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Sustainable development goals and environmental performance: Exploring the contribution of governance, energy, and growth

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ABSTRACT

This study investigates the impact of renewable and non-renewable energy consumption, governance quality, and economic growth on environmental sustainability across frontier, emerging, and developed economies from 2001 to 2021. The Environmental Performance Index (EPI) and Sustainable Development Goals (SDGs) are environmental sustainability measures. The study addresses potential endogeneity issues through advanced econometric techniques and explores the differential impacts of energy sources, governance structures, and economic factors on environmental performance. The findings reveal significant variations in how these factors influence environmental sustainability across frontier, emerging, and developed economies. The results demonstrate a positive relationship between renewable energy consumption and governance quality with environmental sustainability, while non-renewable energy consumption exhibits a negative association. Economic growth emerges as a crucial factor influencing both environmental performance and the advancement of SDGs. This research contributes to the expanding literature on environmental sustainability by presenting a comprehensive analysis of its determinants across different economic contexts. The findings provide valuable insights for policymakers, underscoring the importance of tailored approaches to energy policy, governance reforms, and economic development strategies in the pursuit of environmental sustainability goals.

1. Introduction

In the contemporary landscape of global challenges, environmental sustainability has emerged as a paramount concern at the intersection of ecological preservation, social equity, and economic viability. Environmental sustainability denotes the responsible and

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judicious use of natural resources to meet the needs of the present without compromising the ability of future generations to meet their own needs. As the world grapples with escalating environmental threats, from climate change and biodiversity loss to pollution and resource depletion, fostering sustainable practices has never been more urgent. The significance of environmental sustainability extends beyond the realm of environmental science and policy; it resonates with fundamental principles of ethical stewardship, social responsibility, and economic resilience. At its core, the pursuit of environmental sustainability aims to strike a delicate balance between human activities and the delicate ecosystems that support life on Earth.

The international community has not adequately addressed large-scale environmental issues, including climate change and global warming, and there are significant disparities in environmental performance across communities (Bagh et al., 2024; Hsu and Zomer, 2016). According to the Intergovernmental Panel on Climate Change (IPCC), high risk will arise at a temperature increase of 1.1–3.6° C above pre-industrial levels (O'Neill et al., 2017). Even though climate change is a concern for all countries, responses to this problem vary greatly. Corruption, democracy, political stability, and diverse political institutions have been stressed in the literature, explaining the climate change pattern and other environmental policies (Congleton, 1992; Grooms, 2015; Oliva, 2015). Environmental economics literature employs numerous environmental and ecological indicators to quantify environmental impacts, including ecological footprints (Balsalobre-Lorente et al., 2023; Sharif et al., 2020), air and water pollutant emissions (Chishti and Sinha, 2022; Jabeen et al., 2023), and particulate matter and energy consumption (Damrah et al., 2022; Destek and Sinha, 2020). Nevertheless, the indicators above merely considered the environmental dimension and overlooked the economic aspect of sustainability (Ahmad and Satrovic, 2023).

Sustainable development and environmental performance are critical components of modern economic growth (Bagh et al., 2023; Hunjra et al., 2022; Khan et al., 2024). The need for sustainable development has become increasingly urgent due to pressing global challenges such as environmental degradation and climate change. Recent research has explored various aspects of this topic, including the quality of governance concerning preventing natural catastrophes (Persson and Povitkina, 2017), public goods like water quality (Povitkina and Bolkvadze, 2019), pollution indicators (Welsch, 2004), and corruption pollution (Cole, 2007). Studies have also shown that nations with high-quality governance often achieve elevated levels of economic growth (ECG), making it challenging to separate the impact of governance from economic progress (Povitkina and Matti, 2021). In the realm of energy usage, researchers have contributed extensively to the literature (Achuo et al., 2022; Azam et al., 2023; A. Azam et al., 2021; Cai et al., 2018; Chen et al., 2021; Jian et al., 2019; Le, 2020; Nguyen and Ngoc, 2020; Saldivia et al., 2020). Additionally, Adeel-Farooq et al. (2023) found that financial development positively affects the Environmental Performance Index (EPI) in five developing ASEAN countries, while Lee and Olasehinde-Williams (2024) indicated a positive relation between economic complexity and EPI in OECD countries. Lv et al. (2024) found that natural resources have a significant negative effect on EPI. Morse (2018) investigated EPI component indicators with GDP/capita and Gini coefficient variables, and Yap et al. (2023) found a positive link between financial inclusion and sustainable development. Khan et al. (2022) showed that the energy trilemma and transformative energy developments simultaneously improve economic growth and environmental sustainability. The existing body of literature underscores the need for an integrated approach that considers governance, energy use, economic growth, and other critical factors in achieving sustainable development and enhancing environmental performance.

While existing research has explored various dimensions of environmental sustainability, there is a notable gap in the literature regarding the comprehensive and integrated analysis of the interplay between Sustainable Development Goals (SDGs), EPI, energy, governance, and economic growth. Previous studies have often focused on individual aspects or limited combinations of these factors without providing a holistic understanding of their interconnected dynamics. For instance, research on the relationship between quality of governance, energy use, and environmental sustainability is limited to various elements of the quality of government (Adeel-Farooq et al., 2023; Azam et al., 2023; Kulin and Johansson Sevä, 2019; Povitkina and Matti, 2021) without further research on the conceptual links between these elements and the overarching concept. Future research is needed to explore and explain how the quality of government and energy use affect environmental sustainability efforts directly and indirectly (Povitkina and Matti, 2021).

Exploring the relationship between SDGs, EPI, energy, governance, and growth is crucial for several reasons. Firstly, understanding these interconnections is essential for developing effective policies that simultaneously address multiple global challenges. The SDGs provide a comprehensive framework for sustainable development, and achieving them requires a holistic approach that considers environmental, economic, and governance factors. By examining how these factors interact, we can identify synergies and trade-offs that can guide policymakers in designing more effective and integrated strategies. Secondly, the quality of governance plays a pivotal role in successfully implementing sustainable development initiatives. Good governance ensures that policies are effectively enforced, resources are efficiently allocated, and stakeholders are adequately engaged. By investigating the impact of governance quality on environmental performance and the pursuit of SDGs, we can provide insights into how governance structures can be strengthened to support sustainable development. Thirdly, energy use is a critical component of both economic growth and environmental sustainability. The transition to renewable energy sources is essential for reducing greenhouse gas emissions and mitigating climate change. However, this transition must be managed in a way that supports economic growth and social development. By analyzing the relationship between energy use, environmental performance, and economic growth, we can provide valuable insights into how to achieve a sustainable energy transition. Lastly, economic growth is a key driver of both environmental degradation and sustainable development. Understanding how economic growth influences environmental performance and the achievement of SDGs is crucial for developing sustainable economic models. By examining these relationships, we can identify pathways for achieving economic growth that is both inclusive and environmentally sustainable.

Considering this, we examine the relationship between SDGs, EPI, renewable non-renewable energy, good governance, and economic growth in a sample of frontier, emerging, and developed economies. The novelty of this research lies in its holistic approach, which considers the multifaceted interactions between these critical factors. By examining these relationships, the study seeks to provide valuable insights into achieving sustainable development and enhancing environmental performance. Specifically, the study utilizes the EPI[5] 2022, incorporating 40 performance markers across 11 issue areas to rank 180 nations. This data-driven perspective, pioneered by (Hsu and Zomer, 2016), goes beyond the conventional focus on carbon dioxide (CO2) emissions, offering a holistic assessment of nations' success in addressing climate change, environmental health, and ecosystem vitality. The EPI recognizes environmental leaders and laggards and assesses how close nations are to meeting their national environmental policy objectives. Furthermore, this study incorporates a country's SDG Index score and goal scores, aligning with the Sustainable Development Solutions Network (SDSN) and Bertelsmann Stiftung's annual SDG Index and Dashboards. Unlike past studies that often focused on individual goals, such as GDP/GNI as a proxy for sustainable development, our approach provides a more comprehensive understanding of the broader spectrum of SDGs.

In a methodological innovation, the study classifies the sample based on the FTSE Country Classification, creating three distinct panels representing different stages of economic development and governance structures. This classification includes Frontier Economies, Emerging Economies, and Developed Economies, offering a nuanced analysis tailored to each group's unique characteristics. The adoption of various regression models ensures robustness and reliability in the analysis.

The study's key findings underscore the substantial impact of good governance and the utilization of renewable energy on environmental performance and the pursuit of SDGs. This influence is more pronounced in developed countries, followed by emerging nations and then frontier countries. Furthermore, the study identifies gross domestic investment and primary energy usage as significant hindrances to environmental performance. Lastly, economic growth emerges as a critical factor influencing both environmental performance and the progression of SDGs.

This research significantly contributes to the existing literature by investigating the impact of governance quality, primary energy use, renewable energy use, economic growth, and gross domestic investment on sustainable development and environmental performance. Firstly, it adds to the body of knowledge by exploring the influence of these factors on sustainable development, shedding light on their nuanced roles. Secondly, it examines the impact of the same factors on environmental performance, providing comprehensive insights into their effects on ecological outcomes. The findings of this study hold paramount importance for policymakers and practitioners worldwide who are dedicated to promoting sustainable development and enhancing environmental performance in their respective countries.

The structure of the remaining sections in this study is outlined as follows: Section (2) presents the theory and hypothesis development, while Section (3) details the data and methodology. Following that, Section (4) conducts an in-depth empirical analysis. Finally, the study's conclusions are provided in Section (5).

2. Literature review and theoretical framework

Environmental sustainability has become a critical intersection of ecological preservation, social equity, and economic viability in the contemporary global landscape. This concept denotes the judicious use of natural resources to meet present needs without compromising the ability of future generations (World Commission on Environment and Development, 1987). Amid escalating environmental challenges such as climate change, biodiversity loss, and pollution, the imperative for sustainable practices has intensified, resonating with ethical stewardship, social responsibility, and economic resilience principles.

Environmental sustainability requires a collaborative, multifaceted approach involving governments, businesses, communities, and individuals (Bagh et al., 2024; Hunjra et al., 2022, 2023; La Torre et al., 2024). The United Nations SDGs, encompassing 17 interconnected goals addressing diverse global challenges, are a critical guiding framework in this pursuit (Naseer et al., 2024). Measuring progress in environmental sustainability requires robust metrics, and the EPI is a valuable tool for global comparisons. Developed by Yale University and the Centre for International Earth Science Information Network (CIESIN), the EPI assesses a nation's environmental performance across various indicators.

This study investigates the complex interplay between environmental sustainability, energy sources, governance quality, and economic factors across frontier, emerging, and developed economies. By analyzing data from 2001 to 2021, we seek to contribute insights that inform policy decisions and foster responsible practices for harmonious coexistence with the natural environment.

2.1. Energy and sustainability

Energy plays a pivotal role in discussions surrounding sustainability, both as a catalyst for economic activity and a critical driver of environmental issues. The dichotomy between non-renewable (NRE) and renewable energy (RE) sources presents a spectrum of resources with distinct implications for economic growth and environmental sustainability (Aydin, 2019).

In recent years, the environmental challenges associated with fossil fuel use and increasing energy availability have gained prominence, presenting substantial obstacles to curbing energy consumption tied to economic activities. The paradox lies in the low energy intensity improvements amid escalating economic activities, contributing to heightened CO2 emissions and jeopardizing environmental sustainability. Over the past three decades, energy has been a driving force behind socioeconomic development globally, with the International Energy Agency projecting an annual increase of about 1.4 % in primary energy usage for both industrialized and developing nations by 2035 (A. Azam et al., 2021; Nguyen and Ngoc, 2020). The nexus between energy

[5] Detail methodology Sachs et al. (2022) and https://sdgtransformationcenter.org/reports/sustainable-development-report-2024.

consumption and economic growth has been a subject of ongoing debate since the seminal work (Kraft and Kraft, 1978). The literature synthesizes four key hypotheses: The growth hypothesis posits that increased energy usage drives higher economic expansion (Apergis and Payne, 2010; Hasanov et al., 2017). The conservative hypothesis suggests unidirectional causality from economic development to energy utilization (Ozturk et al., 2013). The feedback hypothesis contends that energy usage and economic expansion are interdependent (Belke et al., 2011). The neutrality hypothesis proposes no causality between economic growth and energy consumption (Dogan, 2014).

Research consistently aligns with the notion that energy consumption is a primary driver of environmental degradation (Baloch et al., 2019; Danish et al., 2020; Jian et al., 2019). Fossil fuels, accounting for more than 87 % of energy production and 89 % of global CO2 emissions, significantly contribute to environmental deterioration (Achuo et al., 2022; Le, 2020).

Efforts to counteract rising greenhouse gas emissions have long focused on substituting fossil fuel energy with renewable sources. Extensive studies across various regions consistently demonstrate a negative association between renewable energy and CO2 emissions, underscoring the role of renewables in mitigating environmental impact (Arain et al., 2020; Chien et al., 2023; Khoshnevis and Ghorchi, 2018; Marcantonini and Valero, 2017; Ofori et al., 2023; Sadorsky, 2009; Usman et al., 2023; Wu et al., 2023; Xu et al., 2022). However, a subset of research, particularly in China, suggests a positive impact of renewable energy on emissions (Akadiri et al., 2022; Alola et al., 2022), introducing complexities in understanding this relationship.

Beyond emissions, broader energy-use investigations reveal that renewable energy promotes environmental quality by reducing ecological footprints, while non-renewable energy consumption is linked to environmental deterioration, particularly in net oil-exporting countries (Adekoya et al., 2022). The concept of energy security further complicates the relationship between energy, economic growth, and environmental sustainability. Nawaz and Alvi (2018) identified energy as the key link between social equity, economic growth, and environmental sustainability in Pakistan. Karatayev and Hall (2020) emphasized that understanding energy security is crucial for addressing global climate change, energy supply security, and global economic crises.

Reconciling energy security with economic growth while reducing greenhouse gas emissions presents a significant challenge, particularly for emerging economies (Almeida Prado et al., 2016). Le and Nguyen (2019) found that energy security promotes economic growth across 74 countries from 2002 to 2013. However, Kurniawan et al. (2021) suggested that decoupling economic growth from environmental sustainability requires incorporating composition and technical effects in the energy system. Khan et al. (2022) demonstrated that addressing the energy trilemma (balancing energy security, affordability, and environmental sustainability) while implementing transformative energy initiatives can concurrently enhance both economic growth and environmental sustainability. This finding suggests a synergistic relationship between energy system improvements, economic development, and environmental conservation.

In conclusion, the intricate connections between energy use and environmental sustainability provide valuable insights for informed policy choices aimed at mitigating climate change and promoting sustainable development.

2.2. Governance and sustainability

The term "quality of government" or "good governance" encapsulates a range of normative standards, including inclusivity, accountability, transparency, efficacy, and impartiality, dictating how nations or political bodies should conduct their affairs (Rothstein and Teorell, 2015). This standard serves as a template for the operation of organizations and, when adhered to, promotes a pristine natural environment as a global public good accessible to all. However, environmental degradation is often attributed to market failures and governance failures.

Market failures arising from information asymmetries, principal-agent problems, non-competitive markets, inconsistent time preferences and externalities lead to inefficient allocations of commodities and services in a free market (Bagh, et al., 2024; Hart and Holmstrom, 1987; Hoch and Loewenstein, 1991; Laffont, 2008; Stiglitz, 1998; Tirole, 1988). These failures result from a collective action dilemma, where rational individuals failing to collaborate around a common benefit leads to societally poor consequences (Olson, 1971). Environmental problems' temporal and spatial dimensions make it challenging to assign personal responsibilities, necessitating government intervention through policy measures referred to as "legitimate coercion" to correct market failures (Galletta et al., 2022; Parry et al., 2007).

Private markets are unlikely to provide public goods related to environmental sustainability due to a high risk of externalities (Min, 2015). To secure environmental sustainability, the state needs institutions or "rules of the game" that promote collective action and commitment to sustainability-related public goods and services.

On the other hand, governance failures occur when governments are unsuccessful in correcting market failures and providing public goods. These failures may result from poor implementation processes or low levels of government quality, where decision-makers and public administration lack the capacity or willingness to decide on, implement, monitor, and enforce environmental policies (Howlett, 2019; Povitkina and Matti, 2021). The quality of government indirectly affects the state's capacity for environmental protection, decision-making, and administrative processes. Good governance can influence public support and preferences for governmental interventions. Effective government intervention is essential for guiding actors toward optimal solutions, considering the diverse forms, causes, and potential solutions to environmental problems.

As key actors in sustainable development, governments play a crucial role in enhancing environmental performance through sustainable strategies, policies, and practices. Research by Bose and Khan (2022); (Galletta et al., 2024); Kulin and Johansson Sevä (2019); Mombeuil (2020) explores the challenges and opportunities for governing climate change and sustainable development, highlighting the importance of multi-level governance, policy integration, and stakeholder engagement. Povitkina and Matti (2021) underscore the role of government policies in promoting sustainable development, emphasizing policy coherence, integration, and long-term planning.

Pedersen et al. (2021) delve into the effectiveness of sustainable development strategies implemented by national governments, emphasizing the need for comprehensive strategies engaging various stakeholders. The effectiveness of government is crucial for the wise use of primary energy consumption and the economic growth of any nation, requiring adherence to democratic values, rules and laws, legislative power, and corruption control (Azam et al., 2023). Effective governance and policy integration are imperative for achieving sustainable development and environmental performance at the national level, necessitating the alignment of sectoral policies and strategies, stakeholder engagement, and the integration of environmental considerations into decision-making processes. However, further research could explore the effectiveness of national policies and local governance structures in addressing climate change and promoting sustainable development (Azam et al., 2023). This study examines the government's role in identifying strategies to enhance environmental performance and achieve sustainability goals.

2.3. *Economic growth and sustainability*

The relationship between economic growth and environmental sustainability has been extensively examined, revealing a complex and often paradoxical interplay. While essential for improving living standards and reducing poverty, economic growth can also lead to increased environmental degradation if not managed sustainably. Several empirical studies have delved into this nexus, highlighting key insights and nuances that are crucial for understanding how to balance economic expansion with environmental stewardship.

Hunjra et al., (2022); Hunjra et al., (2022); Hunjra et al. (2023); (Trinh et al., 2022) have explored the economic growth and sustainable development nexus in developing countries. Their findings indicate a significant positive relationship between economic growth and sustainable development, suggesting that as economies grow, there tends to be more investment in sustainable practices and technologies. This positive correlation implies that economic growth can potentially drive environmental sustainability, provided that growth is accompanied by appropriate policy measures that encourage sustainable development.

In the context of ASEAN economies, Adeel-Farooq et al. (2023) studied the relationship between economic growth and the EPI from 2003 to 2016. They found a significant positive relationship between economic growth and environmental performance. This indicates that economic growth, when aligned with environmental policies, can lead to improvements in environmental quality. It highlights the importance of policy frameworks that integrate environmental considerations into economic planning and development strategies.

However, the impact of economic growth on the environment is not universally positive. Alshehry and Belloumi (2015) examined the effect of economic growth, energy consumption, and trade openness on CO2 emissions in Saudi Arabia. Their study revealed that while economic growth contributes to higher CO2 emissions, trade openness can help mitigate this effect by facilitating the adoption of cleaner technologies. This finding underscores the importance of considering the broader economic context and the role of technological advancements in managing the environmental impacts of growth.

Ben Amar (2021) investigated the relationship between CO2 emissions and economic growth in the United Kingdom, providing empirical evidence for the EKC. The EKC hypothesizes an inverted U-shaped relationship between environmental degradation and economic growth, suggesting that CO2 emissions initially increase with economic growth but eventually decrease as the economy matures and adopts cleaner technologies. This finding is significant as it highlights that economic growth does not inevitably lead to greater environmental degradation, provided that growth is managed with a focus on sustainable practices and technological advancements.

In summary, the relationship between economic growth and environmental sustainability is multifaceted and context-dependent. While economic growth can drive investments in sustainable practices and technologies, it also poses significant risks to environmental quality if not managed properly. Effective policy frameworks that promote green technologies, improve energy efficiency and enforce robust environmental regulations are essential to harness the benefits of economic growth while mitigating its adverse environmental impacts.

2.4. *Conceptual framework*

This study is anchored in four primary theoretical frameworks: the growth hypothesis, conservative hypothesis, Environmental Kuznets Curve (EKC) hypothesis, Institutional Analysis and Development Framework, and ecological modernization theory. The growth hypothesis posits that increased energy usage is associated with higher economic expansion, with energy as a crucial input for productivity (Hasanov et al., 2017). This hypothesis suggests that energy consumption is a primary driver of economic growth and environmental degradation. The conservative hypothesis suggests unidirectional causality from economic development to energy utilization, implying that increased economic activities lead to higher energy use and policies for energy reduction may not adversely affect economic growth (Ozturk et al., 2013). This hypothesis underscores the importance of economic growth in driving energy consumption. The EKC hypothesis proposes an inverted U-shaped relationship between economic growth and environmental degradation. Initially, economic growth leads to increased environmental degradation, but beyond a certain level of income, environmental quality improves as societies demand and can afford better environmental protection (Grossman and Krueger, 1995). Institutional Analysis and Development Framework emphasizes the role of institutions in shaping environmental outcomes. Effective governance and policy integration are imperative for achieving sustainable development and environmental performance at the national level, necessitating the alignment of sectoral policies and strategies, stakeholder engagement, and the integration of environmental considerations into decision-making processes (Ostrom, 1990). Ecological modernization theory posits that technological innovation and institutional reforms can reconcile economic growth and environmental protection. This theory suggests that advanced industrial societies can achieve sustainable development by integrating environmental considerations into economic activities (Mol and

Spaargaren, 2000). Drawing from the theoretical and empirical literature and the conceptual model depicted in Fig. 1, the subsequent section will employ comprehensive statistical models for further testing and analysis.

As discussed earlier, the growth hypothesis and conservative hypothesis provide contrasting views on the energy-growth relationship. In the context of our research questions, these hypotheses help us explore how different energy sources might impact both economic growth and environmental sustainability across various economic contexts. The EKC hypothesis suggests a nonlinear relationship between economic development and environmental degradation, which is particularly relevant when examining the interplay between economic growth and environmental performance in countries at different stages of development. The Institutional Analysis and Development Framework guides our investigation into how governance quality affects environmental outcomes, while ecological modernization theory provides a lens through which we can understand how technological progress and policy interventions might lead to improved environmental performance alongside economic growth.

3. Methodology

3.1. Research approach

Using a well-balanced dataset, we analyzed 525 observations from developed countries, 483 from emerging countries, and 357 from frontier countries. We aimed to empirically evaluate the relationship between primary energy use, renewable energy use, economic growth, quality of governance, gross domestic investment, and EPI and SDGs for the period spanning from 2001 to 2021. Drawing from the FTSE Country Classification, our sample comprises three distinct panels representing different stages of economic development and governance structures. In Panel A, we include Frontier Economies such as Argentina, Bangladesh, and Vietnam, characterized by their initial stages of sustainable development. Panel B encapsulates Emerging Economies like China, India, and Brazil, highlighting notable progress in economic development and sustainability efforts. Developed Economies are listed in Panel C, including the USA, Japan, and Germany, representing nations at advanced economic and social development stages. The study includes countries categorized under Frontier Economies (Panel A), Emerging Economies (Panel B), and Developed Economies (Panel C) based on the FTSE Country Classification, based on the latest September 2023 update of the FTSE Equity 2 Country Classification provides a comprehensive framework for categorizing countries. Table 1 lists the data streams from which the study's input data were drawn.

3.2. Variables description and measurement

The EPI 2022 was utilised to provide a data-driven perspective of the global sustainability condition (Hsu and Zomer, 2016). Using 40 performance markers across 11 issue areas, the EPI ranks 180 nations on their success in tackling climate change, environmental health, and ecosystem vitality; these measures indicate how close countries are to meeting national environmental policy objectives. The EPI provides a ranking that recognizes environmental leaders and laggards for nations aiming to develop toward a sustainable future (Hsu and Zomer, 2016).

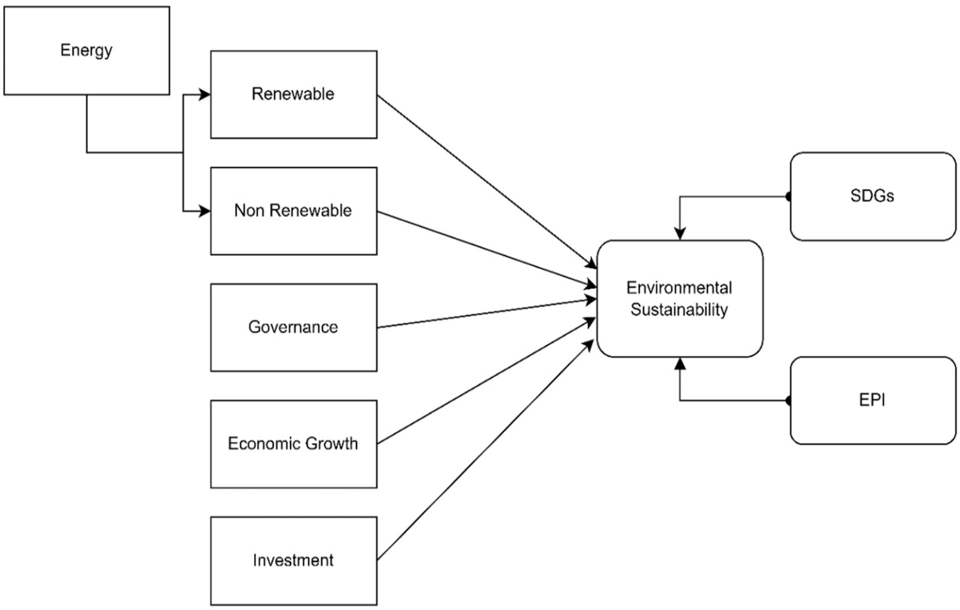

Fig. 1. Theoretical Framework.
Source: Conceptualised based on literature review

Table 1
Variables, measures and sources of data.

Symbol	Name	Measure	Sources	Expected Sign
Dependent Variables				
EPI	Environment Performance Index	Environmental Performance Index (0−100)	Yale University, & Centre for International Earth Science Information Network	
SDGS	Sustainable Development Report Score	"Countries are ranked by their overall score. The overall score measures the total progress towards achieving all 17 SDGs. The score can be interpreted as a percentage of SDG achievement. A score of 100 indicates that all SDGs have been achieved." (0−100).	https://dashboards.sdgindex.org/	
Independent Variables				
GOV	Quality of Governance	ICRG QoG Index	ICRG and University of Gothenburg	+
ECG	Economic Growth	GDP per capita based on purchasing power parity (PPP)	WDI (World Bank Database)	+
RE	Renewable Energy Use	Percent of Total Final Energy Use	WDI (World Bank Database)	+
NRE	Primary Energy Use	Total Final Energy usage	British Petroleum Statistical Review	-
Control Variables				
GDI	Gross Domestic Investment	GDI % of GDP	WDI (World Bank Database)	+

Note: This table provides the variables, measures and data sources used for this study. Quality of governance, renewable energy use, primary energy use, economic growth, and gross domestic investment are independent variables, while sustainable development goals and environmental performance are dependent variables.

The sustainable development reports were used to assess the SDG's performance. The Sustainable Development Solutions Network (SDSN) and Bertelsmann Stiftung have produced the annual SDG Index and Dashboards worldwide. The technique has been peer-reviewed and audited by the European Commission Joint Research Centre. This report analyses countries' SDG progress and gaps. A country's SDG Index score and goal scores signify optimal performance. A country must overcome the percentage point discrepancy between any score and 100 to achieve optimal SDG performance. The SDG Index ranks all countries using the same indicators. The SDG Index is widely accepted and commonly used in recent empirical studies on sustainable development (Hametner, 2022; Jiang et al., 2022; Khan et al., 2022; Kroll and Zipperer, 2020; Luu et al., 2024; Pérez-Martínez et al., 2023; Schmidt-Traub et al., 2017; Škare et al., 2024; Tóthová and Heglasová, 2022; Xu et al., 2020).

We used the International Country Risk Guide (ICRG) rankings from the quality of government database to analyze the role of the quality of governance (GOV) as previously used (Kulin and Johansson Sevä, 2019; Teorell et al., 2018). A composite measurement of three aspects of government quality makes up the ICRG index. The first element focuses on how corruption in the political system causes instability and reduces the effectiveness of the executive branch. The second factor relates to law and order, namely the strength and fairness of the legal system and the degree to which rules are put into practice and upheld. The third factor concerns the bureaucracy's strength and independence in providing government services. Higher scores (near 1) indicate a better level of government quality: the absence of corruption paired with an impartial judicial system and an independent bureaucracy, and vice versa.

We used GDP for economic growth, the value of total final energy usage from the British Petroleum Statistical Review for primary energy use, the percentage of renewable energy in total final energy consumption used for renewable energy use and gross domestic investment percentage in GDP used for gross domestic investment. For economic growth studies like Adeel-Farooq et al. (2023); (Ali et al., 2016; Azam et al., 2021; Ben Amar, 2021) for energy (Arain et al., 2020; Chien et al., 2023; Ofori et al., 2023; Wu et al., 2023) utilised similar approaches. The variables, measures and sources of data are provided in Table 1.

3.3. The estimation techniques and econometrics model

We derive Eq. 1 from the panel effect generalised model to examine the linkage between explanatory variables. In the first stage, study baseline estimations indicate the presence of heteroskedasticity and autocorrelation in the regression model, and to deal with these issues, we employed PCSE, FGLS and GMM suitable ways to address heteroskedasticity and autocorrelation issues. These techniques are reliable for calculating standard errors in panel data regression models because they account for heteroscedasticity and error correlation. They are especially useful when the assumptions of homoscedasticity and error independence are violated, which is typical in panel data settings. Using these techniques, we can acquire more precise estimates of the coefficients and avoid making false conclusions due to biased standard errors: Eqs. 1 and 2 from the general regression model derived according to study variables.

$$EPI_{i,t} = \alpha_0 + \beta_1(LNGOV)_{i,t} + \beta_2(LNECG)_{i,t} + \beta_3(LNNRE)_{i,t} + \beta_4(LNRE)_{i,t} + \beta_5(LNGDI)_{i,t} + \varepsilon_{i,t} \tag{1}$$

$$SDGS_{i,t} = \alpha_0 + \beta_1(LNGOV)_{i,t} + \beta_2(LNECG)_{i,t} + \beta_3(LNNRE)_{i,t} + \beta_4(LNRE)_{i,t} + \beta_5(LNGDI)_{i,t} + \varepsilon_{i,t} \tag{2}$$

In the equations, EPI is Environment Performance Index, SDGS is Sustainable Development Goals Score, GOV is Quality of Governance, ECG is Economic Growth, NRE is Primary Energy Use, RE is Renewable Energy Use, GDI is Gross Domestic Investment and $\varepsilon_{i,t}$ is error term in model. Where i is used for country and t is used for time.

4. Results and discussion

4.1. Descriptive statistics

The dataset's statistical characteristics for the variables under consideration are shown in Table 2. The sample has sixty-five countries including 17 frontier, 23 emerging, and 25 developed. The values for Panel A (Frontier Economies), Panel B (Emerging Economies), and Panel C (Developed Economies) variables' means, standard deviations, maximums, and minimums are shown in Table 2. We observe that the mean value is positive throughout the board. The average EPI is 41, 33, and 52 for frontier, emerging and developed economies. The average sustainable development score is 70, 66, and 78 for frontier, emerging and developed economies, respectively. The average quality of governance score is 0.562, 0.531, and 0.852 for frontier, emerging and developed economies, respectively. The pairwise correlation and VIF values provided in Appendix Table A1.

4.2. Baseline regression results

Table 3 shows the baseline regression results for panels A, B and C. Columns (1) to (5) show a one-to-one relationship between independent variables (GOV, RE, NRE and ECG) and dependent variable EPI, while columns (6) and (7) show an overall relationship.

The GOV positive coefficient in all panels indicates that a higher GOV is associated with better EPI. This finding is consistent with previous research showing that good governance practices, including transparency, accountability, and the rule of law, are important for promoting environmental sustainability. Institutional Analysis and Development Framework, suggesting that better governance improves environmental outcomes. High-quality institutions can create and enforce effective environmental policies, leading to better sustainability performance. For EPI, RE shows mixed results. In frontier and emerging economies, it has a positive impact in the fixed effects model, supporting the ecological modernisation theory that technological advancements in renewable energy can improve environmental performance. However, in developed economies, RE shows a negative relationship, which might be due to the initial environmental costs of transitioning to renewables or potential measurement issues. NRE shows a positive relationship with EPI across all economy types, which is counterintuitive. This might be explained by the energy-led growth hypothesis, where increased energy use, even from non-renewable sources, might lead to economic growth that enables investments in environmental protection. ECG shows a positive relationship with EPI across all economy types. This supports the EKC hypothesis, suggesting that as economies grow, they can invest more in environmental protection and sustainable development. As a control variable, GDI shows mostly negative relationships with EPI.

Table 4 shows the baseline regression results for panels A, B and C. Columns (1) to (5) show a one-to-one relationship between independent variables (GOV, RE, NRE and ECG) and dependent variable SDG Index score while columns (6) and (7) show an overall relationship.

Table 2
Descriptive Statistics.

Variable	Observations	Mean	Std. Dev.	Min	Max
Panel A (Frontier Economies)					
EPI	357	41.107	12.664	18.97	68.663
SGDS	357	70.423	5.856	53.34	80.560
GOV	357	0.562	0.111	0.282	0.833
RE	357	21.167	15.690	0.000	63.51
NRE	357	0.931	0.936	0.102	4.339
ECG	357	19,475	11,889	1659	55,272
GDI	357	25.79	5.805	10.854	41.56
Panel B (Emerging Economies)					
EPI	483	32.931	8.863	15.722	58.533
SGDS	483	66.392	6.169	51.71	80.41
GOV	483	0.531	0.105	0.306	0.778
RE	483	17.769	15.167	0.00	51.54
NRE	483	10.016	22.644	0.464	157.647
ECG	483	25,668	27,983	2197	163,219
GDI	483	24.391	7.313	11.892	48.869
Panel C (Developed Economies)					
EPI	525	51.822	7.685	34.093	74.954
SGDS	525	77.527	3.933	69.32	86.48
GOV	525	0.852	0.109	0.523	1.000
RE	525	16.128	14.700	0.470	62.370
NRE	525	8.655	18.153	0.144	97.430
ECG	525	44,525	18,312	11,121	133,329
GDI	525	23.200	3.976	14.632	54.955

Notes: The descriptive statistics for the main model variables are presented in this table. Data from 2001 to 2021 across three panels Panel A (Frontier Economies), Panel B (Emerging Economies) and Panel C (Developed Economies) presented. Quality of government, renewable energy use, primary energy use, economic growth, and gross domestic investment are independent variables, while sustainable development goals and environmental performance are dependent variables.

Table 3
Baseline regression results - EPI.

Dependent variable = EPI							
Variables	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) FE
Panel A (Frontier Economies)							
GOV	0.225***					0.052**	0.035**
	(0.086)					(0.027)	(0.012)
RE		−0.052***				−0.040***	0.017*
		(0.004)				(0.003)	(0.008)
NRE			0.066*			0.026***	0.075***
			(0.035)			(0.007)	(0.008)
ECG				0.022***		0.099***	0.016***
				(0.005)		(0.004)	(0.005)
GDI					−0.006***	−0.001***	−0.002***
					(0.001)	(0.000)	(0.000)
Cons	4.034***	1.266***	3.626***	0.635***	1.483***	0.414***	1.165***
	(0.054)	(0.005)	(0.038)	(0.056)	(0.021)	(0.048)	(0.049)
N	357	357	304	357	352	299	299
R2	0.129	0.265	0.061	0.276	0.190	0.383	0.414
Panel B (Emerging Economies)							
GOV	0.282**					0.062*	0.033***
	(0.141)					(0.036)	(0.013)
RE		−0.030***				−0.034	0.044***
		(0.003)				(0.025)	(0.008)
NRE			0.084**			0.022***	0.040***
			(0.042)			(0.002)	(0.005)
ECG				0.028***		0.067***	0.003
				(0.009)		(0.005)	(0.006)
GDI					−0.005***	−0.005***	−0.004*
					(0.001)	(0.000)	(0.003)
Cons	3.324***	1.278***	1.227***	1.064***	1.354***	0.645***	1.107***
	(0.064)	(0.005)	(0.005)	(0.039)	(0.012)	(0.054)	(0.061)
N	482	483	423	482	480	423	423
R2	0.009	0.208	0.017	0.040	0.188	0.482	0.206
Panel C (Developed Economies)							
GOV	0.489***					0.067***	0.023*
	(0.054)					(0.027)	(0.012)
RE		−0.006***				−0.055***	−0.036***
		(0.001)				(0.024)	(0.010)
NRE			0.115***			0.012***	0.016***
			(0.021)			(0.001)	(0.003)
ECG				0.433***		0.032***	0.057***
				(0.004)		(0.004)	(0.005)
GDI					−0.003***	−0.002***	−0.001***
					(0.000)	(0.000)	(0.000)
Cons	3.520***	1.377***	1.333***	1.012***	1.432***	1.040***	0.796***
	(0.046)	(0.002)	(0.003)	(0.043)	(0.009)	(0.041)	(0.048)
N	525	525	475	525	525	475	464
R2	0.135	0.047	0.228	0.115	0.084	0.449	0.565

Note: This table provides the estimates for impact of quality of government, renewable energy use, primary energy use and economic growth on dependent variable EPI (Environmental Performance Index). All estimations include OLS (Ordinary Least Square) and FE (Fixed Effect). The standard errors are indicated in brackets following estimated coefficients. The asterisks denote statistical significance at 10 % one-star, 5 % two-star, and 1 % three-star levels, respectively. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

In all economic contexts, governance quality demonstrates a positive and significant relationship with the SDGs, consistent with the Institutional Analysis and Development Framework. This framework posits that superior governance enhances environmental outcomes by fostering the creation and enforcement of effective environmental policies, thereby improving sustainability performance. RE shows a positive relationship, especially in frontier and emerging economies, supporting the idea that renewable energy contributes to broader sustainable development goals. This is consistent with previous research that suggests renewable energy can contribute to sustainable development by reducing greenhouse gas emissions and promoting energy security. For SDGs NRE has a significant positive coefficient in all economic contexts, indicating higher energy usage levels are associated with higher SDGs. This may be because energy usage is a key economic growth and development driver. ECG has a positive coefficient in all panels A, B and C, indicating that higher economic growth is associated with higher SDGs.

4.3. Diagnostic testing

Diagnostic tests such as Cameron & Trivedi's decomposition of IM-test, Breusch–Pagan/Cook–Weisberg test, Modified Wald test,

Table 4
Baseline regression results - SDGs.

Dependent variable = SDGs							
Variables	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) FE
Panel A (Frontier Economies)							
GOV	0.014***					0.013*	0.016***
	(0.004)					(0.007)	(0.005)
RE		−0.005***				0.002**	0.021***
		(0.002)				(0.001)	(0.002)
NRE			−0.002**			0.023***	0.009***
			(0.001)			(0.010)	(0.004)
ECG				0.019***		0.022**	0.016***
				(0.009)		(0.011)	(0.007)
GDI					−0.001***	0.015	−0.004**
					(0.000)	(0.012)	(0.002)
Cons	1.474***	1.444***	1.452***	1.261***	1.467***	1.229***	1.301***
	(0.003)	(0.001)	(0.004)	(0.010)	(0.005)	(0.020)	(0.008)
N	357	357	304	357	352	318	318
R2	0.187	0.060	0.007	0.296	0.049	0.445	0.475
Panel B (Emerging Economies)							
GOV	0.019***					0.110***	0.175***
	(0.005)					(0.031)	(0.030)
RE		−0.002**				0.031***	0.055
		(0.000)				(0.015)	(0.038)
NRE			0.003**			0.041***	0.024***
			(0.002)			(0.002)	(0.004)
ECG				0.071***		0.120***	0.091***
				(0.019)		(0.006)	(0.004)
GDI					−0.025	−0.002***	0.057
					(0.017)	(0.001)	(0.044)
Cons	1.445***	1.436***	1.429***	1.356***	1.434***	2.938***	3.167***
	(0.024)	(0.036)	(0.005)	(0.016)	(0.063)	(0.063)	(0.047)
N	482	483	423	482	480	423	423
R2	0.029	0.021	0.023	0.099	0.061	0.471	0.522
Panel C (Developed Economies							
GOV	0.030***					0.014***	0.231***
	(0.003)					(0.003)	(0.114)
RE		−0.001**				0.0007*	−0.005***
		(0.000)				(0.005)	(0.001)
NRE			0.051***			0.004***	0.026
			(0.006)			(0.002)	(0.022)
ECG				0.005***		0.001	0.019***
				(0.001)		(0.001)	(0.007)
GDI					−0.036	−0.025	−0.081***
					(0.026)	(0.017)	(0.040)
Cons	1.475***	1.471***	1.461***	1.413***	1.471***	1.460***	1.272***
	(0.001)	(0.001)	(0.000)	(0.014)	(0.003)	(0.015)	(0.006)
N	525	525	475	525	525	475	464
R2	0.137	0.020	0.400	0.029	0.000	0.433	0.825

Note: This table provides the estimates for impact of quality of government, renewable energy use, primary energy use and economic growth on dependent variable SDGs. All estimations include OLS (Ordinary Least Square) and FE (Fixed Effect). The standard errors are indicated in brackets following estimated coefficients. The asterisks denote statistical significance at 10 % one-star, 5 % two-star, and 1 % three-star levels, respectively. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

and Wooldridge test are used to identify potential issues with OLS regression such as heteroskedasticity and autocorrelation and result shows in appendix Table A2. The estimates show the presence of heteroskedasticity and autocorrelation. For further analysis, methods such as PCSE, FGLS and GMM were used to address them. These methods can lead to more accurate and reliable results by correcting for potential biases and issues with the OLS model.

4.4. Main analyses results for EPI and SDGs

In panel data regression models, we employ the FGLS, PCSEs, and GMM to account for heteroscedasticity and error correlation. Heteroscedasticity occurs when the variance of the error component does not remain constant across observations. When the errors of one observation are related to the errors of other observations, this is referred to as error correlation. These techniques are reliable methods for calculating standard errors in panel data regression models because they account for both heteroscedasticity and error correlation. They are especially useful when the assumptions of homoscedasticity and error independence are violated, which is typical in panel data settings.

Table 5 shows the main results for panels A, B, and C. Columns (1), (2), and (3) show PCSE, FGLS and GMM results, respectively, for EPI, while (4), (5) and (6) PCSE, FGLS and GMM results respectively for SDGS. The independent variables are GOV, RE, NRE, ECG, and GDI while the dependent variables are EPI and SDGS. In panels A, B and C, the GOV has a positive coefficient indicating that a higher

Table 5
Main analysis results for EPI and SDGs.

	Dependent variable = EPI			Dependent variable = SDGS		
	(1) FGLS	(2) PCSE	(3) GMM	(4) FGLS	(5) PCSE	(6) GMM
Panel A (Frontier Economies)						
L.EPI			0.840***			0.298***
			(0.020)			(0.105)
GOV	0.071***	0.071***	0.129***	0.013*	0.013**	0.113*
	(0.009)	(0.013)	(0.061)	(0.009)	(0.007)	(0.069)
RE	0.026***	0.026***	0.030*	0.073***	0.074***	0.171***
	(0.005)	(0.007)	(0.021)	(0.022)	(0.015)	(0.022)
NRE	−0.140***	−0.140***	−0.214***	0.023**	0.023***	0.131***
	(0.058)	(0.049)	(0.066)	(0.013)	(0.006)	(0.015)
ECG	0.099***	0.099***	0.218***	0.022***	0.022***	0.051***
	(0.024)	(0.029)	(0.101)	(0.009)	(0.011)	(0.016)
GDI	−0.321***	−0.321***	−0.453***	0.147***	0.147***	0.299***
	(0.019)	(0.018)	(0.216)	(0.071)	(0.068)	(0.132)
Constant	0.414***	0.414***	0.054*	1.229***	1.229***	1.229***
	(0.047)	(0.087)	(0.026)	(0.020)	(0.011)	(0.017)
N	299	299	283	318	318	318
Wald – P value	0.000	0.000	0.000	0.000	0.000	0.000
AR 2			0.412			0.341
Sargan			0.154			0.221
Panel B (Emerging Economies)						
L.EPI			1.068***			0.847***
			(0.018)			(0.302)
GOV	0.092*	0.092***	0.119**	0.110***	0.110***	0.301**
	(0.047)	(0.045)	(0.063)	(0.031)	(0.024)	(0.161)
RE	0.042***	0.042***	0.151	0.098***	0.098***	0.413***
	(0.020)	(0.019)	(0.311)	(0.042)	(0.035)	(0.106)
NRE	−0.098	−0.258	0.088***	0.128***	0.028***	0.298***
	(0.114)	(0.419)	(0.006)	(0.033)	(0.005)	(0.091)
ECG	0.067***	0.067***	0.273***	0.120***	0.120***	0.556***
	(0.015)	(0.011)	(0.042)	(0.017)	(0.013)	(0.106)
GDI	−0.215***	−0.215***	−0.222***	−0.322***	−0.322***	−0.412***
	(0.035)	(0.021)	(0.093)	(0.011)	(0.110)	(0.057)
Constant	0.645***	0.645***	−0.102***	2.938***	2.938***	0.618***
	(0.054)	(0.031)	(0.021)	(0.063)	(0.029)	(0.056)
N	423	423	401	423	423	423
Wald – P value	0.000	0.000	0.000	0.000	0.000	0.000
AR 2			0.124			0.163
Sargan			0.137			0.291
Panel C (Developed Economies)						
L.EPI			0.694***			0.997***
			(0.027)			(0.071)
GOV	0.224**	0.224***	0.315***	0.315***	0.315***	0.627***
	(0.110)	(0.109)	(0.112)	(0.013)	(0.106)	(0.233)
RE	0.153***	0.112***	0.229***	0.147***	0.147***	0.781***
	(0.021)	(0.051)	(0.053)	(0.011)	(0.067)	(0.234)
NRE	−0.036***	−0.036***	−0.023***	0.031***	0.031***	0.563***
	(0.011)	(0.015)	(0.009)	(0.015)	(0.011)	(0.208)
ECG	0.132***	0.132***	0.510***	0.455***	0.581***	0.851***
	(0.044)	(0.055)	(0.102)	(0.210)	(0.252)	(0.395)
GDI	−0.103***	−0.103***	−0.158***	−0.130***	−0.150***	−0.279***
	(0.044)	(0.027)	(0.065)	(0.062)	(0.055)	(0.106)
Constant	1.040***	1.040***	0.490***	1.460***	1.460***	1.460***
	(0.041)	(0.052)	(0.127)	(0.014)	(0.019)	(0.114)
N	475	475	440	475	475	440
Wald – P value	0.000	0.000	0.000	0.000	0.000	0.000
AR 2			0.211			0.157
Sargan			0.151			0.213

Note: This table provides estimates for the impact of quality of government, renewable energy use, primary energy use, economic growth, and gross domestic investment on the dependent variable EPI (Environmental Performance Index). All estimations include PCSE (panel-corrected standard errors) and GMM (generalised method of moments). The standard errors are indicated in brackets following estimated coefficients. The asterisks denote statistical significance at 10 % one-star, 5 % two-star, and 1 % three-star levels, respectively. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

GOV is associated with better EPI. This finding is consistent with previous research by Kulin and Johansson Sevä (2019); Povitkina and Matti (2021) which support a positive relationship. RE has a positive coefficient, suggesting that greater use of renewable energy sources is associated with better EPI. Similar results were reported by (Achuo et al., 2022; Musa et al., 2021; Usman et al., 2020). NRE has a negative coefficient, indicating that higher energy usage is associated with worse EPI in panel A and C while positive in panel B. Results are in line with (Achuo et al., 2022; Adeel-Farooq et al., 2023). ECG has a positive coefficient, indicating that higher economic growth is associated with better EPI. This result is counterintuitive, as economic growth is often assumed to be associated with increased environmental degradation. However, it is important to note that this relationship may not always hold true in all cases, and there may be other factors that affect the relationship between economic growth and environmental performance. For instance, some studies have suggested that the relationship between economic growth and environmental degradation may follow an inverted U-shaped curve, meaning that environmental degradation initially increases as economic growth occurs but then decreases once a certain level of economic development is reached. GDI has a negative coefficient, suggesting that higher GDI is associated with worse EPI. This finding may indicate that large investments in physical capital can have negative environmental externalities if they are not

Table 6
Robustness Analysis with simultaneous quantile regression.

	EPI			SDGS		
	(1) SQR (q50)	(2) SQR (q75)	(3) SQR (q90)	(4) SQR (q50)	(5) SQR (q75)	(6) SQR (q90)
Panel A (Frontier Economies)						
GOV	0.067***	0.089***	0.125***	0.024**	0.101***	0.152***
	(0.012)	(0.017)	(0.036)	(0.013)	(0.014)	(0.052)
RE	0.025**	0.048***	0.119***	0.031***	0.078***	0.091***
	(0.013)	(0.021)	(0.055)	(0.010)	(0.015)	(0.038)
NRE	−0.039***	−0.042***	−0.047***	0.002**	−0.044***	−0.073***
	(0.005)	(0.009)	(0.013)	(0.001)	(0.011)	(0.021)
ECG	0.107***	0.095***	0.074***	0.027***	0.023***	0.0197***
	(0.004)	(0.008)	(0.018)	(0.002)	(0.001)	(0.001)
GDI	−0.001***	−0.001***	−0.002***	0.001***	0.0002**	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.314***	0.471***	0.789***	1.169***	1.218***	1.263***
	(0.048)	(0.096)	(0.161)	(0.016)	(0.014)	(0.010)
N	299	299	299	318	318	318
Pseudo R2	0.583	0.387	0.217	0.404	0.460	0.498
Panel B (Emerging Economies)						
GOV	0.022*	0.133***	0.151***	0.078***	0.088***	0.108***
	(0.012)	(0.021)	(0.037)	(0.021)	(0.044)	(0.022)
RE	0.024***	0.017***	0.014***	0.037***	0.036***	0.034***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
NRE	−0.000	−0.000*	−0.000***	0.001***	0.004	−0.035
	(0.000)	(0.000)	(0.000)	(0.000)	(0.005)	(0.044)
ECG	0.086***	0.063***	0.054***	0.120***	0.112***	0.098***
	(0.006)	(0.008)	(0.008)	(0.010)	(0.012)	(0.006)
GDI	−0.005***	−0.004***	−0.002***	−0.002***	−0.001	0.000
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
Constant	0.473***	0.679***	0.794***	2.977***	3.051***	3.195***
	(0.058)	(0.079)	(0.071)	(0.094)	(0.114)	(0.049)
N	423	423	423	423	423	423
Pseudo R2	0.310	0.298	0.333	0.386	0.388	0.426
Panel C (Developed Economies)						
GOV	0.047***	0.066***	0.138	0.012***	0.020***	0.026***
	(0.009)	(0.014)	(0.060)	(0.005)	(0.004)	(0.009)
RE	0.010***	0.012***	0.016***	0.005***	0.037***	0.045***
	(0.001)	(0.002)	(0.003)	(0.001)	(0.013)	(0.009)
NRE	−0.001***	−0.003***	−0.004**	−0.005**	−0.059**	−0.093***
	(0.000)	(0.001)	(0.002)	(0.002)	(0.031)	(0.040)
ECG	0.0294***	0.0183**	0.0283***	0.006	0.004**	0.0041
	(0.007)	(0.00902)	(0.009)	(0.004)	(0.002)	(0.003)
GDI	−0.004***	−0.003***	−0.003***	−0.000	−0.000	−0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Constant	1.084***	1.166***	1.098***	1.401***	1.432***	1.437***
	(0.0682)	(0.0880)	(0.0644)	(0.041)	(0.0212)	(0.029)
N	475	475	475	475	475	475
Pseudo R2	0.262	0.266	0.267	0.198	0.331	0.428

Note: This table provides estimates for the impact of quality of government, renewable energy use, primary energy use, economic growth, and gross domestic investment on the dependent variable EPI (Environmental Performance Index). All estimations include 2SLS (two-stage least squares), PCSE (panel-corrected standard errors), GMM (generalised method of moments) and SQR (simultaneous quantile regression) at q50, q75 and q90. The standard errors are indicated in brackets following estimated coefficients. The asterisks denote statistical significance at 10 % one-star, 5 % two-star, and 1 % three-star levels, respectively. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

accompanied by investments in sustainable practices and technologies.

Table 5, columns (4), (5) and (6) show PCSE, FGLS and GMM results for SDGs. In panels A, B, and C, the GOV positive coefficient indicates that a higher quality of governance is associated with better SDGS. In literature studies, Ahlerup et al. (2016), (2021) support the positive quality of governance and sustainable growth relationships. This relationship is weak in panel A, strong in panel B, and most pronounced in panel C. RE and NRE have positive coefficients, suggesting that greater use of both energy sources is associated with a better SDGS. ECG is positive and significant in panels A and B and insignificant in panel C. GDI has an insignificant impact in panels A and C and a negative significance in panel B. Overall, the results suggest that higher GOV, NRE, RE, and ECG are positively associated with SDGS. These findings could have implications for policymakers who may consider policies that encourage renewable energy use, economic growth, and improve the quality of governance to achieve sustainable development goals.

4.5. Robustness analysis

The analysis of robustness utilised simultaneous quantile regression (SQR) across various quantiles, ensuring a more resilient examination. Quantile regression facilitates a comprehensive exploration of variable relationships throughout the conditional distribution. SQR captures heterogeneity and provides policymakers with valuable insights for targeted interventions. The results of the robustness analysis, conducted using SQR at quantiles of 50, 75, and 90, are presented in Table 6. These findings not only reinforce the outcomes and arguments of our main analysis but also validate our conclusions using alternative econometric techniques.

GOV consistently shows a positive and significant impact on both EPI and SDGs across all percentiles and economic contexts, underscoring its crucial role in implementing effective environmental policies and sustainable development initiatives. These findings suggest that improving governance can yield substantial environmental benefits. Moreover, the increasing magnitude of the coefficient at higher quantiles indicates that the impact of governance on environmental performance becomes more pronounced for countries with better overall environmental performance. RE also demonstrates a robust positive association with EPI and SDGs, reflecting its role in reducing pollution and promoting sustainable practices. Conversely, NRE negatively impacts EPI due to its contribution to pollution and environmental degradation, although its effect on SDGs is more nuanced, reflecting trade-offs between economic development and environmental harm. ECG is positively linked to both EPI and SDGs, indicating that growth provides resources for environmental initiatives and sustainable development. The results also reveal nonlinearities, suggesting that the impacts of these factors may vary across different levels of environmental performance and development stages. Overall, the findings emphasise the importance of strong governance, renewable energy transition, and economic growth in enhancing environmental outcomes and SDGs progress, while highlighting the complexities involved in energy transitions and domestic investment.

4.6. Economic discussion

This study examines the effects on sustainable development and environmental performance of several variables, including the quality of governance, renewable energy, economic growth, and the use of primary energy. Environmental performance and sustainable development are affected by a myriad of factors, including the quality of governance, energy consumption, economic growth, and investment patterns. The results show that the EPI and the SDGs are positively related to GOV.

For environmental sustainability, good governance is essential because it promotes the establishment and implementation of environmental rules, guarantees openness, and lessens corruption. This is in line with research by Kulin and Johansson Sevä (2019); Povitkina and Matti (2021), which emphasise the contribution of excellent governance to the advancement of environmental protection. The Institutional Analysis and Development Framework suggests that high-quality governance fosters the creation and enforcement of effective environmental policies, leading to better environmental and economic outcomes. The positive and significant coefficients across all percentiles and both dependent variables align with this theory, indicating that better governance consistently enhances both environmental performance and progress towards the SDGs.

Achieving sustainable development is unattainable without strong governance mechanisms, which allow for the implementation of sustainable policies and the coordination of efforts to resolve environmental challenges. It is crucial to switch to cleaner energy sources because there is a positive correlation between EPI and SDGs and RE usage. The literature consistently demonstrates that renewable energy reduces greenhouse gas emissions and mitigates climate change, which is corroborated by this (Achuo et al., 2022; Musa et al., 2021; Usman et al., 2020). Reducing reliance on fossil fuels and increasing energy security are two ways in which renewable energy adoption promotes sustainable economic growth and improves environmental performance.

Traditional energy consumption and unsustainable investments have environmental costs, as shown by the negative coefficients of NRE and GDI in relation to EPI. It is well-established that the use of fossil fuels increases pollution and degrades the environment, which in turn negatively affects the performance of non-renewable energy sources (Achuo et al., 2022). Furthermore, investments in physical capital that are not sustainable can have far-reaching negative effects on the environment. The EKC hypothesis posits that reliance on non-renewable energy sources leads to higher pollution and environmental degradation, which can hinder sustainable economic growth. The negative coefficients across all percentiles and both dependent variables are consistent with this theory, suggesting that higher use of non-renewable energy negatively impacts both environmental performance and progress towards the SDGs.

ECG is positively linked to both EPI and SDGs, indicating that growth provides resources for environmental initiatives and sustainable development. The endogenous growth theory suggests that economic growth drives technological advancements and investments in environmental sustainability (Aboagye, 2017; Adeel-Farooq et al., 2023). The positive and significant coefficients across all percentiles and both dependent variables indicate that economic growth supports improvements in both environmental performance and progress towards the SDGs.

5. Conclusion

This study aimed to investigate the effects of energy, governance, economic growth and investment on sustainable development and environmental performance in frontier, emerging, and developed economies over the period from 2001 to 2021. The findings of this study provide valuable insights into the role of governance and energy in shaping sustainable development and environmental performance. The empirical analysis revealed significant relationships between these variables across different panels, highlighting their importance in achieving positive outcomes in terms of sustainability and environmental preservation.

Several important new insights regarding sustainable development and environmental performance are provided by this study. First, it shows how governance quality, energy use, and economic growth affect environmental outcomes and SDGs. The study analyses how these factors interact across economic contexts using robust methods like FGLS, PCSE, and Dynamic System GMM. Second, using the EPI and SDG Index scores as dependent variables allow for a more nuanced assessment of environmental performance and goal achievement than CO2 emissions. Thirdly, the study quantifies the main environmental performance barriers, including primary energy use, while highlighting renewable energy and governance. These contributions highlight the multifaceted dynamics of sustainability and offer practical solutions for improving environmental performance and achieving SDGs.

The findings of this study hold significant implications for policymakers, businesses, and researchers. Policymakers can utilise these observations to develop strategies that achieve a harmonious equilibrium between economic expansion and environmental preservation. The correlation between the quality of governance and environmental performance highlights the necessity of robust and transparent institutions in successfully enforcing environmental regulations and fostering sustainable practices. Businesses can utilise the findings to guide investment decisions, highlighting the significance of embracing renewable energy sources and reducing primary energy consumption to improve their environmental performance. Researchers can expand upon this study by examining the intricate relationships between economic growth, energy consumption, and environmental consequences at various stages of development, which could potentially provide insights for future policy and investment approaches. In summary, the research emphasises that combining sustainable practices with economic development is not just possible but essential for ensuring long-term environmental sustainability.

Some limitations of our study include the potential for bidirectional relationships and endogeneity between environmental sustainability and its determinants. For instance, while economic growth can impact environmental sustainability, poor environmental conditions can also hinder economic progress, and environmental challenges may drive investment in renewable energy. Additionally, while this study focuses on the direct effects of governance, energy consumption, and investments on environmental sustainability, future research could explore more complex relationships. Governance might play a moderating or accentuating role in how investments and energy consumption impact environmental sustainability. Future studies could enrich the analysis by incorporating interaction terms between governance indicators and other explanatory variables, providing more nuanced insights into how governance quality influences the effectiveness of investments and energy policies. Moreover, the environmental sustainability indicators used, such as the EPI and SDG indices, may include elements of governance or energy usage, potentially leading to inherent correlations between dependent and independent variables. We interpret our results with caution and recommend that future research explore alternative measures or decompose existing indices to isolate specific environmental outcomes. Such research could offer valuable guidance for policymakers in designing more targeted and effective strategies for sustainable development.

Despite the limitations of this study, such as the small sample size and cross-sectional nature of the data, the results suggest that governments and businesses should prioritise investments in renewable energy and strive to improve the quality of governance to promote sustainable development and environmental performance. The findings also underscore the importance of limiting primary energy use and moving towards more sustainable practices. Overall, this research highlights the need for more research and action in the areas of sustainable development and environmental performance. By working towards more sustainable practices, businesses and governments can create a more sustainable and resilient future for all.

It is recommended for developed nations to focus on investing more in renewable energy, which has a positive impact on environmental performance. At the same time, efforts should be made to limit primary energy use which have a negative impact on environmental performance. Emerging nations should give precedence to the quality of government, economic growth, and renewable energy use, as they have a positive impact on both environmental performance and sustainable development goals. However, they should also be mindful of their primary energy use which have a negative impact on environmental performance. Frontier nations should prioritise the quality of governance, economic growth, and renewable energy use, as they have a positive impact on environmental performance and sustainable development goals. However, they should also be mindful of their primary energy use investment, which have a negative impact on environmental performance.

Policymakers should aim to strike a balance between economic growth and environmental sustainability. While economic growth is necessary for development, it should not come at the expense of environmental degradation. There is a need for greater international cooperation to address global environmental challenges. Developed nations can provide technical and financial assistance to emerging and frontier nations to promote renewable energy and sustainable development goals.

Author agreement statement

We the undersigned declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. We understand that the Corresponding Author is the sole contact for the Editorial process. She is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

CRediT authorship contribution statement

Tanveer Bagh: Writing – review & editing, Validation, Project administration. **Mirza Muhammad Naseer:** Writing – original draft, Data curation, Conceptualization. **Ahmed Imran Hunjra:** Writing – original draft, Methodology, Data curation, Conceptualization. **Alessia Palma:** Writing – original draft, Investigation, Conceptualization, Data curation.

Appendix A

Table A1
Pairwise Correlation and VIF

Variables	(1)	(2)	(3)	(4)	(5)	VIF
Panel A (Frontier Economies)						
(1) GOV	1.000					2.26
(2) RE	−0.234	1.000				1.36
(3) NRE	−0.409	−0.290	1.000			2.16
(4) ECG	0.537	−0.423	−0.171	1.000		1.67
(5) GDI	−0.195	0.154	−0.009	−0.312	1.000	1.18
Mean VIF						1.73
Panel B (Emerging Economies)						
(1) GOV	1.000					1.52
(2) RE	−0.281	1.000				1.14
(3) NRE	−0.154	−0.031	1.000			1.69
(4) ECG	0.383	−0.578	−0.151	1.000		1.32
(5) GDI	0.239	−0.118	0.550	0.178	1.000	1.61
Mean VIF						1.46
Panel C (Developed Economies)						
(1) GOV	1.000					1.44
(2) RE	0.411	1.000				1.12
(3) NRE	−0.095	−0.203	1.000			1.18
(4) ECG	0.396	0.065	0.007	1.000		1.24
(5) GDI	0.032	0.008	−0.091	0.086	1.000	1.04
Mean VIF						1.20

Notes: The main model variables are presented in this table with pairwise correlation and variance inflation factor (VIF). Data from 2001 to 2021 across three panels Panel A (Frontier Economies), Panel B (Emerging Economies) and Panel C (Developed Economies) presented. Quality of government, renewable energy use, primary energy use, economic growth, and gross domestic investment are independent variables, while sustainable development goals and environmental performance are dependent variables.

Table A2
Diagnostic Tests

(1) Cameron & Trivedi's decomposition of IM-test

	Environmental Performance			SDGs Score		
Source	chi2	df	p	chi2	df	p
Panel A (Frontier Economies)						
Heteroskedasticity	96.37	20	0.000	210.47	20	0.000
Skewness	21.20	5	0.000	76.91	5	0.000
Kurtosis	5.15	1	0.023	13.59	1	0.000
Total	122.72	26	0.000	300.97	26	0.000
Panel B (Emerging Economies)						
Heteroskedasticity	150.04	20	0.000	173.01	20	0.000
Skewness	42.76	5	0.000	71.81	5	0.00
Kurtosis	4.50	1	0.033	1.81	1	0.179
Total	197.30	26	0.000	246.63	26	0.000
Panel C (Developed Economies)						
Heteroskedasticity	128.59	20	0.000	138.13	20	0.000
Skewness	11.07	5	0.050	28.54	5	0.000
Kurtosis	1.29	1	0.256	45.43	1	0.000
Total	140.94	26	0.000	212.10	26	0.000
(2) **Breusch–Pagan/Cook–Weisberg test for heteroskedasticity**						
Assumption: Normal error terms				Assumption: Normal error terms		

(*continued on next page*)

Table A2 (*continued*)

(1) Cameron & Trivedi's decomposition of IM-test						
	Environmental Performance			SDGs Score		
Source	chi2	df	p	chi2	df	p
Variable: Fitted values of EPI				Variable: Fitted values of SDGS		
H0: Constant variance				H0: Constant variance		
	chi2(1)	**Prob > chi2**		**chi2(1)**	**Prob > chi2**	
Panel A (Frontier Economies)	20.25	0.000		3.12	0.077	
Panel B (Emerging Economies)	3.22	0.072		16.53	0.000	
Panel C (Developed Economies)	2.68	0.102		0.52	0.472	
(3) **Modified Wald test for groupwise heteroskedasticity in FE regression model**						
H0: sigma(i)^2 = sigma^2 for all i	**chi2 (16)**	**Prob>chi2**		**chi2 (16)**	**Prob>chi2**	
Panel A (Frontier Economies)	2556.26	0.000		570.18	0.000	
Panel B (Emerging Economies)	29792.41	0.000		6146.39	0.000	
Panel C (Developed Economies)	1197.90	0.000		832.17	0.000	
(4) **Wooldridge test for autocorrelation in panel data**						
H0: no first-order autocorrelation	**F (1, 16)**	**Prob > F**		**F (1, 16)**	**Prob > F**	
Panel A (Frontier Economies)	210.836	0.000		29.323	0.000	
Panel B (Emerging Economies)	200.404	0.000		167.544	0.000	
Panel C (Developed Economies)	43.760	0.000		84.330	0.000	

Note: This table provides the estimates for diagnotic test for independent variables quality of government, renewable energy use, primary energy use, economic growth, and gross domestic investment on dependent variables SDGS (Sustainable Development Goal Index Score) and variable EPI (Environmental Performance Index).

Table A3
List of Countries (FTSE Group)

Frontier Economies (Panel A): Argentina, Bangladesh, Bulgaria, Croatia, Cyprus, Ecuador, Estonia, Kazakhstan, Latvia, Lithuania, Morocco, Oman, Romania, Slovakia, Slovenia, Sri Lanka, Vietnam
Emerging Economies (Panel B): Brazil, Chile, China, Colombia, Czech Republic, Egypt, Greece, Hungary, India, Indonesia, Kuwait, Malaysia, Mexico, Pakistan, Peru, Philippines, Qatar, Russia, Saudi Arabia, South Africa, Thailand, Turkey, United Arab Emirates
Developed Economies (Panel C): Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Israel, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Singapore, South Korea, Spain, Sweden, Switzerland, United Kingdom, USA

Data Availability

Data will be made available on request.

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