) shows the probability values.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A5
Threshold Effect test

Threshold variables	Threshold effect	F-statistics	Prob.	Critical values		
				1%	5%	10%
RED	Single	18.22	0.37	46.84	33.26	25.43
	Double	3.80	0.94	44.69	26.48	20.8
GTI	Single	161.52**	0.00	112.84	78.67	61.37
	Double	65.27**	0.07	82.73	69.46	54.71
NCAP	Single	52.75	0.39	144.67	116.28	89.72
	Double	8.27	0.82	37.24	28.19	24.33
FDI	Single	84.15**	0.04	88.46	64.17	57.91
	Double	57.46**	0.03	25.16	21.75	18.17
NRR	Single	37.98	0.16	51.26	42.37	39.04
	Double	14.21	0.13	22.74	19.37	17.27

***p < 0.01, **p < 0.05, *p < 0.1.

Table A6
Threshold point values

Variables	Model	Threshold values	Interval	
			Lower	Upper
RED	Th-1	2.69	2.69	2.71
	Th-21	2.64	2.64	2.66
	Th-22	2.89	2.84	2.90
GTI	Th-1	13.12	4.10	4.14
	Th-21	11.50	3.45	3.57
	Th-22	9.54	3.51	3.60
NCAP	Th-1	8.52	9.27	9.31
	Th-21	7.72	9.32	9.47
	Th-22	9.53	11.74	12.71
FDI	Th-1	10.40	4.50	5.51
	Th-21	12.55	4.60	6.10
	Th-22	11.64	3.90	4.70
NRR	Th-1	9.24	4.75	4.96
	Th-21	10.11	5.17	5.12
	Th-22	8.27	4.19	4.49

Appendix-B

List of countries

Country Name	Resources	NRR	NCAP	HCAP	RED
Mongolia	Non-oil rich	26.7	24.8	24.6	4.9
Papua New Guinea	Non-oil rich	22.2	25.5	25.3	
Azerbaijan	Oil-rich	19.4	25.9	24.9	1.7
Kazakhstan	Oil-rich	23.1	27.1	27.3	
Russian Federation	Oil-rich I	13.6	29.3	29.6	
Bolivia	Non-oil rich	19.9	25.3	26.1	2.4
Chile	Non-oil rich	28.8	26.8	28.2	
Guyana	Non-oil rich	28.5	23.9	23.5	
Suriname	Non-oil rich	16.9	23.8	22.9	
Trinidad and Tobago	Oil-rich	15.1	24.2	25.5	
Venezuela, RB	Oil-rich	23.5	27.5	28.6	
Iraq	Oil-rich	28.0	28.1	26.9	3.5
Kuwait	Oil-rich	23.5	27.9	26.8	
Oman	Oil-rich	24.4	26.3	26.4	
Qatar	Oil-rich	16.1	27.3	26.7	
Saudi Arabia	Oil-rich	12.9	29.3	28.4	
UAE	Oil-rich	14.0	28.1	28.3	
Chad	Oil-rich	24.6	25.0	24.8	4.0
Gabon	Oil-rich	30.1	25.1	24.3	
Mauritania	Non-oil rich	27.2	24.0	24.3	
Togo	Non-oil rich	17.5	23.3	24.7	
Zambia	Non-oil rich	33.2	25.5	26.0	

Note: NRR, NCAP, HCAP and RED stand for natural resource rent, natural resource capital, human capita and regional development, respectively. In the dataset, the values for certain years were entirely missing. To address this data gap, we applied the interpolation method to calculate and fill the missing values.
Source: Author calculated based on World bank data 2022. The data on NCAP and HCAP has been taken form the World Bank report on the changing wealth of nations 2021. The values show average of entire sample period (2002–2022)

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