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The Role of Mineral Rent, Energy Poverty, and Green Economic Growth in Environmental Degradation: New Insights for Sustainable Futures in G5 Countries

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Abstract

Policymakers and academics continue to focus on environmental degradation as it remains a pressing global issue. This study aims to explore the roles of mineral rents, energy poverty, green economic growth, and human capital in influencing environmental degradation within the G5 countries from 2000 to 2022. By providing new insights, the study seeks to contribute to the ongoing discourse on sustainable futures. A series of econometric estimates namely the augmented mean group, feasible generalized least squares, and fixed and random effects models were employed to achieve the research objectives. The Hausman test was used to validate the feasible generalized least squares results, which formed the basis of the study's conclusions. The findings reveal that mineral rents significantly contribute to environmental degradation, while energy poverty has an inverse relationship with it. Robustness checks affirm the reliability of the study's models and highlight additional insights: trade openness does not significantly impact environmental degradation, whereas human capital has a pronounced detrimental effect on the environment. The study emphasizes the importance of implementing targeted policy measures to effectively mitigate environmental degradation and support sustainable development.

Keywords: Mineral rents, Energy poverty, Environmental degradation, Green Growth, Human capital, Trade openness and G5 Countries.

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INTRODUCTION

The rapid industrial growth, urbanization and massive use of nonrenewable energy in the G5 nations, namely Brazil, China, India, Mexico and South Africa, continue to pose an extreme challenge of environmental degradation. Although not the most politically regal of nations, these countries are also environmentally stressed. For such concrete example, China is still the biggest global emitter of greenhouse gases, with CO_2 emissions of nearly 12 gigatons in 2022, driven mainly by its energy intensive industries. Like India, coal provides 55 percent of energy for India, which generates more than 2.9 gigatons of CO_2 annually, compared to 2.8 gigatons in more developed countries. In Brazil, the "lungs of the Earth" or Amazon region, is seeing record deforestation, losing 13,000 square kilometers in 2022, damaging its status as a global carbon sink. Not only does South Africa's coal fired power plants produce CO_2, they also cause serious air pollution leading to over 2,200 premature deaths a year. Water and air quality are Mexico's most acute problems, and more than 70 percent of the country's rivers are contaminated by industries and agriculture. The ecological pressures these environmental pressures underscore the urgency of integrated strategies that resolve the tension between economic growth and ecological sustainability, and G5 nations hold some of the strongest leverage in global climate action.

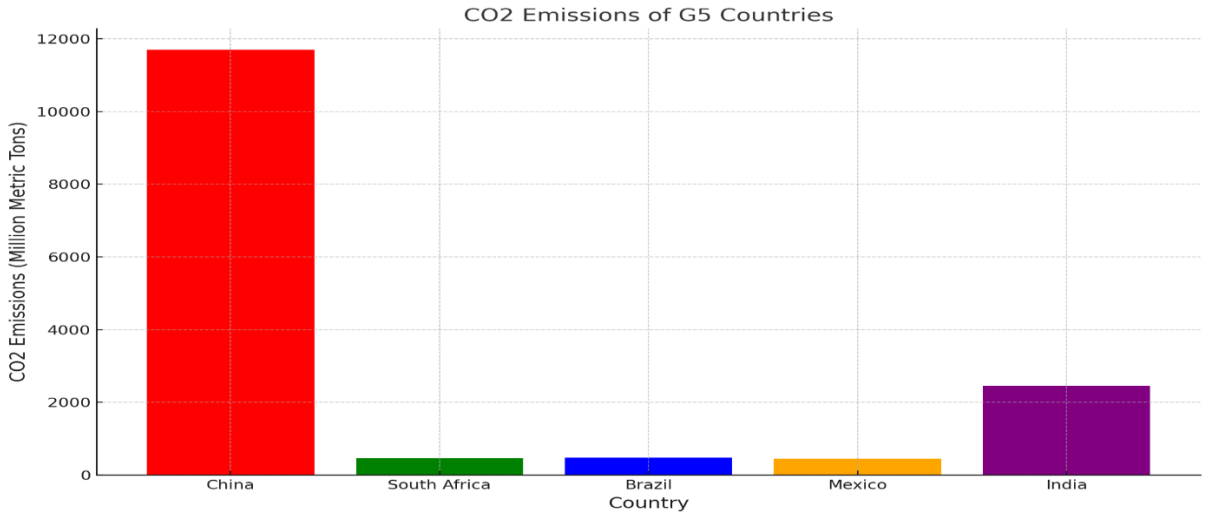


Figure 1.
CO_2 Emissions in G5 Countries

The chart presents (see figure 1) CO_2 emissions from G5 countries, emphasizing significant disparities. Emission levels increase notably from South Africa, Brazil, and Mexico (relatively similar emissions) to India, and then sharply to China, which has the highest emissions by a substantial margin. For many developing economies, including the ones who need economic progress, the very basis of their economic development relies on revenues from natural resource rents (Ben-Salha, Dachraoui, & Sebri, 2021). The extraction of natural resources is the prime mechanism through which these nations enhance their national income and promote the growth of their economies (Rahim et al., 2021). Natural resources are found to play a role in alleviating energy poverty and driving economic growth in many regions of the world (Zhao et al., 2022). This process is however accompanied with many ecological degradations as economies from natural resource extraction are more often detrimental to the environment (Badeeb, Lean & Shahbaz, 2020).

Many environmental challenges are exacerbated by human activities since the discovery of economy of natural resources (Azka Amin, Peng, Işık, Ullah, & Akbar, 2024). Of these, climate change, a byproduct of greenhouse gas emissions from resource extraction, is the most determined environmental threat today (Z. Khan, Hossain, Badeeb, & Zhang, 2023). Significant environmental damage has been associated with activities such as the extraction of minerals, crude oil and natural gas, which are keys to industrial growth (Xiong et al., 2023). This aligns with the production hypothesis, which suggests that rapid economic growth fosters an intensified demand for resources and technological innovation (Luo et al., 2023).

The urgency of this issue is underscored by climate data: Global temperature around 2022: 1.11°C above pre-industrial levels, with the trend upwards remaining over the 2015 to 2021 average of over 10°C (Gani, 2021). These numbers point to how losing check on how our resources are being exploited has degraded planetary health, and we won't be able to continue relying on destructive ways of exploiting our resources. The environmental challenges stemming from resource-dependent economies of G5 nations are related to a relationship between natural resource rents and environmental degradation. Between 2019 and 2022, the Amazon received more natural resource rents, putting it on track to come under deforestation worth over 13,000 square kilometers, leading to a decrease in capacity to absorb carbon. Like South Africa, its coal mining industry grosses 10% of its GDP, and is one of the biggest

per capita emitters of CO_2 in the world. Environmental costs to the nation include water pollution from acid mine drainage. Delhi is one of the most polluted cities in the world, because India relies so heavily on coal rents to generate electricity. As the world's largest extractor of natural resources, and consequently the world's largest creator of environmental degradation from mining activities and industrial emissions, China's CO_2 emissions remain more than 12 gigatons per year. Oil rents have kept Mexico heavily dependent on oil, leading to water and soil contamination that threatens agricultural productivity and public health in resource rich areas. These figures point to the environmental costs of resource exploitation, which urge G5 countries to practice sustainable use of resources, and move away from resource rents to prevent environmental degradation.

Energy poverty refers to the absence of access to affordable, secure and sustainable provision of energy services which hugely constrain the country's economic growth, education, as well as health outcomes. Energy poverty remains an important problem in G5 countries—Brazil, China, India, Mexico, and South Africa. For example, 15% of the world population is in India, where millions depend on traditional biomass for cooking that causes indoor air pollution and associated problems in health. Despite high national electrification rates, energy poverty continues in rural areas of South Africa where more than 40% of households cannot afford electricity. Finally, like Mexico, energy access differences are present in the same way in rural communities that depend on firewood for cooking. Even though electrification has increased in Brazil, marginalised populations continue to lack stable energy services. In that time, China has largely resolved electrification, with coal and biomass being China's primary fuels for rural energy poverty.

As reliance on traditional biomass and fossil fuels push through deforestation, air pollution and greenhouse gas emissions, energy poverty directly links with environmental degradation. Particularly in coal-reliant South Africa and India, CO_2 emissions from coal for electricity prolong climate change. Firewood collection reduces carbon sinks in rural Mexico and Brazil, reducing biodiversity. Clean and renewable energy source transition in G5 nations is bound to tackle environmental effects and avert energy poverty for all the nations. This is not only essential but necessary for the promotion of sustainable development and addressing the interrelated problems of energy poverty and environmental degradation.

A country's trade openness, or the degree to which it practices international trade, is also typically associated with economic growth and globalization. But it also brings enormous environmental challenges to the G5 nations (Brazil, China, India, Mexico and South Africa). Trade is used by these countries to increase industrial production that often means more emissions and damaging resource exploitation. For instance, in 2022, China, which is the largest exporter worldwide, has 28% or so of the global CO_2 emissions caused by its industrial sectors, due to the large energy consumption of manufacturing exports. Just as India's trade led industrialization in areas like textiles and chemicals is contributing to water pollution and air quality degradation as it has 21 of the world's 30 most polluted cities.

In Brazil, soybeans and beef agricultural exports have driven deforestation in the Amazon, with more than 60 percent of deforested land used for cattle grazing. The industrial emissions, however, have increased rapidly in manufacturing hubs along the U.S. border, a result of Mexico's integration into global trade agreements like NAFTA. For example, coal and minerals export out of South Africa contribute 30 per cent to overseas sales and support environmental degradation of soil erosion and water

pollution and the connection between trade openness and environmental degradation is reinforced by the 'pollution haven hypothesis' that argues that trade liberalisation in developing economies often transfers polluting industries to these regions. The reality is that in the G5, all of this leads to increased greenhouse gas emissions, deforestation, water pollution, undermining global sustainability efforts. These challenges need to be addressed through environmental standards and green technology in policies which promote economic growth, while enabling trade, and prevent ecological integrity from being compromised through trade. With its human capital, G5 countries (Brazil, China, India, Mexico and South Africa) drive economic growth and at the same time suffer from environmental degradation. Such nations differ vastly in human capital: education, health, skills.

But while China's Human Capital Index (HCI is 0.65, thanks to big investments in education and healthcare, its industrial growth has made it the biggest carbon emitter in the world, spewing 11 billion metric tons of CO_2 annually. Despite an HCI of 0.49, India's education and tech progress has been significant, but the country is struggling with exceptionally poor air quality in urban cities like Delhi, where PM2.5 levels can be as high as ten times above safe limits, leading to more than 1.67 million pollution deaths in 2022. The HCI of 0.55 in Brazil represents gains in education but the deforestation in the Amazon (including 13,000 square kilometers of forest loss in 2022) has a negative impact on biodiversity and local livelihoods. Although Mexico has a moderate health and education indicator, water scarcity and air pollution, which exceed WHO guidelines, are among the problems that affect cities like Mexico City, where the HCI is 0.61.

Whilst South Africa may have an HCI of 0.57 (relatively high), a very high unemployment rate and some serious environmental issues such as mining related land degradation, and dependence on coal to power 80% of it energy consumption, it is one of the top 20 CO_2 emitters globally. At the same time that they fight to improve their human capital, these nations in aggregate add to global greenhouse gas emissions. China's transition to renewable energy, India's solar mission, Brazil's reforestation efforts, and Mexico's urban sustainability programs are initiatives of balancing economic development with environmental preservation. But repeated progress in overcoming environmental problems like poverty, unequal access to resources, and weak enforcement of environmental regulations is slowed down by systemic issues like poverty and unequal access to resources and weak enforcement of environmental regulations. This complexity of creating and maintaining human capital and environmental sustainability makes for an inextricable link and a need for integration between the two for sustainable long-term growth.

In recent decades, significant progress has been made in green economic growth in the G5 countries (Brazil, China, India, Mexico, and South Africa), however significant challenges remain in terms of environmental degradation. Through renewable energy and energy efficiency, Brazil reduced emissions by 91 million tons annually, making Brazil one of the largest contributors to global cuts. But the main source of CO_2 emissions for the country remains deforestation in the Amazon, at 13,000 square km in 2022. Comprising an annual total of over 11 billion metric tons of CO_2, China is the world's largest emitter. But it has essentially managed to offset growth in emissions with growth in energy efficiency and afforestation initiatives at half economic growth rate. India has reduced its annual carbon emissions by 18 million tons through renewable energy programs and more stringent air pollution laws, but remains mired in severe urban air quality problems, including cities like Delhi well over ten times the WHO safe

limit for PM2.5. While Mexico has decreased deforestation and shifted to natural gas, cutting emissions growth by 5 percent (about 10 million tonnes) a year, its carbon dioxide emissions are expected to grow by 69 percent by 2030 without further action. Heavily coal dependent, but South Africa is slowly introducing clean energy alternatives and bettering its energy efficiency, contributing more than 400 million metric tons of CO_2 annually. Yet, as this number showing shows, 80 percent of its energy still comes from coal, indicating only tepid progress in green transitions. Thanks to policies aimed at increasing renewable energy, efficiency and reforestation, these nations have collectively brought down annual emissions growth by about 300 million tons. But environmental concerns such as pollution, deforestation and the over reliance on fossil fuels mean that there is an urgent need for rapid coordinated cooperation and investment around the globe to balance economic development with ecological resilience.

The contribution of the study is threefold: Secondly, it offers a thorough assessment of the linkages among extremely rapid industrial development, urbanization and environmental degradation in the five (G5) developing nations of Brazil, China, India, Mexico and South Africa, focusing on these countries' critical part in creating environmental stress in the world. For example, this includes concrete metrics, such as Brazil's rate of deforestation as well as carbon emissions in China and South Africa and the resulting environmental price of economic expansion.

Second, the study identifies a crucial relationship between resource dependence, trade openness and environmental challenges. It examines the impact of natural resource rents, energy poverty and trade liberalization on ecological degradation in the G5 countries and discusses how these economic factors intensify ecological degradation and how this factor is also connected to global efforts of sustainability. Third, the study assesses the linkage between development of human capital, environmental sustainability, and green economic growth. The paper outlines initiatives ranging from renewable energy transitions, reforestation attempts, and urban sustainable endeavors, in these nations, and provides policy-relevant insights toward helping economic development with ecological sustainability.

The rest of the study is structured as follows: The introduction is given in section 1, laying out the ground for what follows. The theoretical and empirical foundation of the study in Sections 2 is provided by a detailed literature review. The analysis is conducted on the data provided in Section 3. Results and analysis from the finding are presented in Section 4, with possible intelligent insights presented. Finally, Section five concludes the research with the policy recommendations on the main findings.

LITERATURE REVIEW

Sustainability has been identified as the most important of its three primary pillars, with environmental sustainability being the most prominent due to the direct impact of climate change on low ecological system conditions (Abbass et al., 2022). Climate change and its associated concerns continue to be prominent and crucial aspects of contemporary global policy. This is due to the risks they present to the overall well-being of the population, which subsequently affect other aspects of economic performance such as productivity and standard of living (Raihan, 2023). As a consequence of the factors that contribute to environmental degradation, numerous studies have examined the relationship between various economic and environmental indicators (Kartal & Pata, 2023). Although certain aspects, such as energy poverty and green economic growth, have been extensively studied, trade

openness, human capital, and mineral rents, particularly in certain regions of the globe, have received relatively little attention.

Mineral rents

The influence of mineral resource rents ranges beyond the financial sphere, specifically on green economic growth and additional wellbeing indicators, according to a current argument in the literature (Abdulahi, Shu, & Khan, 2019; J. Wang & Zhang, 2023). As demonstrated by recent research, mineral rents may also have significant environmental repercussions (J. Wang & Zhang, 2023). In addition to water efficiency and global trading, Danish (2019) demonstrates that natural resource rent contributes to an increase in global carbon emissions. This evidence is consistent with the empirical finding of J. Wang and Zhang (2023) that mineral rent causes a long-term increase in carbon emissions.

This implies that an excessive reliance on natural resources is deleterious to the environment, particularly when resource conservation and management policies are disregarded by nations (Wassie, 2020). It is worth noting that the empirical evidence concerning the environmental impacts of resource dependence has emerged relatively recently (Cheng, Li, & Liu, 2020). Although there is a growing interest in investigating it, its scope remains restricted. The constraint also encompasses resource-rich nations whose resource dependence status on environmental quality has not been assessed. This investigation fills this empirical gap. Recent scholarly discourse posits that mineral rents have implications that transcend the economic domain, specifically concerning green economic growth and various welfare indicators (Luo et al., 2023). As demonstrated by recent research, mineral rents may also have significant environmental repercussions.

In addition to water efficiency and global trading that mineral rent contributes to an increase in global carbon emissions (Danish, 2020). This evidence is consistent with the empirical finding that natural resource rent causes a long-term increase in carbon emissions (Agboola, Bekun, & Joshua, 2021). Contemplating sixteen countries of the European Union present comparable evidence (Grigorescu, Pelinescu, Ion, & Dutcas, 2021). This implies that an excessive reliance on natural resources is deleterious to the environment, particularly when resource conservation and management policies are disregarded by nations. It is worth noting that the empirical evidence concerning the environmental impacts of resource dependence has emerged relatively recently. Even though exploration is increasing, its potential remains limited. The constraint also encompasses resource-rich nations whose resource dependence status on environmental quality has not been assessed. This investigation fills this empirical gap.

Green Economic Growth

The relationship between green economic growth and the environment has undoubtedly been the subject of extensive scholarly investigation (Ahmed, Asghar, Malik, & Nawaz, 2020), particularly with regard to environmental indicators such as carbon emissions and ecological footprint, and green economic growth. Despite the extensive body of research that has already been undertaken, resource-rich nations appear to be excluded from empirical evaluations. However, research focusing on the G5 countries or certain of its constituents may have been susceptible to aggregation bias due to the heterogeneity of the countries, particularly with regard to their resource endowments (Iziga & Takagi, 2023). To elucidate matters, a concise literature review encompassing several significant studies is presented.

Su, Wang, Li, and Wang (2022) Examine the relationship between the ecological and economic factors in 116 countries. Their results provide support for the correlation between the two indicators. Additionally, Usman, Kousar, Yaseen, and Makhdum (2020) examine the correlation between economic growth and ecological footprint in the 27 countries with the highest CO2 emissions. The results suggest that green economic growth has a positive impact on ecological footprint, suggesting that environmental degradation occurs in tandem with economic expansion (Ahmad et al., 2020). Contrary to the findings of Ansari, Villanthenkodath, Akram, and Rath (2023), which present comparable evidence for fourteen Sub-Saharan African states. Degbedji, Akpa, Chabossou, and Osabohien (2024) Demonstrate that increased green growth in Senegal serves to alleviate environmental degradation.

Additionally, it is worth noting that a feedback mechanism is present between pollutant emissions and economic growth in the countries under consideration. Several studies have employed carbon emissions and ecological footprints as indicators of environmental degradation in an effort to verify or disprove the hypothesis (Beton Kalmaz & Awosusi, 2022). AlZgool, Shah, and Ahmed (2020) Identify a correlation between green economic growths and the expansion or contraction of the ecological footprint in EU countries. This finding is consistent with the results presented by Cheng et al. (2020), which indicate that there is a relationship between green economic growth and resource extraction reliance on the environment. This implies that affluent individuals are less inclined to depend exclusively on the environment as a source of resources. Conversely, Zahra and Badeeb (2022) examine the environmental degradation hypothesis's validity through the lens of twenty-four OECD countries.

Energy poverty

Prominent researchers worldwide have transitioned their focus from non-renewable energy to renewable energy as a result of the environmental hazards associated with the former. Notably, the use of renewable energy helps prevent thermal pollution brought on by conventional energy sources (Panwar, Kaushik, & Kothari, 2011), significantly reduces fossil fuel emissions by functioning as a substitute for them. In contrast to fossil fuels, does not deplete. This results in a reduction of environmental degradation and the environmental burden associated with resource extraction and mining (Costa et al., 2021). The availability of electricity on a national scale is a key indicator of energy poverty, which must be addressed.

The contribution of energy poverty to the mitigation of environmental degradation in Malaysia is emphasized by Idris et al. (2021). Similar results were observed in Algeria, as demonstrated by Zhao, Jiang, Dong, and Dong (2021), who discovered that energy poverty has a positive effect on emissions. Literature also reveals the existence of additional country-specific countries for developed nations. Kerr, Gillard, and Middlemiss (2019) Provide evidence of the emissions-reducing effects of energy poverty in the England, Ireland and France.

Panel analysis is a method utilized by certain studies to encompass the regional ramifications of energy poverty on environmental degradation (Asad Amin et al., 2020). A negative relationship between energy poverty and emissions has been established for developing economies (Asad Amin et al., 2020) and 16 OECD countries (Hassan, Song, Khan, & Kirikkaleli, 2022). AGUIR BARGAOUI (2021) Examined the situation in 12 MENA countries, of which present comparable evidence. Akbas and Lebe (2021) Study, which indicates that energy poverty has a negative impact on carbon emissions in 74 countries, is additionally noteworthy. Some studies contend

that energy poverty may also have a negative impact on environmental quality (Ehsanullah et al., 2021). This argument is mitigated by the fact that pure energy does not include combustible energy or waste. Thus, Saidi and Omri (2020) contend that an increase in emissions is possible if their share of renewable energy sources is substantial. Renewable energy sources, such as solar, biofuels, geothermal, and wind, necessitate substantial amounts of land and water. Ecological footprint can be increased by energy poverty if land and water resources are scarce in some areas, which can result in environmental degradation (S.-U.-D. Khan, 2021).

Khan et al. (2022) Conducted a study that substantiates this notion, demonstrating that energy poverty leads to a greater ecological footprint due to increased inefficiency in land and water use. An environmental degradation ensues as a consequence. Additional criticisms directed towards the efficacy of energy sources encompass the sporadic characteristics of their discharges and the absence of storage technologies that operate efficiently. Therefore, during periods of high demand, electricity generation typically relies on a break-up power source, which includes fossil fuels (Batlle & Rodilla, 2010). Therefore, energy poverty can be attributed to the positive impact of renewable and nonrenewable energy consumption on CO2 emissions in ten MENA countries (Farhani & Shahbaz, 2014). Additionally, Arouri, Youssef, M'henni, and Rault (2012) demonstrate that energy poverty has a beneficial impact on emissions in five North African nations. However, Rzetelska and Combrinck (2022) conclude that energy poverty has no discernible impact on emissions.

To summarize, it is widely acknowledged in the literature that energy derived from conventional sources (such as fossil fuels) produces emissions. However, it is anticipated that the efficient utilization of energy resources will contribute to environmental improvement, with the exception of the aforementioned circumstances. Despite this, the impact of energy on the environment has received comparatively less attention, and there is no consensus among the available evidence. Thus, it is necessary to investigate whether renewable energy has any effect on the environmental condition of the G5 countries, which are resource-rich.

Gap Highlights

Based on the literature review presented above, it is apparent that this study is the first to investigate the interplay between energy poverty, mineral rents, and green economic growth in relation to environmental degradation in the G5 nations. Furthermore, the robustness of the measure is enhanced through the utilization of Carbon dioxide and or Ecological foot print as environmental degradation measures in the research. The review demonstrates that the vast majority of prior research has relied exclusively on Carbon dioxide emissions or Ecological foot print, which can be deceptive. Therefore, this research represents a scholarly contribution to the existing body of literature. Likewise, more robust metrics were employed in the research to evaluate the influence of energy poverty.

As a third construct, the green economic growth was introduced. An additional piece of literature is warranted due to the absence of robust tests utilizing trade openness and human capital in any of the reviewed studies. The impact of mineral rents on environmental degradation measures is broken down by mineral in this study. Methodologically, this research integrated the fixed effect (FE), random effect (RE), Feasible Generalized Least Squares (FGLS), and augmented mean group techniques, an uncommon occurrence in studies pertaining to G5 countries. The study's contributions to the discourse surrounding the interrelation between environmental

degradation, green economic growth, and natural resources-energy poverty are comprised of addressing these significant gaps in the literature.

METHODOLOGY

This study investigates the contribution of green economic growth, energy poverty, and mineral rents to environmental degradation in the G-5 countries through the use of balanced panel data observations spanning the years 2000 to 2022. This research utilized mineral rents as a measure of natural resource rent. The natural resources that the G-5 nations possess in abundance substantially contribute to their economic development and growth, as does their income. Ecological Footprint and CO2 were similarly used as environmental degradation indicators. The rationale behind the adoption of CO2 and environmental degradation indicators is their significant contribution to the overall production of greenhouse gases. Conversely, ecological footprint is a contemporary indicator of ecological quality. Greenhouse gases make up the largest portion of greenhouse gas emissions. The metric takes into account the element of rent in areas required to support an economy uniquely. Included in these natural zones are agricultural land, forested regions, carbon sinks, developed areas, fishery grounds, and grazing territories. Mining activities contribute to the degradation of soil, groundwater, and surface water, which provides additional support for the EFP indicator.

Due to the correlation between environmental degradation and green economic development, energy poverty may have far-reaching consequences, including the extraction of natural resources (Zhang & Khan, 2023). The G-5 Countries rely heavily on natural resource exports as their primary revenue stream; therefore, green economic growth is vital to their survival. To capture energy poverty, the study utilized national electricity access output, as suggested in recent literature on energy poverty (Murshed & Ozturk, 2023). Indicators of national electricity access evaluate real-time fluxes and operations. The unit of measurement for green economic growth, which is distinct from negative externalities to the environment including the depletion of natural resources and the expense associated with CO2 emission damage, is found to be a percentage.

The study's inferences regarding energy poverty and green economic growth underwent two robustness checks. The literature has established that both variables have an impact on emissions. For example, there is a direct correlation between the expansion of green economic growth and the escalation of ecological pressures on natural resources. The comprehensive exposition of the study variables, including their respective measurements and sources, is summarized in Table 1.

Table 1.
Summary and Source of Variables

Constructs	Definition and Measure	Source
Green Economic Growth (GEG)	Economic growth separated from negative externalities to the environment, such as depreciation of natural resources and the cost of Carbon dioxide emission damage, the unit of measurement is a %.	World Bank
Environmental Degradation (ED)	CO2 emissions from the consumption of fuel derived from petroleum as an energy source with the unit of measurement is kilo tons	International Energy Agency
Energy poverty (EP)	Access to electricity (% of population)	World Bank

Trade Openness (TO)	Total exports and imports of goods and services measured as a share of GDP with the unit of measurement being a percentage of GDP	World Bank
Human Capital	Humn Capital Index	Penn World
Mineral Rents to Total Natural Resources Rents (MRTN)	Mineral rents are the difference between the value of production for a stock of minerals at world prices and their total costs of production. (% of GDP) Total natural resources and soft), mineral rents, and forest rents. (% of GDP) rents are the sum of oil rents, natural gas rents, coal rents (hard	World Bank

MODEL ESTIMATIONS

Cross-sectional dependency test

CSD presents a significant obstacle in panel data estimation. The robustness of projected parameters; illustrated from samples with the probability of being cross sectional dependency (CSD) (Pesaran, 2021). Disregarding the cross-sectional dependency feature inherent in panel data analyses introduces the potential for estimated coefficients to be inconsistent and inefficient. Thus, it is essential to conduct a cross-sectional dependency test between variables to overcome this issue. According to De Hoyos and Sarafidis (2006), cross-sectional dependency does not pose a challenge when working with micro panels; however, it does become a concern when dealing with macro panels. The sample data for this investigation covers 23 time periods and 5 countries. Due to this, a cross-sectional dependency test is essential given that the panel dataset has a macro structure. In pursuit of this objective, this research employed four cross-sectional dependency tests: the Lagrange multiplier test (Engle, 1984); the scaled LM test and CSD test; and the bias-corrected scaled LM test utilized. The equation for the test is given below:

$$CSD = \sqrt{\frac{WM(M-1)}{2}}\left[\frac{2}{M(M-1)}\right]\sum_{t=1}^{M-1}\sum_{k=t+1}^{M}\gamma 2tk \quad \text{----------(1)}$$

The pair-wise CS-correlation parameters are denoted by γ^{2tk}. Where W denotes the time unit or sample period and M signifies the cross-sectional size of the panel. After confirming the existence of cross-sectional dependency, the relevant econometric techniques applicable to cross-sectional dependency problems will be implemented. The precise formulation cross-sectional dependency equation is as follows:

$$CSD = W\sum_{t=1}^{M-1}\sum_{k=t+1}^{M}\gamma 2tk \quad \text{----------(02)}$$

and the cross-sectional dependency test is described as

$$CSD = \sqrt{\frac{2W}{M(M-1)}}\sum_{t=1}^{M-1}\sum_{k=t+1}^{M-1}\gamma_{ij} \quad \text{----------(03)}$$

More attention should be paid to the results of the cross-sectional dependency test and the LM test, given that the research dataset is characterized by W > M.

Panel unit root tests

The evaluation of the constructs' stationarity occurs after the results of the cross-sectional dependency tests. Traditional unit root methods of the first generation, fail to adequately address cross-sectional dependency concerns. In light of the existence of Cross Sectional Dependency, this investigation employed mutually 1st-generation and 2nd-generation Cross Sectional Unit Root Tests (CSURT). The 1st generation cross sectional dependency unit root test is implemented. The second-generation unit root

tests consist of cross-sectional augmented Dickey-Fuller (CADF) and cross-sectional IPS (CIPS) respectively. As such, the CADF test statistic is expressed in equation form:

$$\Delta Mtk = \infty tk + \tau kMk, t-1 + \delta k\bar{M}t-1 + \varphi k\Delta\bar{M}t + \epsilon tk \quad \text{----------(04)}$$

where the intercept, research constructs, and error term are represented, respectively, by ∞_{tk}, M_{tk}, and ϵ_{tk}. The following equation yields when the first lag expression is inserted.

$$\Delta Mkt = \infty it + \tau kMk, t-1 + \delta k\bar{M}t-1 + \sum_{L=0}^{p} \varphi kL\Delta\bar{M}t-j + \sum_{L=1}^{p} \tau kL\Delta\bar{M}k, t-L + \epsilon$$

----------(05)

In the context of specific cross-sections, $M_{t\text{-}L}$ and $\Delta M_{k,t\text{-}L}$ represent the mean of the lagged and first difference operators, respectively. By applying the subsequent equation, one can obtain the CIPS test statistics:

$$CIPS = \frac{1}{M}\sum_{k=1}^{M} \tau k(M, W) \quad \text{----------(06)}$$

The cross-sectional augmented Dickey-Fuller test statistics are denoted by the coefficient τk(M, W), which can be calculated as follows:

$$CIPS = \frac{1}{M}\sum_{k=1}^{M} CADF_k \quad \text{----------(07)}$$

Preceding parameter estimation, cointegration testing becomes necessary assume the tests validate the research's constructs are stationary at integrated order one. Panel series heterogeneity and CSD are substantiated with confidence by the cross-sectional augmented Dickey-Fuller and CIPS panel unit root tests.

Cointegration test for panel Data

Following the implications of the unit root test which includes Cross sectional dependency, it is crucial to determine whether a long-run relationship exists between the constructs. An appropriate cointegration test that incorporated CSD into its estimation procedure. An error-correction model-based test for cointegration. Nevertheless, the implementation of the Westerlund (2008) cointegration test in this analysis was limited due to its restriction to a maximum of five covariates per model. In pursuit of this objective, the researchers utilized three residual-based panel cointegration tests: the Westerlund (2008) test, the Pedroni (1999), and the Kao (1999) tests.

Although the null hypothesis of none of the three tests is cointegration, the alternatives of the Kao and Pedroni tests are that all panels are cointegrated. The default test of the Westerlund (2008) test, on the other hand, is constructed upon a framework that explicitly includes the autoregressive coefficient, as determined by the variance ratio test statistics. There is a division in the alternative hypothesis regarding whether to employ partial or complete panel cointegration. Following the approach suggested by Burdisso and Sangiácomo (2016), the cointegration tests were performed without deducting the cross-sectional means from the series to account for the CSD characteristic of the series.

Fixed and Random Effect Model

Following conventional wisdom, panel data investigates the influences of time and group, which correspond to the specific and heterogeneity effects, denoted as FE or RE. Specific effects, time effects, or both may be investigated by a panel data model. FE and RE models are frequently utilized for this purpose. Unlike the RE, which investigates variations in error variances, the FE verifies whether constants vary between periods or individuals. These are the advantages of both effects:

- Time-constant covariates are estimated using the RE model.
- To derive unbiased estimates, the FE model is implemented.
- Arising the genuine causal influence of an object is facilitated by a more dependable estimate provided by the FE.
- Time-series and cross-sectional data are used in panel analysis, and both effects help.

Notably, the parameter estimations of the fixed and random effect are probable to experience negligible variation if W is substantial and M is negligible.

Solely on account of computational convenience does the estimation method prevail in this circumstance? The FE may be more desirable in light of this logic. The estimates derived by both methods may, however, differ significantly when M is large and W is tiny.

The following represents the general estimation of RE for the study:

$$Y_{kt} = (\beta_0 + \mu_{0L}) + \sum_{L=1}^{N} \beta_j X_{L,kt} + \in_{kt} \text{ ----------(08)}$$

Y denotes the outcome variable, X represents the predictors' variable, €$_{0L}$ signifies the random intercept, and β_0 signifies the global intercept.

Likewise, the overall fixed effect estimation for the research is denoted as:

$$Y_{kt} = \theta_k + \omega_k + \sum_{L=1}^{N} \beta_L X_{L,kt} + \ + \in_{kt} \text{ ----------(09)}$$

In the given context, θ_k denotes the time-fixed effect and ω_k represents the specific fixed effect component for individual.

Introduction to Feasible Generalized Least Squares (FGLS)

Hansen (2007) Proposed the FGLS and PCSE methods for coping with autocorrelation, heteroscedasticity, and cross sectional dependency in panel data. The efficiency of the FGLS approach is determined by whether the period is equal to or greater than cross-sectional units, which is the criterion for comparing the two methods. Conversely, if the situation is reversed, the PCSE method should be implemented. By default, neither technique produces outcomes that are influenced by autocorrelation, heteroscedasticity, or CSD. As the data from this analysis are consistent with the Feasible Generalized Least Squares condition, the Panel-Corrected Standard Errors method was therefore not estimated.

The Feasible Generalized Least Squares estimator of c is typically expressed as follows:

$$\beta_{FGLS} = (X^{W^{-1}} X)^{-1} X^W \Omega^{-1} y \text{ ∨----------(10)}$$

In this context, Ω represents a model-derived innovation covariance estimate. Therefore, the parameter covariance matrix that is computed is represented as follows:

$$\sum FGLS = \varpi^2{}_{FGLS} (X^W \Omega^{-1} X)^{-1} \text{ ---------- (11)}$$

Then,

$$\varpi^2{}_{FGLS} = y^W [\Omega^{-1} - \Omega^{-1} X (X^W \Omega^{-1} X)^{-1} X^W \Omega^{-1}] y / (W - p) \text{ ---------- (12)}$$

To calculate the Feasible Generalized Least Squares parameters, the subsequent conditions must be met:

- Ordinary least square is applied to the data before estimating residuals.

- Ω̂ is calculated in the presence of a model that accounts for the covariance of innovations.
- The FGLS is calculated alongside the covariance matrix FGLS.

Therefore, if Ω̂ consistently approximates Ω and the constructs comprising X are independent, the Feasible Generalized Least Squares estimators are deemed efficient and reliable. It is important to acknowledge that to attain maximum efficiency, an efficient estimation of the coefficients in β may not be necessary. Instead, a consistent estimate is sufficient, and the FGLS technique offers that. Long-run effects may be attributed to estimated parameters derived from the FGLS process.

AMG model

The AMG was utilized to facilitate additional comparisons of the research parameters, as recommended by Bond and Eberhardt (2013). The augmented mean group likewise (Dogan et al., 2020) incorporates CSD and heterogeneity into panel data analysis. The methodology integrates a shared dynamic process into a two-step interdependent regression process, as illustrated by Equations (13) and (14).

Step 1

$$\Delta y_{kt} = \alpha_k + b_k \Delta x_{kt} + \psi_k R_t + \sum_{w=2}^{w} 2\varsigma_k \Delta Q_t + \in_{kt} \text{ ---------- (13)}$$

Step 2 AMG

$$b_{AMG} = M^{-1} \sum_{k=1}^{M} b_k \text{ ---------- (14)}$$

Rt denotes the unobserved common factor, xkt and ykt are the observables, çi represents the parameter of the period dummies, b_k is the nation-specific estimation of the parameter, and bAMG represents the AMG estimator.

Descriptive statistics

The combined descriptive statistics of the G5 countries during the study period are presented in Table 2. For the G 5 nations, the overall green economic growth rate is 6.98. Regarding mineral rent, the aggregate mean value is 1.449, while energy poverty is 0.755. China and Brazil, according to individual outputs in Table 3, are the least and most receptive, respectively, of the G5 nations. Comparatively, theTable 3 presents the specific average Carbon dioxide emissions of the G5 countries. According to the International Energy Agency (2021), the country's average CO2 emissions per capita are approximately 2.87 Mtoes, which is significantly higher than or close to the national average.

According to the data, South Africa has the highest average CO2 emissions at 7.02 (Mtoes), whereas India has the lowest mean at 2.17 (Mtoes). The average EFP for the G 5 countries is approximately 2.06 (gha), as shown in Table 3. The author takes the average of the provided averages from the Global Footprint Network for 2022. India has the lowermost ecological footprint average of 1.21 gha, whereas China has the greatest mean of 3.01 (gha), as shown in Table 4. China has the greatest mean value for mineral rent among the G5 nations (1.765), as shown in Table 3. Brazil has the lowest mean value (0.07). In contrast, China has the lowest energy poverty mean (0.065), whereas Brazil has the highest at 2.87. Comparatively, South Africa and Bolivia have the lowest green economic growth rates (1.57 and 1.55, respectively), while China has the highest at 9.765.

Table 2.
Aggregate Descriptive statistics

Constructs	Average	S.D	Minimum	Maximum
CO2	2.671	2.301	0.214	9.675
EFP	12.01	20.141	1.086	66.975
MR	1.449	0.876	0.001	6.805
EP	0.755	2.342	0.001	4.543
GEG	6.983	8.876	0.0065	29.654

Table 3.
Country-wise Descriptive Statistics

Constructs		Brazil	China	South Africa	Mexico	India
CO2	Average	2.54	6.89	7.02	2.97	2.17
	S.D	1.98	1.11	1.765	0.134	2.14
EFP	Average	1.456	3.01	2.654	1.965	1.21
	S.D	0.089	0.241	2.324	1.654	0.24
MR	Average	0.07	1.96	1.064	1.765	1.01
	S.D	0.09	0.017	0.675	1.567	0.76
EP	Average	2.87	0.065	0.789	1.578	1.65
	S.D	0.92	0.134	1.456	0.523	1.1
GEG	Average	1.56	9.765	1.567	1.456	2.17
	S.D	1.45	2.71	1.456	2.276	0.98

Correlation and cross-sectional dependency (CSD) test

The correlation between the majorities of the study constructs is feeble, as shown in Table 4, except for the correlation between mineral rent to CO2 and ecological footprint. As a result, a test was performed to determine the variance inflation factor (VIF), and the results are presented in the lower panel of Table 4. Table 5 demonstrates that the average variance inflation factor value for the research predictors is below 5, which suggests the existence of a modest correlation among the predictors and reduced severity of multicollinearity concerns. An analysis of the results presented in Table 6 indicates that the estimated cross sectional dependency test furnishes substantial support for the existence of cross-sectional dependency in the panel data. The results of the 04 tests provide support for rejecting the null hypothesis that there is no cross-sectional dependency for the constructs examined in the panel study.

Table 4.
Correlation Matrix

	CO2	EFP	MR	EP	GEG
CO2	1				
EFP	—0.644	1			
MR	0.932	0.543	1		
EP	0.485	0.402	0.034	1	
GEG	—0.125	—0.352	—0.344	0.234	1

Table 5.
Multicollinearity

VIF	1/VIF
4.65	0.215
4.31	0.232
5.41	0.185
Mean VIF	4.790

Table 6.
Cross-Sectional Dependency Test

	CO2	*EFP*	*MR*	EP	*GEG*

Breusch-Pagan LM	167.75***	119.502***	145.033***	141.648***	176.034***
Pesaran scaled LM	41.543***	23.234***	29.121***	29.201***	38.455***
Bias-corrected Scaled LM	38.678***	25.176***	29.196***	28.115***	46.379***
Pesaran CD	4.441***	8.481***	12.183***	12.893***	33.112***

Unit root and heterogeneity

The outcomes of the adjusted slope heterogeneity tests are presented in Table 7. The findings confirmed the alternative hypothesis that the slope parameters were homogeneous. Simultaneously, this confirms the existence of slope heterogeneity among the study variables' parameters across the G-5 nations. To validate the constructs' slope heterogeneity and cross-sectional dependency, unit root test techniques were utilized, which account for both heterogeneity and cross-sectional dependency in the unit root process. The outcomes of the 1st and 2nd generation are summarized in Table 8. For all constructs, the null hypothesis of the Wu, and unit root tests of Pesaran CIPS, which state that series are I(1) was devastatingly recognized. Likewise, the null hypothesis of stationarity at the first difference, which underpinned the unit root test of Pesaran CADF, was rejected for every series. Therefore, all series embrace the alternative hypotheses.

Table 7.
Slope heterogeneity Test.

	Value of Δ	**Value of Δ adjusted**
CO2	9.654***	10.678***
EFP	5.543***	6.245***

Table 8.
Unit Root Test

	First-generation unit root		**Second-generation unit root**			
	Wu (1999)		**Pesaran's CADF (2003)**		**Pesaran's CIPS (2007)**	
	Without trend	**With trend**	**Without trend**	**With trend**	**Without trend**	**With trend**
CO2	5.542	6.081	—2.87***d	—3.355***d	1.438	2.252
EFP	3.847	5.494	—3.176**d	—3.108**d	—0.876	3.15
MR	6.721	4.354	—1.759***s	—2.112**d	—3.279**	—0.672
EP	8.745	2.173	—2.977*	—2.918*	0.087	1.654
GEG	11.581	6.676	—3.552**s	—5.441***d	—1.876**	0.221
H0	Series is Integrated order 1		Series is non-stationary		Series is Integrated order 1	

Note: stationarity represent with s and fd represents the 1st difference

*, represent 10%** represent 5%, and *** represent 1%

Panel Cointegration test

The cointegration connection among the research constructs is illustrated in Table 9. While the Kao test indicates weak cointegration between the constructs for the first model, its results for the remaining models provide support for the long-run association. On the contrary, the Pedroni cointegration test confirms that long-run associations exist among the 03 models. Similarly, the Westerlund variance ratio test rejects the null hypothesis that there is no cointegration and supports the alternative that certain

panels for all 03 models are cointegrated. As a result, it can be deduced that a long-term correlation exists among the three study models.

Table 9.
Cointegration test

	CO2	EFP
Test 1-Kao	Values	Values
Modified Dickey-Fuller (MDF) t	—1.431***	—2.348**
Dickey-Fuller (DF) t	—1.021	—2.467**
Augmented Dickey-Fuller (ADF) t	—0.107	—1.976**
Unadjusted modified Dickey-Fuller t	—2.203*	—7.387***
Unadjusted Dickey-Fuller t	—1.365	—4.346**
Test 2- Pedroni		
Modified variance ratio (MVR)	—2.547***	—2.421***
Modified Phillips-Perron (MPP) t	1.235*	1.607*
Phillips-Perron t	—0.153	—3.493**
Phillips-Perron t	—0.234	—3.198**
Augmented Dickey-Fuller t	—1.765***	—3.134**
Test 3- Westerlund		
Variance ratio	3.234**	—1.764**

Note: *, **, and *** indicate significance at 10%, 5% and 1% respectively.

Estimated Results

The output of the random effect and fixed effect is detailed in Table 10. The outcome indicates that the fixed effect model is deemed reliable concerning CO2, whereas the EFP model's random effect estimate is deemed efficient. Nevertheless, the impact of mineral rents on the output of the consistent fixed effect and efficient random effect is negligible. The comparison between the Feasible Generalized Least Squares approach and the consistent fixed effect and efficient random effect models was conducted using the Hausman test, as shown in Table 11. The effects of energy poverty and mineral rents on environmental degradation are estimated to be substantial by the Feasible Generalized Least Squares models.

Additionally, the Hausman test confirmed that the FGLS results were superior to the FE and RE results. In the same way, a comparison was made between the estimated outputs of the feasible generalized least squares as present in Table 11 and the estimated outcome of the augmented mean group present in Table 12, with a summary of the findings. In addition, the efficiency of the FGLS outputs in comparison to the AMG results was assessed using the Hausman test. Therefore, the Feasible Generalized Least Squares outputs are the most robust to the fixed effect, random effect, and augmented mean group estimations, according to the findings of this study. The Feasible Generalized Least Squares outputs are therefore utilized to originate the research's conclusions.

Table 10.
Fixed and Random Effect

	CO2		EFP	
	RE	**FE**	**RE**	**FE**
MR	0.073***	0.065**	1.176***	0.864***
EP	—0.043	—0.041	—0.344	—0.314
GEG	0.11	0.11	0.045	0.08
cons	1.765**	1.767***	4.667	—0.306
Wald test	23.36***		46.41***	
No. of Obs.	155	150	155	150
No. of groups	5	5	5	5
Hausman test		>0.05	<0.05	

Table 11.
Fixed, Random and FGLS Effect

	CO2		EFP	
	FE	FGLS	RE	FGLS
Mr	0.157**	0.801***	1.263***	4.965***
EP	—0.036	0.917***	—0.291	2.854***
GEG	—0.176	0.07	0.056	0.67
cons	1.761***	7.494***	3.87	27.097***
Wald test		844.14***	45.31***	1137.81***
Observations (No.)	155	150	155	150
Groups (No.)	5	5	5	5
Hausman		6335.87***		334.39***

DISCUSSION

Mineral resources rent have a significant positive effect on the Carbon dioxide and ecological footprint environmental measures, as demonstrated in Table 12. As a consequence, the findings demonstrate that mineral rents contribute to environmental degradation in the G5 nations. Since the G-5 countries accounted for approximately 42% of the total mineral production in 2022 alone, the result is plausible. Copper, diamonds, gold, aluminium, iron ore, limestone, and various other minerals are extracted in these nations. The environment is known to be negatively impacted by both industrial and artisanal mining methods. Arsenic, cyanide, and mercury are just a few of the heavy metals disseminated by artisanal mining that have negative effects. Additionally, Brazil and South Africa are two of the main nations in the globe that contribute significantly to the global inventory of natural resources.

This study is consistent with previous research that has documented the detrimental effect of minerals rents on the environment. On the contrary, Table 12 illustrates that energy poverty has a significant negative influence on environmental degradation indicators. Conversely, green economics demonstrate positive effects on the aforementioned two environmental degradation measures. The knowledge and technologies that are predominantly transmitted from developed economies to the G-5 countries are frequently of low quality, obsolete, and fail to advance the cause of environmental sustainability. The inverse effect of the energy poverty measures, on the other hand, suggests that extant trade or commerce and speculation guidelines, association in global bodies, international agreements, and responsiveness in the G 5 countries can substantially lessen environmental degradation in these nations. Hence, by incorporating ecological sustainability strategies into the financial, community, and governmental liberalization treaties of the G-5 nations, environmental degradation can be effectively reduced.

Because the positive effects of green economic growth outweigh the negative effects of energy poverty, this study concludes that green economic growth reduces environmental degradation. The submission is consistent with research (Usman et al., 2022a,b) that has demonstrated the environmental benefits of green economic growth. The findings indicate that the overall impact of green economic growth, energy poverty, mineral rent, and energy poverty on environmental degradation in the G-5 countries. Nevertheless, substantial environmental degradation can be significantly mitigated by implementing and applying stringent environmental-friendly trade and speculation strategies, regulations, and operative guidelines in these nations. To create a future green society, China's G Reen Economy. Moreover, both India and South Africa initiated efforts to promote low-carbon mobility and

sustainable development. By 2030, following the sustainable development goals (SDGs), a green and secure environment is to be established. As a result, the government promotes green cities and encourages reduced carbon emissions.

Robustness test

The robustness check performed on the research inferences resulting from the Feasible Generalized Least Squares result in Table 12 is presented in Table 13. Two outputs of robustness checks are presented in Table 13. The 1st outcome indicates the influence of GDP per Capita models on the study models that were adopted, whereas the second output demonstrates the results of trade openness and human capital. The conclusions drawn in Output 1 indicate that the coefficients for trade openness do not differ markedly from the values obtained in Table 12. The environmental degradation indicators, however, show that trade openness has no discernible effect. By additionally integrating human capital, as demonstrated in outcome 2 present in Table 13, the conclusions drawn from Table 12 continue to be sound. As a result, the conclusions drawn from Table 12 are acceptable and dependable for strategy formulation, according to this study. While trade openness may have a negligible impact on environmental degradation, it has been reported that human capital has considerable positive effects on Carbon dioxide emissions and EFP. The result indicates that the G-5 countries have inadequate human capital, which exacerbates environmental degradation in these nations. These nations, except for China, engage in activities like indiscriminate tree cutting for the production of charcoal and firewood, shrub sweltering for agricultural and hunting purposes, and inadequate refuse administration, particularly in rural societies.

Table 12.
Output of FGLS and AMG

	CO2		EFP	
	FGLS	AMG	FGLS	AMG
MR	0.717***	—0.687	5.857***	5.134
EP	—0.134***	0.008	—0.897***	0.275*
GEG	0.557***	—4.162	2.586***	—71.312
cons	6.76***	1.271***	29.176***	4.075
Wald test	844.14***	22.17***	1121.71***	246.66***
Observation (No.)	155	150	155	150
Groups (No.)	5	5	5	5
Hausman	419.24***		609.71 ***	

Table 13.
Robust Output of FGLS

	Output 1		Output 2	
	CO2	EFP	CO2	EFP
MR	0.716***	5.507***	0.661***	5.917***
EP	0.853***	2.521***	0.557***	3.104***
GIDF	0.13***	1.019***	0.096***	1.119***
GDPPC	—0.005	0.197	—0.013	0.192
HC			2.011***	1.113*
cons	6.741***	21.842***	4.546***	27.113***
Wald test	834.10***	1138.56***	920.08***	1139.88***
No. of Obs.	155	155	155	155
No. of groups	5	5	5	5

IMPLICATIONS AND CONCLUSION

Consistently garnering the interest of policymakers and academicians, environmental degradation has remained a significant global concern. In examining the effects of green economic growth, energy poverty, and natural resource rents on environmental degradation in the G-5 countries between 2000 and 2022, this study thus makes an additional scholarly contribution. The fixed effect, random effect, feasible generalized least square, and augmented mean group methodologies were implemented. To validate the FGLS results and, by extension, the inferences drawn from the study, the Hausman test was employed. The study's results indicate that environmental degradation in the G-5 countries is substantially influenced by natural resource rents. In contrast, the G 5 Countries' environmental effect on poverty is inverse. The model inferences' validity and dependability were ascertained through robustness checks conducted on the study models. Further evidence derived from the robustness tests indicated that human capital development has a considerable negative impact on the environment, whereas trade openness does not have a significant effect on environmental degradation.

This study identifies pertinent policy measures that have the potential to significantly mitigate environmental degradation in the G-5 countries. First, concerned governments and policymakers should, like the developed world, concentrate on strategies that will reduce dependency on the exploitation and utilization of natural resources (such as fossil fuels and gas) and highly environmental degradation-prone minerals. Therefore, there is a need to increase research and investment in energy that is renewable. It would not be inappropriate for concerned governments to investigate potential policy measures regarding renewable hydrogen (H2) as an alternative greener natural resource. There is a growing recognition that renewable H2 energy is a more favorable substitute for fossil fuels in the transportation sector as well as in industrial and residential energy systems. Additionally, H2 is environmentally benign and more efficient than conventional energy sources. However, G-5 countries must incorporate conservative methodologies into their natural resource exploration and exploitation practices in the interim. Prioritizing methods that enhance natural resource exploration through the implementation of new technologies should take precedence over their initial investment cost, provided that such methods are environmentally sustainable.

Green economic growth facilitates the transmission of environmentally sustainable technologies to developing nations, thereby contributing to the alleviation of energy poverty. By increasing the demand for clean business strategies, governments can facilitate the reduction of environmental degradation and establish a sustainable trajectory for electricity provision on a national scale. Governments should therefore increase their funding for modern, environmentally benign extractive technologies. It is advisable to promote investment in technologies, skills, and techniques that eliminate emissions. In pursuit of this objective, concerned governments may implement regulatory and legal frameworks that deter environmentally damaging activities while encouraging environmentally sustainable investment via tax incentives and other similar schemes. To increase sustainability and decrease energy poverty, competent organizations can use trade openness. Firms discovered attempting to pollute the environment while conducting exploratory operations on the continent should also be subject to punitive measures. By adopting this measure, conservation efforts may be maintained in addition to emissions being eliminated. Promoting trade openness requires the regulation of the interchange of products and the enforcement

of multilateral and two-sided trade contracts with the possible to reduce negative environmental impacts. Additionally, countries must increase their efforts to achieve green development. Therefore, there is a need for more exceptional replications of smart cities in densely populated areas. Energy-efficient household appliances and transportation will also need to be adopted by the affected countries. A reduction in environmental degradation therefore necessitates enhanced human capital development. To foster a conscientious imperative to consider environmental issues while striving to satisfy human necessities, it would be necessary for governments to increase their investments in human capital development. Considerable emphasis should be placed on the development of educational curricula that foster environmental sustainability throughout the advanced levels of schooling.

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