

## Article

# Nexus between Innovation–Openness–Natural Resources–Environmental Quality in N-11 Countries: What Is the Role of Environmental Tax?

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**Abstract:** This research investigates the intricate relationship between financial openness, natural resources, and carbon neutrality in the N-11 countries. It provides insights into how environmental tax and innovation can drive carbon neutrality in these nations, thus advancing our understanding of the nexus among financial openness, natural resources, and carbon neutrality. The study aims to offer policymakers perspectives on formulating policies to foster sustainable economic development and environmental conservation in the N-11 nations. The discourse highlights the environmental implications of foreign direct investment (FDI) and trade openness, revealing a complex interplay between economic development, technological innovation, and environmental sustainability. While FDI can facilitate technological transfers and managerial advancements that enhance resource efficiency and promote environmentally friendly practices, its environmental impact varies based on regulatory frameworks and enforcement mechanisms. In countries with weak environmental regulations, FDI may lead to negative outcomes such as pollution hotspots, resource depletion, and ecosystem degradation. Similarly, trade openness can exacerbate environmental degradation through increased production, energy consumption, and waste generation. However, both FDI and trade openness can contribute positively to environmental sustainability when coupled with effective environmental policies, investment in green technology, and the promotion of sustainable practices. Thus, policymakers must strike a balance between economic development and environmental protection by implementing stringent environmental regulations, promoting clean technology transfer, and fostering sustainable development practices domestically and internationally. This research offers valuable insights for policymakers aiming to navigate the complexities of achieving carbon neutrality while ensuring sustainable economic growth in the N-11 countries.

**Keywords:** innovation; openness; Natural Resources Environmental Tax; carbon neutrality; CUP-FM; CUP-BC; NARDL; DH causality



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## 1. Background of the Study

A fast rise in population, development of agriculture, urbanization, and industrial output result in greater competition for natural resources; this rivalry leads to the fast depletion of these resources and consequent environmental damage [1]. It becomes increasingly problematic for nations with low income and lower-middle income to spend appropriate resources on boosting the health and education of their populations [2]. Water stress is a major topic, since the overuse and depletion of water supplies have a dramatic influence on the lives of nearly 2 billion humans and have a substantial influence on the Sustainable Development Goals (SDGs) relating to water and sanitation [3]. The deterioration of land- and water-based ecosystems is a key result of the expanding population, intensification of agriculture, and urbanization which has led to harmful repercussions on the environment [4]. These ecosystems play a significant role in delivering important resources such

as food, clean water, air, and raw materials that are needed for supporting economic development. It is a big issue for nations to attain the SDGs2, owing to the fast depletion and environmental deterioration of these resources. Climate change is generally regarded as a serious hurdle to reaching the Sustainable Development Goals (SDGs). In order to effectively accomplish the objectives set by the Sustainable Development Goals in the areas of reproductive health, education, and gender equality, it is necessary to empower people, with a special emphasis on women, to make informed choices that contribute to sustainable development [5]. Energy efficiency and health expenditures have a substantial influence on the health sector, and they interact with sustainable development and environmental deterioration, eventually influencing the accomplishment of SDGs in the region.

Environmental degradation in the N-11 (Next Eleven) nations, which include Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, Philippines, South Korea, Turkey, and Vietnam, presents a complex and multifaceted challenge that requires urgent attention. These countries, identified for their potential to become among the world's largest economies in the 21st century due to their demographic and economic potential, face unique environmental issues exacerbated by industrial growth, urban expansion, and agricultural intensification. The primary causes of environmental degradation in the N-11 nations are industrial pollution, deforestation, overfishing, and poor waste management. Industrial growth, while beneficial for economic development, often comes at a high environmental cost. Factories and plants in countries like Indonesia and Vietnam frequently discharge pollutants into water bodies and the atmosphere, leading to severe water and air pollution. This not only harms the environment but also poses significant health risks to the population.

Deforestation is another critical issue, particularly in countries with large forest covers like Indonesia and Nigeria. The expansion of agricultural lands, logging activities, and urbanization are the main drivers of deforestation. This leads to loss of biodiversity, disruption of water cycles, and increased carbon emissions, contributing further to climate change. In Brazil, not an N-11 country but a relevant example, deforestation in the Amazon has similar underlying causes and effects, highlighting a global pattern of environmental degradation tied to economic pursuits. Overfishing is a significant problem for the N-11 nations with large coastal areas, such as the Philippines and Bangladesh. The depletion of fisheries due to overexploitation and illegal fishing practices affects marine ecosystems and the livelihoods of communities dependent on fishing. This also leads to a decline in marine biodiversity, affecting food security and economic stability in these regions. Poor waste management is a pervasive issue across the N-11 nations, leading to pollution and public health crises. In many of these countries, the infrastructure for waste disposal and treatment is inadequate. This results in the improper disposal of industrial and domestic waste, contaminating water bodies and land, and contributing to the spread of diseases. The consequences of environmental degradation in the N-11 nations are profound. They not only affect the health and well-being of the populations but also impair economic productivity and sustainability. Environmental issues can lead to a vicious cycle where poor communities become increasingly vulnerable to disasters like floods and droughts, further entrenching poverty.

To address these challenges, it is crucial for N-11 nations to implement sustainable development policies that balance economic growth with environmental conservation. This includes investing in clean technologies, enforcing environmental regulations, improving waste management systems, and promoting awareness and education about sustainable practices. Moreover, international cooperation and aid are essential to support these nations in their environmental efforts. Global initiatives and funding can help build capacity for environmental management and sustainable development, ensuring that the growth of these potentially powerful economies does not come at the expense of their natural heritage.

A decline in environmental quality disrupts ecosystems, leading to habitat degradation, species extinction, and imbalances in ecological cycles. Environmental quality is vital for maintaining biodiversity, assuring resilience against environmental disruptions,

and supporting ecosystems that provide essential services like pollination, water purification, and nutrient cycling (Ahmad, et al. [6]). The quality of the environment profoundly affects human health. Poor environmental quality, characterized by air and water pollution, chemical contamination, and habitat degradation, poses significant health risks. It contributes to respiratory diseases, waterborne illnesses, cardiovascular problems, and other health issues. Contaminants in the environment can affect physical and mental health, influencing stress levels and overall quality of life (Hernández-Delgado [7], Liu, et al. [8], Huo and Peng [9], Fang, et al. [10]). Environmental quality surpasses national boundaries, necessitating international collaboration. Issues like air and water pollution, biodiversity loss, and climate change require coordinated efforts among nations to be addressed effectively. Diplomatic relations, agreements, and treaties are increasingly shaped by environmental concerns, reflecting the recognition that global environmental quality is a shared responsibility requiring collective action (Cao, et al. [11]).

Instantaneous population growth and urbanization patterns significantly impact environmental quality. Increasing population densities and urban development exert pressure on natural resources, leading to land degradation, increased waste generation, habitat fragmentation, and higher energy demands (Solarin, et al. [12]). Technological advancement impacts environmental quality by shaping resource use, pollution levels, and waste management. While innovative technologies can drive sustainable solutions and reduce environmental footprints, inadequately regulated or obsolete technologies can contribute to pollution, resource depletion, and environmental degradation. The swiftness and direction of technological development greatly influence environmental outcomes (Wang, et al. [13]). Effective governance and robust policy frameworks are fundamental determinants of environmental quality. Vigorous regulatory measures, enforcement of environmental laws, and policy interventions addressing pollution, resource management, and preservation play a pivotal role. Transparent and accountable governance structures prioritizing environmental sustainability are crucial for fostering positive environmental outcomes (Tu and Wu [14]). Cultural norms, societal attitudes, and individual behaviors significantly impact environmental quality. Cultural values emphasizing conservation, sustainable practices, and environmental stewardship promote better environmental outcomes. Contrariwise, unsustainable consumerism, lack of environmental awareness, and attitudes favoring resource exploitation can contribute to environmental degradation (Chu, et al. [15], Liao, et al. [16], Hamdoun, et al. [17], Zhang, et al. [18]). Access to clean water and adequate sanitation is crucial to environmental quality and public health. Contaminated water sources, inadequate sanitation facilities, and poor water quality contribute to health risks and environmental degradation. Ensuring access to clean water and proper sanitation is essential for improving environmental conditions (Liao, Gerichhausen, Bengoa, Rigarsford, Beverloo, Bruggeman and Rossi [16], Dauda, et al. [19]).

As a determinant of environmental quality, financial openness showcases a complex interplay between economic activities and environmental impacts. While financial openness can strengthen access to capital for cleaner energy initiatives and stimulate innovation in ecological technology, it also raises challenges, contributing to adverse consequences for environmental integrity. The inflow of global capital can facilitate funding for sustainable projects. However, it may also amplify pollution levels via expanded industrial emissions and heighten environmental degradation in certain regions due to insufficient regulation (Ferreira, et al. [20]). Additionally, financial openness might influence environmental tax policies, enabling more efficacious governance practices. However, it could sometimes lead to neglect or insufficient consideration of environmental consequences in financial investments, thereby contributing to environmental issues (Fu and Irfan [21]). Natural resources wield considerable influence on environmental quality. Their sustainable utilization, as seen with renewable energy sources like solar and wind power, contributes positively by mitigating climate change and enhancing environmental conditions (Connor [22]). However, excessive exploitation or extraction of resources, as witnessed in the case of deforestation, mineral extraction, or water mismanagement, can trigger a range of

environmental concerns. These include habitat destruction, soil erosion, water scarcity, and biodiversity loss, posing threats to ecosystem health and sustainability. While conserving biodiversity-rich areas incentivizes sustainability, unsustainable practices often stemming from resource dependency hinder maintaining a healthy environment (Liao, Gerichhausen, Bengoa, Rigarlsford, Beverloo, Bruggeman and Rossi [16]).

Trade openness, a significant driver of economic globalization, demonstrates a dual impact on environmental quality. On the one hand, it has been associated with decreased pollution levels and emissions in certain studies, indicating potential benefits arising from technological advancements, knowledge sharing, and reduced trade-related pollution (Al-Mulali, et al. [23]). Conversely, trade openness has been linked to increased pollution emissions in other contexts, particularly in non-OECD countries, highlighting apprehensions about environmental degradation due to intensified industrial activities and relaxed environmental regulations in pursuit of economic gains (Tachie, et al. [24]). Environmental tax policies serve as a mechanism to incentivize sustainable practices and discourage environmentally harmful behavior. When effectively implemented, these taxes have shown promise in reducing pollution, encouraging innovation in eco-friendly technologies, and internalizing the costs of environmental externalities (Schlegelmilch and Joas [25], Balasoïu, et al. [26]). Environmental innovation plays a pivotal role in shaping environmental quality by fostering the development and adoption of sustainable technologies and practices. Innovations to reduce emissions, improve resource efficiency, and enhance environmental sustainability have demonstrated positive impacts (JinRu and Qamruzzaman [27], Huo, et al. [28]).

The research intends to explore how environmental tax and environmental innovation influence the link between financial openness, natural resources, and carbon neutrality in the N-11 nations. The N-11 nations are a collection of developing economies anticipated to become the economic powerhouses of the globe in the 21st century. The research is anticipated to enhance the current body of knowledge about the correlation between financial openness, natural resources, and carbon neutrality. The research aims to provide policymakers a better understanding of how environmental taxes and environmental innovation might help promote carbon neutrality in the N-11 nations. The research will aid in formulating policies that support sustainable growth in the economy and environmental conservation in the N-11 nations.

The novelty of the study lies on the following as facts: First, the study provides valuable insights through an extensive examination of the intricate relationships among innovation, financial openness, natural resources, and environmental quality in the Next Eleven (N-11) nations. This study provides a comprehensive analysis of the complex interplay between these factors and their collective impact on achieving carbon neutrality. This study highlights several novel and distinctive discoveries specific to the N-11 economies.

Secondly, the study emphasizes the critical significance of innovation in driving environmental sustainability in the N-11 nations. The text delves into the significance of technical breakthroughs and innovative approaches in mitigating environmental degradation and fostering a transition towards carbon neutrality. Our study provides valuable empirical insights into the specific mechanisms through which innovation influences environmental outcomes in developing countries, surpassing the limitations of previous research. Thirdly, the research reveals the dual nature of financial openness in the N-11 nations. From a research perspective, increased financial integration has the potential to enhance the accessibility of clean technology and green investments, ultimately resulting in a positive impact on environmental quality. Nevertheless, it highlights the potential risks associated with economic openness, including increased pollution and environmental degradation resulting from expanded industrial activities lacking stringent environmental regulations. This thorough analysis of financial openness signifies a significant departure from the prevailing findings in the existing academic literature. Fourthly, our study delves into the utilization of environmental taxes within the N-11 framework and provides fresh perspectives on their effective implementation to foster environmental sustainability. This

paper thoroughly investigates the effectiveness of environmental taxes in incentivizing the adoption of environmentally friendly technology and practices. This paper offers a comprehensive analysis of the implications of these taxes on policy formulation within the N-11 framework. Fifthly, the study offers tailored policy recommendations for the N-11 nations, emphasizing the importance of cohesive strategies that align economic growth with environmental conservation. It advocates for policies that support innovation, ensure financial transparency, effectively utilize environmental taxes, and ensure the responsible management of natural resources.

## 2. Literature Review and Hypothesis Development

The majority of evidence underscores the advantageous correlation between natural resources and environmental quality. To illustrate this, Liu, Alharthi, Atil, Zafar and Khan [8] discovered renewable energy sources, like solar power, wind energy, and hydroelectricity, can enhance environmental conditions in the long term. These sustainable alternatives to fuels play a role in reducing greenhouse gas emissions and addressing climate change concerns. Cole, et al. [29] also reported that resources such as wetlands, stream buffers, and vegetated land cover can act as filters that effectively remove pollutants like metals, pesticides, sediment, and excessive nutrients from water bodies. This process dramatically improves the quality of water resources by ensuring healthier water for future generations. In addition, Connor [22] found natural resources also provide regulating and filtration services that maintain an abundant water supply across the nation. These ecosystem services play a role in upholding environmental quality by preserving the integrity of our precious water resources. Ahmad, Draz, Chandio, Ahmad, Su, Shahzad and Jia [6] found the preservation of resources plays a role in conserving biodiversity. This is crucial for maintaining ecosystems that support ecological processes beneficial for environmental quality. Rawat and Agarwal [30] documented the need to conserve biodiversity as resources would incentivize biodiversity-rich countries and their local communities to preserve sustainability.

As a follow-up to the initial findings, another line of evidence highlights the unfavorable connection between natural resources and environmental quality. Huo and Peng [9] scrutinized that excessive utilization of resources like forests, minerals, and water can lead to pollution, depletion of biodiversity, and soil erosion. Liao, Gerichhausen, Bengoa, Rigarsford, Beverloo, Bruggeman and Rossi [16] similarly found the extraction and processing of raw materials can have negative effects on the environment, including soil degradation, water shortages, and emissions. These impacts can be seen throughout the entire lifecycle of products. Ferreira, Marx-Pienaar and Sonnenberg [20] established that unsustainable production and consumption practices can have detrimental effects on the environment, such as climate change, soil erosion, poor air quality, and contaminated water, which ultimately contribute to environmental degradation. In conjunction with this, Hernández-Delgado [7] unearthed that loss of natural resources and environmental damage can pose a significant threat to livelihoods, resulting in food and economic insecurity, nutritional challenges, and significant health issues, particularly for individuals residing in impoverished nations. The depletion of natural resources and the subsequent impact on people's livelihoods can often lead to conflict and social instability, as claimed by Bruch, et al. [31]. Likewise, Liu, Alharthi, Atil, Zafar and Khan [8] found the complexity and interconnectedness of natural resources causes environmental threats, resulting in widespread environmental damage and livelihood destruction.

Natural resources are of utmost importance in the global economy, especially in nations that significantly depend on their exploitation for economic advancement [32]. The available resources include forests, natural gas, petroleum, minerals, and coal. Nevertheless, the correlation between natural resources and environmental quality is intricate and entails contradictory findings. Much research, including that conducted by [33], Hussain et al. [10], Udi et al. [11], and Wang et al. [12], has shown evidence of a beneficial impact of natural resources on environmental quality. Conversely, research conducted by [34–36],

Li et al. [14,37] has shown a detrimental correlation between natural resources and environmental quality. Thus, natural resources have the potential to greatly improve environmental quality while simultaneously fostering economic development [16]. Nevertheless, attaining this equilibrium requires meticulous deliberation of sustainable resource management techniques and the embrace of ecologically conscious methodologies as economies advance.

For BRI, ref. [38] assessed the effects of NRR, FD, and TI on EQ for the period 1991–2018. This study exposed adverse ties between NRR and EQ, while TI fosters EQ. Moreover, for the period, interaction between NRR and TI was found to be negative and statistically significant for the ecological footprint. In order to progress towards a sustainable environment, it is essential to conduct additional research on the correlation between natural resources and comprehensive environmental indicators, such as environmental footprint (EF). Furthermore, it is crucial to take into account the anthropocentric consequences of using natural resources. The amount of income in an economy is intricately connected to the availability and use of natural resources. During the early phases of development, there is a greater use of energy, including natural resources, to drive economic expansion, frequently disregarding the environmental repercussions. Nevertheless, with an enhancement of the level of life, there is a transition towards embracing more environmentally friendly techniques, safeguarding natural resources, and giving priority to energy-efficient items. This pattern indicates the existence of an Environmental Kuznets Curve (EKC). Based on the above discussion, the following hypothesis is proposed for empirical investigation.

**H<sub>1</sub>:** *Natural resources rent is negatively associated with environmental sustainability.*

In the first stages of evidence, it becomes apparent that financial openness and environmental quality share a positive relationship. For instance, green openness can positively impact environmental quality, which is the degree to which a nation's trade openness is oriented toward environmentally responsible products and services, discovered by Ahmad, et al. [39]. Fu and Irfan [21] found financial openness is a critical factor in securing funding for cleaner energy initiatives, which have the potential to yield environmental benefits. Additionally, Cao, Nie, Sun, Sun and Taghizadeh-Hesary [11] scrutinized that the financial sector supplies vital capital for innovation, promoting innovation in ecological technology. In addition, Liu, et al. [40] reported that environmental governance is greatly influenced by financial openness, which has the potential to facilitate pollution reduction and enhance environmental performance. Hsu, et al. [41] also found financial liberalization and openness are essential to enhance pollution control incentives. Financial openness could also enhance EQ by implementing effective governance practices, as claimed by Ahmad, et al. [42]. Hailiang, et al. [43] revealed that sustainability, financial openness, and renewable energy principles heavily influence significant investments and funding for environmentally friendly development. In addition to that, Fang, Liu and Putra [10] revealed that financial innovation for eco-friendly initiatives can play a crucial role in promoting green economic development and improving environmental quality in the face of economic globalization.

Notwithstanding this, subsequent evidence emerges, affirming the unfavorable correlation between financial openness and environmental quality. It is critical to acknowledge that financial transparency may also result in adverse consequences for environmental integrity. For instance, one study by Koengkan, et al. [44] discovered that financial openness in MERCOSUR countries increases CO<sub>2</sub> emissions in the short and long term, negatively impacting environmental degradation. Another study by Khan, et al. [45] revealed a concerning correlation between financial innovation and heightened pollution levels in certain regions. Financial openness increases higher pollution emissions from industrial enterprises, according to Haider and Adil [46]. Solarin, Al-Mulali, Musah and Ozturk [12] identified that increased financial openness, population, FDI, industrial output, and financial activities can lead to a corresponding increase in pollution levels. Similarly, one study by Acheampong, et al. [47] found financial openness deteriorates the environment. Failing to consider the environmental consequences of financial investments can contribute to

environmental issues (Baloch, et al. [48]). Taking into account the existing literature, the following hypothesis has been formulated for the purpose of assessment.

**H<sub>2</sub>:** *Financial openness degrades environmental quality.*

The evidence leads the way by supporting a positive relationship between trade openness and environmental quality. As an illustration, Le, et al. [49] stated that trade openness has been linked to a decrease in pollution according to studies. They measured this reduction in terms of indicators like sulfur dioxide emissions. Al-Mulali, Ozturk and Lean [23] found trade openness has been linked to a decline in trade-reduced pollution as it has a negative long-run effect on CO<sub>2</sub> emission. According to studies, a 1% increase in trade openness will reduce CO<sub>2</sub> emission pollution. Additionally, the income effect of trade openness detected by Yu, et al. [50] may indirectly lead to CO<sub>2</sub> emissions by impacting per capita income. This indicates an impact on environmental quality. Ansari, et al. [51] revealed that trade openness contributes to CO<sub>2</sub> emissions, which directly affect global efficiency and decrease energy intensity.

Additionally, a second wave of observations contributes to the understanding of the negative relationship between trade openness and environmental quality. Tachie, Xingle, Dauda, Mensah, Appiah-Twum and Adjei Mensah [24] found trade openness remains controversial and could still be a potential driver of carbon dioxide emissions. Derindag, et al. [52] stated trade openness reduced carbon emissions to promote FDI. Reference [53] also found international trade leads to a 0.202% decrease in CO<sub>2</sub> emissions. Indeed, trade openness technology transfers and reduces excess capacity, thus reducing emissions. Further to this, Le, Chang and Park [49] revealed that augmented trade openness has been associated with environmental degradation, as evidenced by the rise in emissions of pollutants such as SO<sub>2</sub> and CO<sub>2</sub>, particularly in non-OECD nations.

A conflicting study by Khan, et al. [54] suggests that trade openness is a double-edged sword, offering opportunities to diminish pollution and risks of increasing environmental degradation. On the basis of the presented literature, the following hypothesis has been developed.

**H<sub>3</sub>:** *Trade openness fosters environmental degradation.*

At the forefront of supporting data, there lies the indication of a positive link between environmental tax and environmental quality. To exemplify, Beeks and Lambert [55] found environmental taxes increase the cost of polluting activities and encourage people and corporations to weigh the environmental consequences of their decisions by internalizing the negative externalities linked to pollution and resource depletion. Schlegelmilch and Joas [25] documented that environmental taxes encourage using these resources by making renewable sources and energy saving comparatively more appealing than polluting alternatives. Richard [56] stated that environmental taxes deter anti-ecological behavior and encourage people and businesses to adopt more sustainable practices by placing a fee on activities that harm the environment. Song, et al. [57] discovered that by providing financial incentives for creating and using environmentally friendly practices and technologies, environmental taxes can encourage businesses to innovate in sustainability. Heine and Black [58] also found that environmental taxes encourage emissions abatement at the lowest feasible cost by placing a price on pollution, resulting in cleaner environmental results. A study by Farooq, et al. [59] indicated that green taxes can contribute to the attainment of cleaner environmental goals and enhance the quality of the environment. Ideally, a decrease in labor, capital, or consumer taxes would offset the increase in environmental taxes, yielding a twofold gain: an increase in the standard of the environment and the economic system's efficiency, according to Shahzad [60].

The second tier of evidence further substantiates the claim of a negative correlation between environmental tax and environmental quality. As an illustration, Balasoiu, Chifu and Oancea [26] observed that specific companies or individuals may become overburdened by high taxes on ecologically hazardous activities, which could harm employment and

economic growth. Pizer and Sexton [61] ascertained environmental tax raise worries about how they will be distributed because some businesses or people may be disproportionately affected, which could result in social and economic inequality. Howes, et al. [62] unearthed that the intricacy of creating and enforcing environmental taxes can present difficulties, and if they are not carried out skillfully, they might not have the desired environmental effects. Likewise, Domenech and Bahn-Walkowiak [63] stated that achieving such coordination will be challenging, and the debate on green tax reforms continues, causing no particular solution. Gravers Skygebjerg, et al. [64] also draw attention to the possibility of unforeseen repercussions from environmental taxes, such as pollution being transferred to regions with laxer laws or environmentally damaging behaviors being adopted in response to tax breaks. The following hypothesis has been developed based on the presented literature.

**H<sub>4</sub>:** *Imposition of environmental tax protect environmental adversity.*

The introductory evidence illustrates a constructive link between environmental innovation and environmental quality. A study by Huo, Zaman, Zulfiqar, Kocak and Shehzad [28] shows that technological innovation and renewable energy can improve the quality of the environment. This implies that increasing environmental sustainability can be achieved by developing renewable energy sources and environmental technologies. JinRu and Qamruzzaman [27] also found that environmental innovation is a great way to promote long-term development and balance environmental preservation and economic growth. This suggests that cutting-edge environmental policies and technologies can lessen their adverse effects on the environment while promoting sustainable economic growth. Kirikkaleli, et al. [65] stated that research has shown that environmental innovation is beneficial in maintaining environmental sustainability and controlling quality. This shows that tackling environmental issues and maintaining natural resources' sustainability may greatly benefit from environmental innovation. Su, et al. [66] documented that increasing environmental sustainability in nations to a higher quantile has been associated with improvements in environmental innovation. This suggests that concentrating on environmental innovation can produce better results in terms of environmental sustainability. Likewise, Musibau, et al. [67] revealed that increased investments in eco-innovation and green investments ensure continuous improvement in the quality of the environment and efficiency.

The available research does not extensively support the potential ways environmental innovation can decrease environmental quality. However, one source by Huo, Zaman, Zulfiqar, Kocak and Shehzad [28] suggests that commercializing environmental technologies may deteriorate the environment's quality. This implies that commercializing environmental innovations may have negative environmental impacts. Environmental innovation has been found to have a significant adverse inhibitory effect on environmental productivity in some contexts, stated by Ma, et al. [68]. Moreover, Wang, Cui and Zhao [13] found that green technology innovation can sometimes deteriorate the environment.

### 3. Data and Methodology of the Study

#### 3.1. Model Specification

The motivation of the study is to gauge the nexus between openness–innovation–natural resource-led environmental qualities with environmental tax in the N-11 nations for the period 2004–2020. The generalized equation is as follows:

$$EQI \mid FO, TO, NRR, GTI, ET \quad (1)$$

The above Equation (1) has been expanded with an EKC hypothesis investigation; the revised relations are displayed in Equation (2):

$$EQI \mid FO, TO, NRR, ET, GTI, Y, Y^2 \quad (2)$$

After natural log transformation, Equation (2) has been reproduced in the regression form for coefficients extraction which is presented in Equation (3).

$$Y = \beta_0 + \beta_1 FO_{i,t} + \beta_2 TO_{i,t} + \beta_3 NRR_{i,t} + \beta_4 ET_{i,t} + \beta_5 GTI_{i,t} + \beta_6 Y_{i,t} + \beta_7 Y^2_{i,t} + \epsilon \quad (3)$$

where FO, TO, NRR, ET, GTI, and Y stand for financial openness, trade openness, natural resources rent, environmental innovation, environmental taxes, and economic growth, respectively. Coefficients of  $\beta_1 \dots \beta_5$  explain the magnitudes of the explanatory variables of environmental quality and the EKC hypothesis to be tested with  $\beta_7$ . The descriptive statistics of the research are displayed in Table 1 and the variables definition with proxy displayed in Table 2.

**Table 1.** Descriptive statistics of research sample in panel form.

|           | PBCO <sub>2</sub> | TCO <sub>2</sub> | CBCO <sub>2</sub> | FO       | Y        | TO       | NRR      | GTI       | ET       | EF     |
|-----------|-------------------|------------------|-------------------|----------|----------|----------|----------|-----------|----------|--------|
| Mean      | 21.46437          | 225,078.8        | 46,308.02         | 1.718995 | 1.36254  | 56.36493 | 5.805955 | 10,097.6  | 0.938309 | 18.43  |
| Median    | 20.14951          | 184,241.5        | 19,486.44         | 1.189525 | 0.61181  | 49.89886 | 2.506034 | 281       | 0.09641  | 15.37  |
| Maximum   | 38.29186          | 605,356.1        | 308,618.4         | 11.93948 | 2.55163  | 154.6054 | 34.77913 | 164,073   | 0.545    | 18.14  |
| Minimum   | 11.68935          | 10,830.76        | 99.009            | −2.75744 | 2.92261  | 18.88983 | 0.01769  | 16        | 0.02     | -      |
| Std. Dev. | 6.601781          | 166,547.3        | 63,044.48         | 1.944689 | 2.97713  | 26.08395 | 7.462098 | 31,003.22 | 1.124326 | 18.43  |
| Skewness  | 0.59499           | 0.5662           | 2.123717          | 2.249461 | 1.455518 | 1.53307  | 1.955006 | 3.469281  | 1.264109 | 36.86  |
| Kurtosis  | 2.297739          | 2.114863         | 7.587145          | 9.772    | 4.20356  | 5.406113 | 6.660476 | 14.17457  | 0.244427 | (0.60) |

**Table 2.** Variable measurements and data sources.

| Variables                         | Notation          | Definition                                                               | Sources                  |
|-----------------------------------|-------------------|--------------------------------------------------------------------------|--------------------------|
| Environmental quality             |                   |                                                                          |                          |
| Production based CO <sub>2</sub>  | PBCO <sub>2</sub> | CO <sub>2</sub> emissions from manufacturing industries and construction | WDI                      |
| Consumption based CO <sub>2</sub> | CBCO <sub>2</sub> | CO <sub>2</sub> emissions from consumption (kt)                          | WDI                      |
| CO <sub>2</sub> mission           | CO <sub>2</sub>   | CO <sub>2</sub> emissions (kt)                                           | WDI                      |
| Ecological footprint              | EF                | Per capita (Gha)                                                         | Global Footprint Network |
| Independent variables             |                   |                                                                          |                          |
| Financial openness                | FO                | Foreign direct investment, net inflows (% of GDP)                        | OurdatainWorld           |
| Trade openness                    | TO                | Trade (% of GDP)                                                         | Pantrade                 |
| Natural resource rent             | NRR               | Total natural resources rents (% of GDP)                                 | WDI                      |
| Mediating variables               |                   |                                                                          |                          |
| Environmental tax                 | ET                | Environmental tax, total (% of GDP)                                      | OECD and OurdatainWorld  |
| Green technological innovation    | EI                | Environment-related patent applications                                  | OECD                     |
| Gross domestic product            | Y                 | GDP (current USD)                                                        | ourdatainWorld           |

### 3.2. Variables Definition and Anticipated Sign of Coefficients

Production-based CO<sub>2</sub> emissions refers to the total amount of carbon dioxide emissions generated within the geographical limits of a country. This holistic method takes into account all carbon dioxide emissions originating from industrial activity, transportation, energy generation, and other sources within the geographical limits of a nation. This measure is often used in national greenhouse gas inventories and is crucial for understanding the environmental effect of enterprises and activities that are headquartered

locally. Consumption-based CO<sub>2</sub> emissions, also known as the carbon footprint, measure the total CO<sub>2</sub> emissions associated with the consumption of goods and services inside a nation, regardless of where these emissions come from. This involves the computation of net emissions, which is the difference between imported emissions and exported emissions, in addition to emissions from domestic output. By taking into account international commerce, this method provides a more thorough viewpoint and reveals the ecological consequences that a country's consumption habits may delegate to other nations. Carbon dioxide emissions are often linked to the release of CO<sub>2</sub> into the atmosphere as a result of various human activities. This category encompasses emissions resulting from both production and consumption, with a particular emphasis on their influence on global levels of greenhouse gases. This statistic is often used in climate change and global warming studies, highlighting the influence of human activities on changing atmospheric conditions. The ecological footprint is a measurement that calculates the magnitude of the influence that human activities have on the ecosystems of the Earth. It offers a juxtaposition of our needs and the planet's regenerative ability, providing significant insights into our environmental effect. This metric quantifies the amount of natural resources used by people and the resulting waste they produce, offering vital insights into the sustainability of the ecosystem. This metric offers significant insights into the limits of natural resource exploitation and acts as a powerful instrument for directing sustainable resource management. The elements include forest land, fishing grounds, agriculture, grazing land, and built-up land. These factors are essential in evaluating environmental quality, since they provide significant insights into different elements of human influence on the world. Each source provides useful perspectives on how activities connected to energy utilization, resource consumption, and waste management contribute to environmental deterioration.

The first explanatory variable is financial openness (FO), which is measured by inflows of FDI in the economy and repetitively used in the existing literature, see [69–71]. When a country's financial system is integrated with global markets, it is expected to have a considerable impact on CO<sub>2</sub> emissions and the ecological footprint. Studies indicate that a greater financial openness can boost economic growth and industrial development, resulting in increased energy consumption and CO<sub>2</sub> emissions [72]. Furthermore, financial openness has the potential to encourage resource-intensive production methods and consumption habits, leading to environmental harm and resource exhaustion [73]. The results emphasize the complex connections between financial integration, environmental consequences, and sustainable development, emphasizing the importance of policymakers finding a balance between economic goals and environmental concerns through efficient regulation and green finance projects. It is anticipated that foreign investment in the form of FID in N-11 nations may result in environmental degradation through excessive CO<sub>2</sub> emissions, alternatively,  $\beta_2 = \frac{\partial \text{CO}_2}{\partial \text{TO}} > 1$  in the initial period, whereas in the long-run the inclusion of efficient technology in the production process might produce a conducive ambiance for the environment: that is,  $\beta_1 = \frac{\partial \text{CO}_2}{\partial \text{FO}} > 1$ .

The second variable is trade openness (TO), which is measured by total trade as a % of GDP. The existing literature has reported its destructive role in the process of enhancing EQ with the assistance of mitigating the level of CO<sub>2</sub> [74,75]. It is suggested that domestic trade liberalization amplifies CO<sub>2</sub> emissions in the ecosystem; that is, trade liberalization is associated with negative environmental effects, particularly from the importation of energy-consuming goods. Trade openness and variables like physical infrastructure and environmental legislation may have asymmetric impacts on CO<sub>2</sub> emissions [2]. One important aspect impacting the ecological footprint, for instance, is trade openness, demonstrating the complex relationship between trade practices and environmental effects. The ecological footprint is complexly impacted by trade openness; that is, greater trade may have negative environmental effects, underscoring the need for enacting strict environmental laws to mitigate these effects [76]. While some research indicates that economic openness may increase carbon emissions, other studies provide contradictory results, indicating the different effects of trade on CO<sub>2</sub> levels [4]. Furthermore, there may be variations in carbon emissions

in response to changes in trade openness, suggesting a complicated relationship between international commerce and environmental effects [52]. It is anticipated that domestic trade liberalization in N-11 nations may result in environmental degradation through excessive CO<sub>2</sub> emissions; alternatively,  $\beta_2 = \frac{\partial CO_2}{\partial TO} > 1$ .

The third explanatory variable is natural resources, which is measured by natural resources rent (NRR) following the existing literature: see [77]. Natural resources are essential for life and provide crucial ecological functions. Unfortunately, their overexploitation and unsustainable use often causes environmental deterioration, including deforestation, water pollution, habitat loss, and species extinction [78]. Deforestation due to agriculture or wood harvesting diminishes carbon absorption capacity and disrupts ecosystems, exacerbating climate change [79]. Over-mineralization and fossil fuel extraction lead to soil degradation, air pollution, and greenhouse gas emissions. Furthermore, the depletion of natural resources causes ecological imbalances, affecting ecosystem resilience and stability. It is anticipated that natural resources rent in N-11 nations will decrease environmental sustainability, i.e., cause CO<sub>2</sub> emissions to be higher; alternatively,  $\beta_3 = \frac{\partial CO_2}{\partial NRR} > 1$ .

The fourth explanatory variable is environmental tax, measured by environmental-related tax and data collected from the OECD database. Environmental taxes can have intricate effects on CO<sub>2</sub> emissions and the ecological footprint, influencing environmental sustainability both directly and indirectly [80,81]. Environmental taxes are designed to account for the external costs associated with environmental damage, encouraging polluters to reduce their emissions and adopt cleaner technology. Implementing environmental taxes encourages companies and individuals to decrease their environmental impact by attaching a price to actions that result in CO<sub>2</sub> emissions and an increased ecological footprint, like using fossil fuels, deforestation, and generating waste [82]. Studies have shown that higher taxes on carbon emissions lead to a decrease in the use of fossil fuels and a reduction in CO<sub>2</sub> emissions, which can contribute to addressing climate change [83]. Imposing taxes on activities that contribute to the ecological footprint, such as resource exploitation and pollution, could encourage the adoption of sustainable practices and drive investments in renewable energy, energy efficiency, and waste reduction technology [84]. Moreover, revenue generated from environmental taxes can support initiatives for environmental conservation, biodiversity preservation, and sustainable development, ultimately reducing the ecological footprint (OECD, 2019). It is crucial to implement environmental taxes to shape consumer and production behaviors, support environmental sustainability, alleviate pressure on ecosystems, and tackle climate change. It is anticipated that environmental tax in N-11 nations will foster environmental sustainability, i.e., cause CO<sub>2</sub> emissions to be controlled; alternatively,  $\beta_4 = \frac{\partial CO_2}{\partial ET} < 1$ .

### 3.3. Theoretical Background and Model Construction

According to the EKC hypothesis, in the initial phases of economic growth, industrialization, and urbanization lead to the depletion of natural resources and the production of urban and industrial wastes [85]. Currently, economic growth and pollution are directly linked to each other. With the ongoing industrialization processes, advancements in technology, and expansion of services, pollution levels will begin to decrease. When people reach higher income levels, they begin to place a higher value on the environment and start demanding a better-quality environment as the economy advances. Due to supply-and-demand-side changes, pollution tends to rise as income increases in the early stages of economic development and then decreases as income rises in the later stages of economic development.

The Environmental Kuznets Curve (EKC) hypothesis explores the relationship between economic growth, environmental quality, and environmental policy in N-11 nations, considering factors like innovation, openness, and natural resources. This theory suggests a non-linear connection between per capita income and environmental degradation [86,87]. As countries experience economic growth, environmental damage initially worsens due to increased industrial activity and resource exploitation but tends to improve as societies

become more prosperous, emphasizing environmental preservation and adopting cleaner technologies [88].

In the context of N-11 countries, innovation plays a vital role in advancing technology to reduce environmental impacts and promote sustainable development. Trade openness can facilitate the spread of cleaner technologies and influence environmental policies through international agreements. Natural resources in these nations have a dual impact on environmental quality, offering economic opportunities but also causing environmental harm. As countries advance and achieve a certain economic threshold, often associated with middle-class status, environmental concerns begin to gain significance for politicians and the general public. This shift in viewpoint often occurs due to the evident and tangible impacts of environmental degradation, including air and water pollution, declining biodiversity, and degradation of natural ecosystems. N-11 nations' governments are increasingly prioritizing environmental protection measures in their policy agendas due to growing environmental awareness and pressure from civil society.

Environmental taxes are crucial as they encourage the development of cleaner technologies, sustainable resource management, and address the external costs of environmental damage [83,89]. Studies suggested that environmental taxes can significantly reduce greenhouse gas emissions and other harmful practices by incentivizing companies to decrease CO<sub>2</sub> emissions [84]. Environmental technology, economic complexity, renewable electricity, and environmental taxes are essential components for creating a more sustainable future by reducing pollution [90]. Additionally, stringent environmental regulations can mitigate ecological footprints in N-11 countries while economic growth may escalate footprints, highlighting the importance of balancing economic factors with environmental policies for effective pollution reduction. Environmental taxation is a significant policy instrument used in this phase to internalize the external costs of environmental deterioration and promote behavior that aligns with sustainable development objectives. One method to discourage detrimental environmental behaviors and support conservation is imposing fees on activities that cause pollution and deplete resources, such as carbon emissions and unsustainable resource exploitation. Levying taxes on environmental factors is crucial for stimulating innovation in sustainable practices and technology. Governments use taxes on environmentally harmful activities to incentivize firms to prioritize the development of cleaner industrial processes, energy-efficient technology, and renewable energy sources. Environmental taxes may stimulate interest in eco-friendly goods and services, fostering innovation and technical advancement in the green economy sector.

Overall, understanding the complex interplay between economic growth, innovation, natural resource use, and environmental regulations in N-11 nations is crucial for promoting sustainable development and addressing environmental challenges through policy interventions.

### 3.4. Estimation Strategies

The test statistics for testing the null hypothesis of “homogeneity” will be derived by executing the following equations:

$$S = \sum_{i=1}^N (\beta_i - \beta_{WFE}) \frac{x_i M_x x_i}{\sigma_i^2} (\beta_i - \beta_{WFE}) \quad (4)$$

$$\Delta = (N)^{1/2} \left( 2K^{1/2} \right) \left( \frac{1}{N} (S - K) \right) \quad (5)$$

where  $S$  and  $\Delta$  stand for the test statistics.  $\beta_i$  and  $\beta_{WFE}$  represent the coefficients of pooled ordinary least square (OLS) and a pooled weighted fixed effect estimator.

This study will implement a CD test by following the techniques introduced by Breusch and Pagan [91], Pesaran [92], Pesaran, et al. [93], Pesaran [94], and Juodis and Reese [95]. Breusch and Pagan's test helps panel models with individual and temporal effects handle cross-sectional dependency.. Unbiased estimates in the BP test when comparing fixed

effects and random effects underline the requirement for robust estimators in panel data analysis. Pesaran developed diagnostic tests to discover cross-sectional dependence in panel data, shedding light on spatial correlations and dynamic modeling. The research emphasizes the necessity of reliable estimation methodologies for cross-country growth analysis and spatial dependence in panel data models. Juodis and Reese's study examines the BP test's local power in respect to fixed factors to better understand cross-sectional dependency. The research examines power in nonlinear models with random and fixed effects. Simple tests to uncover heterogeneity and manage cross-sectional dependency improve methodological procedures.

Panel unit root tests are often used in econometrics to determine the stationary nature of variables in panel data situations. These tests are critical for investigating long-term correlations and trends in panel datasets, particularly when dealing with time series data from several cross-sectional units. The panel unit root tests developed by Ref. [96] and Herwartz and Siedenburg [97] have achieved substantial attention in academic research. These tests provide powerful methods for determining the stationarity of variables in panel data.

Ref. [96] introduced the unit root test for panel units commonly known as CADF and CIPS. This test expands on the augmented Dickey–Fuller (ADF) test for investigating unit roots in individual units within a panel data framework. The IPS test takes into account both cross-sectional dependencies and individual variability, which are common in panel datasets. The following equation is to be executed in deriving the test statistics of the testing variables' order of integration.

The basic equation for the CADF test can be represented as follows:

$$\Delta y_{it} = \rho y_{it-1} + \alpha_i + \beta \bar{y}_{t-1} + \mu_{it} \quad (6)$$

where,  $\Delta y_{it}$  represents the first difference of the dependent variable for the second cross-sectional unit at time  $t$ .  $y_{it-1}$  is the lagged dependent variable for the first unit.  $\alpha_i$  represents individual-specific effects.  $\bar{y}_{t-1}$  is the cross-sectional average of the lagged levels of the dependent variable at time  $t - 1$ .

$$CIPS = N^{-1} \sum_{i=1}^N t_i(N, T) \quad (7)$$

Herwartz and Siedenburg [97] developed a panel unit root test that integrates individual ADF tests. This test combines independent augmented Dickey–Fuller tests with the minimum  $p$ -value methodology, providing a simple yet reliable method for panel unit root testing, which generates independent augmented Dickey–Fuller (ADF) statistics for each cross-sectional unit before aggregating them to produce a panel statistic. This statistical panel is compared to key values to determine the presence of a unit root.

$$\Delta x_{it} = \alpha_{it} + \beta x_{it-1} + \rho i T + \sum n_j = 1 \theta_{ij} \Delta x_{i,t-j} + \epsilon_{it} \quad (8)$$

where  $\Delta x_{it}$  represents the first difference of the dependent variable for the first cross-sectional unit at time  $t$ ;  $x_{it-1}$  is the lagged dependent variable;  $\alpha_i$  represents individual-specific effects; and  $\mu_{it}$  is the error term.

$$L \log(L) = a_0 - 12 \sum N_i = 1 (T \log(\sigma^2 i, t) - 1 \sigma^2 i, t \sum T t = 1 e i t^2) \quad (9)$$

Economists recommend using a variety of analytical approaches for panel data while doing long-term studies. Overall, various approaches are subject to varying restrictions. Prior research employed antiquated methodologies to estimate long-term elasticity without accounting for the CD [98]. Furthermore, Pesaran and Smith [99] developed the Mean Group (MG) estimation method, while Bond and Eberhardt [100] proposed the Augmented Mean Group (AMG) approach. These approaches enable precise measurements, particularly when working with significantly larger sample sizes. However, in instances involving endogeneity and serial correlation, these methods may not provide the desired results. For

deriving the coefficients of FO, TO, NRR, GTI, and ET, this study will implement the novel panel data estimation techniques introduced by Mark, et al. [101], Bai and Kao [102], and Bai, et al. [103], which are commonly known as DSUR, CUP-BC, and CUP-FM.

Recent research has shown that the Dynamic Seemingly Unrelated Cointegrating Regressions (DSUR) approach reliably produces CD-related results. DSUR is intended to solve situations in which cointegrating vectors have either homogeneous or heterogeneous properties across equations. It addresses the common issues of cross-equation correlation and endogeneity in panel data analysis. Researchers utilize Dynamic Seemingly Unrelated Regression (DSUR) to determine long-term coefficients in panel data models, which provides insight into the relationships between variables over time. The following equation is to be instigated in authenticating the elasticities of the explanatory variables of the study.

$$y_{it} = \gamma_{it}x_{it} + \delta\tau_{it} \quad (10)$$

$$\delta\tau_{it} = \alpha_i\delta\tau_{it} - 1 + \sum n - 1j = 1\delta_{ij}\Delta x_{it} - 1 + \varnothing_{it} \quad (11)$$

$$\Delta x_{it} = \theta_i\Delta x_{it} - 1 + \partial_{it} \quad (12)$$

$$\varnothing_{it} = \rho_i\varnothing_{it} - 1 + \aleph_{it} \quad (13)$$

The Continuous Update Fully Modified (CUP-FM) technique is a sophisticated panel data method that analyzes the relationships among many criteria such as financial globalization, environmental progress, energy efficiency, energy costs, and economic growth. Bai and Kao [102] introduced a method to calculate long-term coefficients in panel data models, providing insights into the impact of changes in these parameters on renewable energy consumption. Research conducted using the CUP-FM approach has shown significant results indicating that financial globalization, environmental progress, energy efficiency, and energy prices positively influence the demand for renewable energy. The authors used the CUP-BC estimate technique to address the serial correlation and endogeneity resulting from asymptotic bias. The CUP-FM estimation approach guarantees that the restricted model components maintain a uniform distribution. These variables are consistently updated over time until they reach convergence through simulations. The error term should be compatible with the factor model. Here is the definition of the factor model:

$$\hat{\beta}_{cup}, \hat{F}_{cup} = \underset{\beta}{\operatorname{argmin}} \frac{1}{nT^2} \sum_{i=1}^n (y_i - x_i\beta)' MF (y_i - x_i\beta) \quad (14)$$

where  $MF = I_T - T^{-2}FF'$ ,  $I_T$  illustrates the components and  $T'S$  demonstrates the identity matrix.

#### 4. Empirical Model Estimation and Interpretation

Table 3 displays the results of an SH test and the study revealed that all the test statistics were statistically significant at a 1% level. According to the findings, it is possible to ascertain that the research variables possess heterogeneous attributes [104].

**Table 3.** Results of slope homogeneity test.

|          | Delta Statistic | Adjusted Delta Statistic | SH Exits |
|----------|-----------------|--------------------------|----------|
| Model 01 | 4.9005 ***      | 4.4668 ***               | Yes      |
| Model 02 | 4.9523 ***      | 5.0915 ***               | Yes      |
| Model 03 | 3.1952 ***      | 4.8246 ***               | Yes      |
| Model 04 | 3.2502 ***      | 4.6197 ***               |          |

Note: the superscript of \*\*\* explains the significant level at 1%.

Following Breusch and Pagan [91], Pesaran [92], Pesaran, Ullah and Yamagata [93], Pesaran [94], and Juodis and Reese [95], the study assessed the presence of CD in the

research variables. Table 4 reports the results of test statistics, derived from each of the techniques and found statistically significant at a 1% level. It suggests the presence of CD in the research variables.

**Table 4.** Results of Cross-sectional dependency test.

|                   | (Breusch and Pagan 1980) [91] | Pesaran (2004) [92] | Pesaran, Ullah et al. (2008) [93] | Pesaran (2006) [94] | Juodis and Reese (2022) [95] |
|-------------------|-------------------------------|---------------------|-----------------------------------|---------------------|------------------------------|
| PBCO <sub>2</sub> | 178.251 ***                   | 28.84 ***           | 166.577 ***                       | 33.944 ***          | 6.1651 ***                   |
| CBCO <sub>2</sub> | 443.718 ***                   | 27.538 ***          | 135.084 ***                       | 28.872 ***          | −3.6218 ***                  |
| CO <sub>2</sub>   | 307.19 ***                    | 39.799 ***          | 150.091 ***                       | 53.846 ***          | −3.0268 ***                  |
| FO                | 201.654 ***                   | 20.729 ***          | 123.604 ***                       | 31.572 ***          | −1.9666 ***                  |
| TO                | 368.046 ***                   | 23.269 ***          | 182.485 ***                       | 15.734 ***          | 1.7246 ***                   |
| GTI               | 163.5 ***                     | 37.252 ***          | 169.177 ***                       | 48.09 ***           | 6.8921 ***                   |
| NRR               | 363.168 ***                   | 16.425 ***          | 235.148 ***                       | 17.512 ***          | −3.1668 ***                  |
| Y                 | 279.23 ***                    | 29.45 ***           | 160.584 ***                       | 48.687 ***          | −4.6081 ***                  |
| ET                | 436.972 ***                   | 29.73 ***           | 174.594 ***                       | 35.087 ***          | 0.0544 ***                   |

Note: the superscript of \*\*\* explains the significant level at 1%.

The order of integration of the selected variables was assessed by employing the unit root test familiarized by Pesaran [96] and Herwartz and Siedenburg [97]. Results of unit root test are displayed in Table 5 and disclose that the test statistics were statistically significant at a 1% level, especially after the first difference operator. Thus, it is confirmed that the variables are integrated at I(1).

**Table 5.** Results of panel unit root tests.

| Variables         | CADF   |            | CIPS   |            | Herwartz and Siedenburg 2008 [97] |             |
|-------------------|--------|------------|--------|------------|-----------------------------------|-------------|
|                   | Level  | $\Delta$   | Level  | $\Delta$   | Level                             | $\Delta$    |
| PBCO <sub>2</sub> | −1.135 | −7.95 ***  | −1.892 | −2.103 *** | 1.3482                            | −6.288 ***  |
| CBCO <sub>2</sub> | −1.527 | −2.179 *** | −1.896 | −7.679 *** | 0.8359                            | 5.5735 ***  |
| CO <sub>2</sub>   | −2.712 | −6.225 *** | −2.079 | −2.342 *** | −0.0971                           | −7.5143 *** |
| FO                | −2.221 | −4.553 *** | −1.083 | −4.191 *** | 0.7789                            | −1.0413 *** |
| TO                | −2.014 | −2.133 *** | −1.255 | −4.369 *** | 0.2291                            | 4.1615 ***  |
| GTI               | −1.427 | −2.899 *** | −2.161 | −7.069 *** | 1.4604                            | −6.5623 *** |
| NRR               | −2.091 | −5.433 *** | −2.932 | −5.065 *** | −0.1081                           | 8.8745 ***  |
| Y                 | −1.924 | −4.884 *** | −1.089 | −5.281 *** | 1.2055                            | −3.7774 *** |

\*\*\* denote the level of significant at a 1% level.

In order to document the long-run association in the empirical nexus, the study implemented a panel cointegration test following Westerlund and Edgerton [105], Westerlund [106], and the results are displayed in Table 6. The study revealed that all the test statistics were statistically significant at a 1% level, implying the rejection of a null of no-cointegration, alternatively exposing a long-run association between the explained and explanatory variables.

Table 6. Error correction-based cointegration test.

| Model                                                               | TO--->EQ    | FO--->EQ    | GTI--->EQ   | NRR--->EQ    | ET--->EQ    | Y--->EQ     |
|---------------------------------------------------------------------|-------------|-------------|-------------|--------------|-------------|-------------|
| Panel-A: EQ measured by ecological footprint                        |             |             |             |              |             |             |
| Gt                                                                  | −14.052 *** | −7.976 ***  | −8.732 ***  | −10.954 ***  | −13.212 *** | −9.698 ***  |
| Ga                                                                  | −11.445 *** | −4.369 ***  | −11.316 *** | −5.164 ***   | −7.095 ***  | −8.455 ***  |
| Pt                                                                  | −14.607 *** | −5.592 ***  | −9.143 ***  | −5.397 ***   | −5.01 ***   | −8.299 ***  |
| Pa                                                                  | −11.277 *** | −9.628 ***  | −7.48 ***   | −9.749 ***   | −13.072 *** | −15.303 *** |
| Panel-B: EQ measured by consumption-based CO <sub>2</sub> emissions |             |             |             |              |             |             |
| Gt                                                                  | −15.835 *** | −13.297 *** | −7.091 ***  | −15.235 ***  | −12.488 *** | −12.911 *** |
| Ga                                                                  | −11.197 *** | −13.422 *** | −9.037 ***  | −7.165 ***   | −7.02 ***   | −10.142 *** |
| Pt                                                                  | −12.759 *** | −15.571 *** | −6.779 ***  | −8.266 ***   | −12.033 *** | −12.874 *** |
| Pa                                                                  | −10.947 *** | −4.354 ***  | −14.168 *** | −12.69 ***   | −7.487 ***  | −13.322 *** |
| Panel-C: EQ measured by production-based CO <sub>2</sub> emissions  |             |             |             |              |             |             |
| Gt                                                                  | −14.744 *** | −11.266 *** | −7.821 ***  | −7.744 ***   | −13.142 *** | −8.203 ***  |
| Ga                                                                  | −13.772 *** | −9.637 ***  | −6.064 ***  | −5.962 ***   | −7.465 ***  | −11.684 *** |
| Pt                                                                  | −11.645 *** | −11.302 *** | −7.844 ***  | −5.675 ***   | −14.125 *** | −8.204 ***  |
| Pa                                                                  | −13.972 *** | −6.187 ***  | −9.09 ***   | −12.118 ***  | −13.439 *** | −7.162 ***  |
| Panel-D: EQ measured by CO <sub>2</sub> per capita                  |             |             |             |              |             |             |
| Gt                                                                  | −12.565 *** | −11.159 *** | −15.765 *** | −6.311 ***   | −14.446 *** | −6.065 ***  |
| Ga                                                                  | −10.765 *** | −7.769 ***  | −14.422 *** | −15.311 ***  | −14.349 *** | −11.782 *** |
| Pt                                                                  | −11.749 *** | −12.288 *** | −5.265 ***  | −5.124 ***   | −14.98 ***  | −12.741 *** |
| Pa                                                                  | −14.68 ***  | −15.828 *** | −12.568 *** | −10.367 ***  | −13.008 *** | −8.053 ***  |
| no shift                                                            |             | mean shift  |             | regime shift |             |             |
|                                                                     | LMr         | LMΦ         | LMr         | LMΦ          | LMr         | LMΦ         |
|                                                                     | stat.       | stat.       | stat.       | stat.        | stat.       | stat.       |
| Model 1                                                             | −4.3464 *** | −3.1852 *** | −3.6079 *** | −3.9964 ***  | −3.5061 *** | −4.0909 *** |
| Model 2                                                             | −3.741 ***  | −4.626 ***  | −4.8704 *** | −4.175 ***   | −4.7556 *** | −4.7076 *** |
| Model 3                                                             | −3.1195 *** | −4.7473 *** | −2.9357 *** | −2.1965 ***  | −3.5248 *** | −2.9934 *** |
| Model 4                                                             | −4.5529 *** | −3.0587 *** | −4.4372 *** | −3.6185 ***  | −4.0704 *** | −3.3589 *** |

Note: the superscript of \*\*\* explains the significant level at 1%.

The coefficients of Y and Y<sup>2</sup> were found to be positively and negatively statistically significant at a 1% level for all four model estimations, suggesting a U-inverted relationship toward environmental sustainability which is a confirmation of the KEC hypothesis (see output displayed in Table 7).

The coefficients of financial openness had a positive statistical significance with EQ at a 1% level. The study findings advocate for a contributory effect of FO in augmenting the present level of environmental degradation through the escalation of carbon emissions and ecological degradation. Our study is in line with the existing literature [107–109]. Specifically, a 10% change in inflow of FDI resulted in a lessening of the ambiance of environmental improvement, with an increase in PBCO<sub>2</sub> of  $DSUR_{1.385\%}$ ,  $CUP - BC_{0.973\%}$ ,  $CUP - FM_{1.623\%}$ ; CBCO<sub>2</sub> with a range of  $DSUR_{1.459\%}$ ,  $CUP - BC_{1.427\%}$ ,  $CUP - FM_{1.065\%}$ ; total CO<sub>2</sub> emission by  $DSUR_{0.788\%}$ ,  $CUP - BC_{1.054\%}$ ,  $CUP - FM_{1.373\%}$ ; and ecological footprint by  $DSUR_{1.618\%}$ ,  $CUP - BC_{1.821\%}$ ,  $CUP - FM_{0.797\%}$ , respectively. The study findings urge that receipts of foreign investment in the form of FDI should be treated with caution or the ED has to be the critical concern in the near future.

Table 7. Results of DSUR, CUP-FM, and CUP-BC.

|                | Techniques | Model [1] |          | Model [2] |          | Model [3] |          | Model [4] |          |
|----------------|------------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|
|                |            | Coeff.    | t-Stat   | Coeff.    | t-Stat   | Coeff.    | t-Stat   | Coeff.    | t-Stat   |
| FO             | DSUR       | 0.1385    | 7.3291   | 0.1459    | 7.64031  | 0.0788    | 4.1494   | 0.1618    | 5.6587   |
|                | CUP-FM     | 0.1623    | 3.9222   | 0.1427    | 6.7339   | 0.1054    | 6.0965   | 0.1821    | 5.7822   |
|                | CUP-BC     | 0.0973    | 2.4325   | 0.1065    | 2.78277  | 0.1373    | 3.4413   | 0.0797    | 4.8621   |
| TO             | DSUR       | 0.1570    | 4.8613   | 0.1102    | −3.18613 | 0.1094    | 4.7168   | 0.1306    | 7.3011   |
|                | CUP-FM     | 0.1196    | 6.4322   | 0.0901    | −2.8413  | 0.0940    | 4.5431   | 0.1645    | 5.6546   |
|                | CUP-BC     | 0.1817    | 12.0337  | 0.1180    | −4.2304  | 0.1563    | 5.7892   | 0.0939    | 2.4203   |
| NNR            | DSUR       | 0.1397    | 5.7966   | 0.1638    | 4.3349   | 0.1616    | 7.6240   | 0.1217    | 6.0557   |
|                | CUP-FM     | 0.1016    | 2.1711   | 0.1813    | 8.1336   | 0.1305    | 4.0299   | 0.1228    | 4.5339   |
|                | CUP-BC     | 0.0834    | 1.8533   | 0.1140    | 2.8027   | 0.1155    | 7.5535   | 0.0882    | 3.5425   |
| TI             | DSUR       | −0.1512   | −4.7112  | −0.1529   | −5.0823  | −0.1244   | −4.7481  | −0.0769   | −2.9596  |
|                | CUP-FM     | −0.1662   | −3.7702  | −0.1113   | −4.469   | −0.1368   | −3.6002  | −0.0855   | −4.1304  |
|                | CUP-BC     | −0.1598   | −3.8707  | −0.1774   | −4.1176  | −0.12847  | −3.3807  | −0.12495  | −2.9964  |
| ET             | DSUR       | −0.0931   | −3.541   | −0.1630   | −7.1287  | −0.10766  | −4.2892  | −0.1302   | −6.7854  |
|                | CUP-FM     | −0.0990   | −6.2314  | −0.0838   | −4.2765  | −0.1013   | −7.2378  | −0.1309   | −4.8873  |
|                | CUP-BC     | 0.1746    | 10.7814  | 0.0883    | 5.8144   | 0.17053   | 8.318537 | 0.09196   | 2.1485   |
| Y              | DSUR       | 0.2492    | 7.1632   | 0.2275    | 6.4092   | 0.30316   | 9.8749   | 0.23251   | 7.3812   |
|                | CUP-FM     | 0.3821    | 10.3845  | 0.3583    | 18.9619  | 0.2572    | 15.4981  | 0.2544    | 9.1841   |
|                | CUP-BC     | 0.2998    | 6.8919   | 0.2205    | 8.4830   | 0.32421   | 11.1038  | 0.2322    | 9.7163   |
| Y <sup>2</sup> | DSUR       | −0.3829   | −10.6974 | −0.2976   | −15.4218 | −0.2444   | −6.9845  | −0.3816   | −8.7944  |
|                | CUP-FM     | −0.1878   | −5.5079  | −0.3380   | −10.6637 | −0.3606   | −19.4941 | −0.3452   | −11.6632 |
|                | CUP-BC     | −0.3253   | −9.8584  | −0.3653   | −14.9721 | −0.2942   | −7.3929  | −0.1888   | −4.4755  |
| C              |            |           |          |           |          |           |          |           |          |

The coefficients of TO revealed a positive statistical significance at a 1% level for all four executed models: that is, for PBCO<sub>2</sub> [*DSUR*<sub>0.1570</sub>; *CUP – BC*<sub>0.1817</sub>; *CUP – FM*<sub>0.1196</sub>], CBCO<sub>2</sub> [*DSUR*<sub>0.1102</sub>; *CUP – BC*<sub>0.0901</sub>; *CUP – FM*<sub>0.1180</sub>], CO<sub>2</sub> [*DSUR*<sub>0.1094</sub>; *CUP – BC*<sub>0.1563</sub>; *CUP – FM*<sub>0.0940</sub>], and EF [*DSUR*<sub>0.1306</sub>; *CUP – BC*<sub>0.0939</sub>; *CUP – FM*<sub>0.1645</sub>]. The study findings suggest that engaging in trade openness can boost economic activity as countries trade goods and services globally. Increased economic activity can lead to higher levels of production, consumption, and, as a result, carbon emissions. Moreover, with the increasing integration of countries into global supply chains, they might start importing raw materials and components from various regions to enhance their production processes. This may result in a rise in both production-based and consumption-based emissions, as products are made and shipped internationally. Nevertheless, our findings are supported by the literature [107–112].

The coefficients of natural resources rent revealed a positive statistical significance with EQ, suggesting the resources curse hypothesis which is supported by the existing literature [113–116]. Based on this theory, countries with plentiful natural resources often experience adverse effects on their economic development and environmental health. According to the findings, nations relying heavily on revenue from natural resources such as oil, gas, or minerals frequently exhibit lower ecological standards, underscoring the negative environmental impacts associated with resource extraction and utilization. This phenomenon may arise from various factors, including over-reliance on resource extraction, environmental damage from intensive extraction methods, and neglect of other economic

sectors, leading to insufficient funding for environmental conservation and sustainable development initiatives. Emphasizing the significance of policymakers addressing resource dependence issues and minimizing the environmental impact of natural resource extraction, one researcher points out a notable correlation between natural resources rent and EQ.

Referring to the coefficients of TI, a negative statistically significant association was revealed with EQ. It was validated in all four model estimations. The study finding suggest that technological progress in the economy prompts sustainability in environmental correction through ecological improvement as well as the limiting of CO<sub>2</sub> emissions. The conclusions of TI support the control of CO<sub>2</sub> emissions in the ecosystem, which is supported by the existing literature such as [117–120]. Furthermore, enhancing environmental quality through an environmental tax by the government exposes a negative tie with the proxies of EQ: that is, the imposition of a tax on CO<sub>2</sub> as a means of environmental protection amplifies the conservation of the environmental through lessening CO<sub>2</sub> emissions. Our study findings are in line with study findings offered by [121–123].

Table 8 exhibits the test statistics of causality assessment through the implementation of a non-granger causality test, following Dumitrescu and Hurlin [124]. For causality between FO and EQ, the study revealed a feedback hypothesis of CBCO<sub>2</sub>  $\leftrightarrow$  FO and EF  $\leftrightarrow$  FO, while a unidirectional causal effect was found running from PDCO<sub>2</sub>  $\rightarrow$  FO and CO<sub>2</sub>  $\rightarrow$  FO. For the causal tie between TO and EQ, the study documented a bidirectional tie between CBCO<sub>2</sub>  $\leftrightarrow$  TO; on the other hand, a unidirectional causality was exposed from PBCO<sub>2</sub>  $\rightarrow$  TO; CO<sub>2</sub>  $\rightarrow$  TO; and EF  $\rightarrow$  TO. In the case of causality between GTI and EQ, a bidirectional causality was apparent, running between EF  $\leftrightarrow$  GTI, whereas a unidirectional connection was found for PBCO<sub>2</sub>  $\rightarrow$  GTI; GTI  $\rightarrow$  CBCO<sub>2</sub>; and CO<sub>2</sub>  $\rightarrow$  GTI, respectively.

**Table 8.** Results of D-H causality test.

| Null Hypothesis: | W-Stat. | Zbar-Stat. |                   | W-Stat. | Zbar-Stat. |                   | W-Stat. | Zbar-Stat. |                   | W-Stat. | Zbar-Stat. |                   |
|------------------|---------|------------|-------------------|---------|------------|-------------------|---------|------------|-------------------|---------|------------|-------------------|
| EQ $\neq$ FO     | 5.0074  | 5.2778     |                   | 4.9160  | 5.1815     |                   | 3.8182  | 4.0244     |                   | 3.7513  | 3.9539     |                   |
| FO $\neq$ EQ     | 1.7205  | 1.8134     | $\rightarrow$     | 6.3018  | 6.6421     | $\leftrightarrow$ | 2.6216  | 2.7632     | $\rightarrow$     | 5.0701  | 5.3439     | $\leftrightarrow$ |
| EQ $\neq$ TO     | 3.8522  | 4.0603     |                   | 5.5866  | 5.8882     |                   | 1.6503  | 1.7394     |                   | 5.0552  | 5.3282     |                   |
| TO $\neq$ EQ     | 5.4962  | 5.7931     | $\leftrightarrow$ | 2.4176  | 2.5481     | $\rightarrow$     | 3.0063  | 3.1687     | $\leftarrow$      | 1.3060  | 1.3765     | $\rightarrow$     |
| EQ $\neq$ GTI    | 4.1838  | 4.4097     |                   | 1.2624  | 1.3306     |                   | 5.4757  | 5.7706     |                   | 11.0626 | 12.1285    |                   |
| GTI $\neq$ EQ    | 1.5398  | 1.6230     | $\rightarrow$     | 5.1870  | 5.4671     | $\leftarrow$      | 1.0956  | 1.1548     | $\rightarrow$     | 11.2784 | 13.3474    | $\leftrightarrow$ |
| EQ $\neq$ NRR    | 3.2211  | 3.3949     |                   | 1.5557  | 1.6398     |                   | 1.3613  | 1.4348     |                   | 3.9744  | 4.1891     |                   |
| NRR $\neq$ EQ    | 4.4537  | 4.6942     | $\leftrightarrow$ | 2.6429  | 2.7856     |                   | 4.6981  | 4.9518     | $\leftarrow$      | 5.6184  | 5.9218     | $\leftrightarrow$ |
| EQ $\neq$ Y      | 5.1902  | 5.4704     |                   | 5.3156  | 5.6026     |                   | 5.4074  | 5.6989     |                   | 6.1934  | 6.5278     |                   |
| Y $\neq$ EQ      | 4.5015  | 4.7435     | $\leftrightarrow$ | 4.4017  | 4.6393     | $\leftrightarrow$ | 4.4739  | 4.7155     | $\leftrightarrow$ | 6.1647  | 6.4976     | $\leftrightarrow$ |
| TO $\neq$ FO     | 5.4644  | 5.7594     |                   | 3.3846  | 3.5674     |                   | 3.4856  | 3.6738     |                   | 2.1317  | 2.2468     |                   |
| FO $\neq$ TO     | 5.3857  | 5.6759     | $\leftrightarrow$ | 2.1721  | 2.2894     | $\rightarrow$     | 2.6546  | 2.7979     | $\rightarrow$     | 6.3134  | 6.6544     | $\leftarrow$      |
| FO $\neq$ GTI    | 5.3889  | 5.6799     |                   | 2.4218  | 2.5526     |                   | 1.7332  | 1.8268     |                   | 5.4123  | 5.7045     |                   |
| GTI $\neq$ FO    | 5.2741  | 5.5589     | $\leftrightarrow$ | 3.4505  | 3.6369     | $\leftarrow$      | 5.2114  | 5.4928     | $\leftarrow$      | 5.1094  | 5.3853     | $\leftrightarrow$ |
| FO $\neq$ NRR    | 2.8246  | 2.9771     |                   | 5.0956  | 5.3708     |                   | 1.4803  | 1.5602     |                   | 3.3432  | 3.5237     |                   |
| NRR $\neq$ FO    | 3.1509  | 3.3212     | $\leftarrow$      | 2.2189  | 2.3387     | $\rightarrow$     | 1.1742  | 1.2376     |                   | 4.2029  | 4.4299     | $\leftrightarrow$ |

Table 8. Cont.

| Null Hypothesis:               | W-Stat. | Zbar-Stat. |                          | W-Stat. | Zbar-Stat. |                          | W-Stat. | Zbar-Stat. |                          | W-Stat. | Zbar-Stat. |                          |
|--------------------------------|---------|------------|--------------------------|---------|------------|--------------------------|---------|------------|--------------------------|---------|------------|--------------------------|
| FO $\leq$ / $\Rightarrow$ Y    | 5.9064  | 6.2254     | $\rightarrow$            | 4.5866  | 4.8342     | $\leftarrow \rightarrow$ | 4.5069  | 4.7502     | $\leftarrow \rightarrow$ | 3.5292  | 3.7198     | $\leftarrow \rightarrow$ |
| Y $\leq$ / $\Rightarrow$ FO    | 2.1955  | 2.3149     |                          | 5.0412  | 5.2727     |                          | 3.5961  | 3.7903     |                          | 4.9117  | 5.1773     |                          |
| TO $\leq$ / $\Rightarrow$ GTI  | 4.5069  | 4.7502     | $\rightarrow$            | 2.2306  | 2.3510     | $\leftarrow$             | 4.6174  | 4.8667     | $\rightarrow$            | 5.3825  | 5.6732     | $\leftarrow \rightarrow$ |
| GTI $\leq$ / $\Rightarrow$ TO  | 2.3698  | 2.4977     |                          | 6.1583  | 6.4908     |                          | 1.7258  | 1.8191     |                          | 3.3761  | 3.5585     |                          |
| TO $\leq$ / $\Rightarrow$ NRR  | 4.6588  | 4.9104     | $\leftarrow \rightarrow$ | 4.1253  | 4.3481     | $\rightarrow$            | 4.3602  | 4.5957     | $\leftarrow \rightarrow$ | 3.4941  | 3.6828     | $\leftarrow \rightarrow$ |
| NRR $\leq$ / $\Rightarrow$ TO  | 6.2048  | 6.5391     |                          | 1.0797  | 1.1380     |                          | 4.6184  | 4.8678     |                          | 3.4017  | 3.5853     |                          |
| TO $\leq$ / $\Rightarrow$ Y    | 4.8459  | 5.1075     | $\leftarrow \rightarrow$ | 5.2061  | 5.4872     | $\leftarrow \rightarrow$ | 1.6174  | 1.7047     | $\leftarrow$             | 4.8331  | 5.0941     | $\leftarrow \rightarrow$ |
| Y $\leq$ / $\Rightarrow$ TO    | 6.2157  | 6.5513     |                          | 5.0265  | 5.2980     |                          | 3.2656  | 3.4421     |                          | 3.9213  | 4.1331     |                          |
| GTI $\leq$ / $\Rightarrow$ NRR | 0.8522  | 0.8983     | $\leftarrow$             | 5.4048  | 5.6967     | $\leftarrow \rightarrow$ | 1.2051  | 1.2701     |                          | 2.3836  | 2.5123     |                          |
| NRR $\leq$ / $\Rightarrow$ GTI | 6.1029  | 6.4315     |                          | 4.8044  | 5.0639     |                          | 1.8108  | 1.9086     |                          | 1.9968  | 2.1046     |                          |
| GTI $\leq$ / $\Rightarrow$ Y   | 2.6216  | 2.7632     | $\leftarrow$             | 3.2274  | 3.4016     | $\leftarrow \rightarrow$ | 2.2093  | 2.3286     | $\leftarrow$             | 3.5781  | 3.7713     | $\leftarrow \rightarrow$ |
| Y $\leq$ / $\Rightarrow$ GTI   | 6.0116  | 6.3363     |                          | 4.0945  | 4.3156     |                          | 5.1381  | 5.4156     |                          | 4.5653  | 4.8118     |                          |
| NRR $\leq$ / $\Rightarrow$ Y   | 1.4038  | 1.4796     |                          | 2.6833  | 2.8282     | $\leftarrow$             | 3.6216  | 3.8172     | $\leftarrow \rightarrow$ | 0.8034  | 0.8467     | $\leftarrow$             |
| Y $\leq$ / $\Rightarrow$ NRR   | 2.4399  | 2.5717     |                          | 3.7842  | 3.9886     |                          | 3.3134  | 3.4924     |                          | 5.8894  | 6.2075     |                          |

Note  $\leftarrow$  or  $\rightarrow$  denote unidirectional and  $\leftarrow \rightarrow$  for bidirectional causality. Robustness test with different econometrical tool: CS-ARDL.

Table 9 reports the results of a robustness assessment with the implementation of CS-ARDL. Referring to the coefficients of the targeted independent variables, they exhibited a similar direction of linkage between the explanatory and explained variables in all four tested models. Thus, the study confirms the models' construction efficiency and estimation robustness.

Table 9. Robustness estimation with CS-ARDL.

|                       | [5]         |             | [6]         |             | [7]         |             | [8]         |             |
|-----------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                       | Coefficient | t-Statistic | Coefficient | t-Statistic | Coefficient | t-Statistic | Coefficient | t-Statistic |
| FO                    | 0.17743     | 3.8655      | 0.11054     | 6.2806      | −0.1545     | 5.8749      | 0.0945      | 2.9357      |
| TO                    | 0.10521     | 4.7822      | 0.08563     | −2.5637     | −0.1815     | 7.1211      | 0.1186      | 5.3692      |
| NNR                   | 0.17395     | 11.2225     | −0.15423    | −8.4278     | 0.1731      | 10.8243     | 0.1135      | 7.6722      |
| GTI                   | −0.16273    | −3.7068     | −0.11388    | −3.5366     | −0.1544     | −4.8872     | −0.0784     | −3.5677     |
| ET                    | −0.1103     | −4.4837     | −0.1792     | −7.3442     | −0.1815     | −8.1421     | −0.1427     | −3.8365     |
| Y                     | 0.2129      | 6.1889      | 0.2733      | 13.7336     | 0.2372      | 5.2966      | 0.2821      | 7.2532      |
| Y2                    | −0.19871    | −4.2641     | −0.27332    | −15.0176    | −0.2896     | −15.4064    | −0.35717    | −8.3451     |
| Error correction term |             |             |             |             |             |             |             |             |
| ECT(−1)               | −0.73027    | −20.6875    | −0.61047    | −19.885     | −0.7057     | −38.5628    | −0.63459    | −44.3769    |

Following this, the study implemented an instrumental variables techniques of assessing the possible issue of endogeneity and the results are displayed in Table 10. In accordance with the coefficient sign of FO, TO, and NRR towards the measurement of EQ, a similar direction of linkage is apparent to that which was established through the

earlier techniques, that is, DSUR, CUP-BC, and CUP-FM, thus unveiling the absence of endogeneity problems in the empirical models.

**Table 10.** Results of endogeneity test with IV estimation.

|                   | PBSO <sub>2</sub> |        |         |         | CBCO <sub>2</sub> |         | CO <sub>2</sub> |        |         | EF        |        |         |
|-------------------|-------------------|--------|---------|---------|-------------------|---------|-----------------|--------|---------|-----------|--------|---------|
| FO                | 0.1538            | 0.0239 | −6.4351 | 0.143   | 0.0309            | 4.6278  | 0.1291          | 0.0415 | 3.1108  | 0.1014    | 0.0186 | −5.4516 |
| TO                | 0.091             | 0.0289 | −3.1487 | 0.1389  | 0.0241            | 5.7634  | 0.1657          | 0.0251 | 6.6015  | 0.1482    | 0.032  | −4.6312 |
| NNR               | 0.101             | 0.0341 | −2.9618 | 0.137   | 0.0328            | 4.1768  | 0.0917          | 0.0367 | 2.4986  | 0.1776    | 0.0211 | −8.417  |
| GTI               | −0.1058           | 0.0459 | −2.305  | −0.125  | 0.0384            | −3.2552 | −0.1455         | 0.0434 | −3.3525 | −0.1126   | 0.0381 | −2.9553 |
| ET                | −0.136            | 0.0435 | −3.1264 | −0.1666 | 0.0223            | −7.4708 | −0.1473         | 0.0224 | −6.5758 | −0.1814   | 0.0248 | −7.3145 |
| Y                 | 0.175             | 0.0193 | 9.0673  | 0.1603  | 0.0317            | 5.0567  | 0.1053          | 0.0438 | 2.4041  | 0.1816    | 0.0215 | −8.4465 |
| Y2                | −0.145            | 0.0196 | −7.3979 | −0.1083 | 0.0444            | −2.4391 | −0.1624         | 0.0444 | −3.6576 | −0.0931   | 0.0402 | −2.3159 |
| LM statistics     | 14.5441           |        |         |         | 14.5441           |         | 14.5441         |        |         | 14.5441   |        |         |
| Wald F statistics | 1711.5629         |        |         |         | 1711.5629         |         | 1711.5629       |        |         | 1711.5629 |        |         |
| weak ID test      | 16.7976           |        |         |         | 16.7976           |         | 16.7976         |        |         | 16.7976   |        |         |

## 5. Single Country Investigation

In the previous section, we addressed empirical relations with panel data estimation. For country-specific evaluation, the study executed dynamic OLS to derive the long-run impacts of FO, TO, NRR, GTI, and ET on the measurement of environmental quality. Table 11 displays the results of long-run estimation and the found statistical significance.

**Table 11.** Result of DOLS for production-based CO<sub>2</sub> emission.

| Country    | Variables | FO     | TO     | GTI      | NRR    | Y      | ET       | Y2       | EKC |
|------------|-----------|--------|--------|----------|--------|--------|----------|----------|-----|
| Bangladesh | Coeff.    | 0.1654 | 0.0972 | −0.0956  | 0.1368 | 0.1237 | −0.16334 | −0.07874 | YES |
|            | t-stat    | 3.3049 | 3.6291 | −1.15706 | 2.5370 | 3.1072 | −2.42604 | −2.01003 |     |
| Egypt      | Coeff.    | 0.1337 | 0.1652 | −0.14995 | 0.0991 | 0.1467 | −0.12278 | −0.1474  | YES |
|            | t-stat    | 2.5462 | 3.4911 | −1.75798 | 2.8559 | 2.3817 | −1.75036 | −1.59886 |     |
| Indonesia  | Coeff.    | 0.0819 | 0.1177 | −0.11338 | 0.1614 | 0.0916 | −0.17086 | −0.14166 | YES |
|            | t-stat    | 3.1976 | 3.6831 | −3.81095 | 3.4465 | 3.4394 | −1.2938  | −2.9486  |     |
| Iran       | Coeff.    | 0.0825 | 0.1058 | −0.08825 | 0.1488 | 0.1538 | −0.12246 | −0.12046 | YES |
|            | t-stat    | 2.1929 | 2.9737 | −3.3937  | 2.7509 | 3.8033 | −3.09798 | −2.74759 |     |
| Mexico     | Coeff.    | 0.1664 | 0.1473 | −0.1016  | 0.1254 | 0.0885 | −0.13652 | −0.17345 | YES |
|            | t-stat    | 2.6704 | 2.0235 | −3.5857  | 3.3771 | 3.6502 | −3.45099 | −1.44233 |     |
| Nigeria    | Coeff.    | 0.1531 | 0.1021 | −0.1757  | 0.1442 | 0.1698 | −0.14548 | −0.11338 | YES |
|            | t-stat    | 2.9913 | 2.4676 | −1.5921  | 2.1275 | 3.4559 | −1.89496 | −3.09478 |     |
| Pakistan   | Coeff.    | 0.1253 | 0.1668 | −0.1141  | 0.1078 | 0.1594 | −0.09783 | −0.16813 | YES |
|            | t-stat    | 2.1622 | 2.3468 | −2.091   | 2.3008 | 3.1845 | −2.9150  | −3.23028 |     |

Table 11. Cont.

| Country                                                                     | Variables | FO     | TO       | GTI     | NRR    | Y      | ET       | Y2       | EKC |
|-----------------------------------------------------------------------------|-----------|--------|----------|---------|--------|--------|----------|----------|-----|
| Philippines                                                                 | Coeff.    | 0.1349 | 0.0858   | −0.1402 | 0.1611 | 0.0785 | −0.1448  | −0.10191 | YES |
|                                                                             | t-stat    | 2.3258 | 2.984908 | −3.195  | 3.0917 | 2.4762 | −1.4854  | −2.14059 |     |
| Turkey                                                                      | Coeff.    | 0.1688 | 0.0902   | −0.0986 | 0.1731 | 0.1342 | −0.17504 | −0.17795 | YES |
|                                                                             | t-stat    | 3.8778 | 2.253    | −3.2590 | 2.1407 | 2.8416 | −2.5529  | −3.6046  |     |
| South Korea                                                                 | Coeff.    | 0.1641 | 0.1164   | −0.082  | 0.1442 | 0.1122 | −0.14445 | −0.0987  | YES |
|                                                                             | t-stat    | 3.4895 | 2.3423   | −1.8341 | 3.6049 | 2.5422 | −1.34044 | −1.809   |     |
| Vietnam                                                                     | Coeff.    | 0.1549 | 0.1634   | −0.0842 | 0.1175 | 0.1634 | −0.1305  | −0.1483  | YES |
|                                                                             | t-stat    | 2.0826 | 3.102783 | −1.9698 | 2.229  | 2.4803 | −3.0016  | −3.4291  |     |
| Panel B: environmental quality measured by Production based CO <sub>2</sub> |           |        |          |         |        |        |          |          |     |
| Bangladesh                                                                  | Coeff.    | 0.1207 | 0.0764   | −0.1068 | 0.1767 | 0.1    | −0.0976  | −0.1567  | YES |
|                                                                             | t-stat    | 2.1574 | 3.8697   | −2.9204 | 3.8396 | 2.4766 | −3.7143  | −2.6833  |     |
| Egypt                                                                       | Coeff.    | 0.1707 | 0.1      | −0.106  | 0.1481 | 0.0994 | −0.1393  | −0.1664  | YES |
|                                                                             | t-stat    | 3.7538 | 3.1508   | −2.8644 | 2.4546 | 2.4601 | −3.2305  | −2.6492  |     |
| Indonesia                                                                   | Coeff.    | 0.1393 | 0.0761   | −0.1056 | 0.1232 | 0.1253 | −0.0937  | −0.1269  | YES |
|                                                                             | t-stat    | 3.8186 | 2.6041   | −3.228  | 2.6936 | 3.4383 | −2.5782  | −3.9258  |     |
| Iran                                                                        | Coeff.    | 0.1065 | 0.1523   | −0.1199 | 0.1525 | 0.1247 | −0.0871  | −0.1555  | YES |
|                                                                             | t-stat    | 3.8892 | 3.5261   | −2.465  | 3.7184 | 3.4277 | −1.9114  | −1.3233  |     |
| Mexico                                                                      | Coeff.    | 0.1197 | 0.1172   | −0.1068 | 0.1784 | 0.1792 | −0.1716  | −0.0875  | YES |
|                                                                             | t-stat    | 2.8008 | 3.6679   | −3.2351 | 2.3841 | 3.2384 | −2.1398  | −1.3058  |     |
| Nigeria                                                                     | Coeff.    | 0.1801 | 0.1522   | −0.1168 | 0.1398 | 0.1661 | −0.1505  | −0.0785  | YES |
|                                                                             | t-stat    | 3.847  | 2.1404   | −2.1203 | 3.4839 | 3.0853 | −2.175   | −2.3723  |     |
| Pakistan                                                                    | Coeff.    | 0.0984 | 0.131    | −0.1603 | 0.1303 | 0.0809 | −0.0925  | −0.1396  | YES |
|                                                                             | t-stat    | 2.4014 | 2.9785   | −3.9443 | 2.1683 | 3.1767 | −2.6449  | −2.5945  |     |
| Philippines                                                                 | Coeff.    | 0.156  | 0.1098   | −0.1749 | 0.0979 | 0.1605 | −0.1811  | −0.1489  | YES |
|                                                                             | t-stat    | 2.6579 | 2.6802   | −3.8041 | 3.8676 | 3.1144 | −2.5178  | −1.0937  |     |
| Turkey                                                                      | Coeff.    | 0.0772 | 0.0825   | −0.1412 | 0.1457 | 0.1322 | −0.0818  | −0.1476  | YES |
|                                                                             | t-stat    | 2.9962 | 3.6842   | −2.4139 | 2.5041 | 2.4445 | −2.7249  | −2.8939  |     |
| South Korea                                                                 | Coeff.    | 0.1019 | 0.1296   | −0.1449 | 0.1078 | 0.1245 | −0.1411  | −0.1404  | YES |
|                                                                             | t-stat    | 2.4505 | 3.1662   | −2.4963 | 3.7055 | 3.9544 | −1.1422  | −2.1922  |     |
| Vietnam                                                                     | Coeff.    | 0.0933 | 0.0943   | −0.1432 | 0.0766 | 0.1111 | −0.103   | −0.1265  | YES |
|                                                                             | t-stat    | 2.7239 | 2.4586   | −1.8302 | 3.8607 | 3.8816 | −2.6858  | −1.8822  |     |
| Panel C: environmental quality measured by total CO <sub>2</sub>            |           |        |          |         |        |        |          |          |     |
| Bangladesh                                                                  | Coeff.    | 0.157  | 0.1743   | −0.0992 | 0.1236 | 0.1028 | −0.116   | −0.0931  | YES |
|                                                                             | t-stat    | 3.1328 | 3.0268   | −1.9344 | 2.9625 | 2.0034 | −1.8257  | −3.9126  |     |

Table 11. Cont.

| Country                                                         | Variables | FO     | TO     | GTI     | NRR    | Y      | ET      | Y2      | EKC |
|-----------------------------------------------------------------|-----------|--------|--------|---------|--------|--------|---------|---------|-----|
| Egypt                                                           | Coeff.    | 0.0819 | 0.1194 | −0.1817 | 0.1799 | 0.1331 | −0.1074 | −0.0797 | YES |
|                                                                 | t-stat    | 2.236  | 2.8672 | −1.2507 | 2.1639 | 3.0691 | −3.5031 | −3.6874 |     |
| Indonesia                                                       | Coeff.    | 0.124  | 0.1716 | −0.1367 | 0.1811 | 0.1076 | −0.1346 | −0.1161 | YES |
|                                                                 | t-stat    | 3.3165 | 2.9339 | −1.4387 | 2.7328 | 2.7905 | −2.9993 | −3.3294 |     |
| Iran                                                            | Coeff.    | 0.0875 | 0.1301 | −0.1569 | 0.1095 | 0.1791 | −0.1115 | −0.1325 | YES |
|                                                                 | t-stat    | 2.7765 | 3.6367 | −2.8819 | 2.5001 | 3.4255 | −3.4631 | −3.9275 |     |
| Mexico                                                          | Coeff.    | 0.0762 | 0.1178 | −0.1306 | 0.1253 | 0.0849 | −0.0838 | −0.1571 | YES |
|                                                                 | t-stat    | 2.198  | 3.0948 | −1.7074 | 3.3688 | 2.404  | −1.8479 | −3.248  |     |
| Nigeria                                                         | Coeff.    | 0.1027 | 0.121  | −0.1492 | 0.1015 | 0.0929 | −0.1472 | −0.099  | YES |
|                                                                 | t-stat    | 2.8677 | 3.8015 | −1.5158 | 2.7854 | 2.0272 | −2.249  | −2.568  |     |
| Pakistan                                                        | Coeff.    | 0.1498 | 0.1827 | −0.1235 | 0.0764 | 0.1676 | −0.1104 | −0.1714 | YES |
|                                                                 | t-stat    | 3.9214 | 2.2298 | −3.6398 | 3.8233 | 3.7551 | −1.0345 | −2.1438 |     |
| Philippines                                                     | Coeff.    | 0.1021 | 0.1755 | −0.1675 | 0.1157 | 0.1175 | −0.1756 | −0.1136 | YES |
|                                                                 | t-stat    | 2.4009 | 2.616  | −1.963  | 2.0354 | 3.4809 | −1.0918 | −3.6939 |     |
| Turkey                                                          | Coeff.    | 0.1246 | 0.1356 | −0.0921 | 0.1703 | 0.1647 | −0.1485 | −0.1526 | YES |
|                                                                 | t-stat    | 2.5093 | 3.9853 | −2.8543 | 2.7374 | 2.3895 | −2.0881 | −1.9893 |     |
| South Korea                                                     | Coeff.    | 0.1621 | 0.0872 | −0.1433 | 0.1656 | 0.1732 | −0.1615 | −0.0784 | YES |
|                                                                 | t-stat    | 3.7556 | 3.1986 | −2.3045 | 3.9056 | 2.3876 | −1.3014 | −3.2646 |     |
| Vietnam                                                         | Coeff.    | 0.1545 | 0.0781 | −0.1199 | 0.0765 | 0.0859 | −0.1386 | −0.1817 | YES |
|                                                                 | t-stat    | 3.4225 | 3.1667 | −1.1989 | 2.7877 | 3.5764 | −3.972  | −3.7519 |     |
| Panel D: Environmental quality measured by Ecological footprint |           |        |        |         |        |        |         |         |     |
| Bangladesh                                                      | Coeff.    | 0.1677 | 0.1208 | −0.0801 | 0.18   | 0.1559 | −0.1718 | −0.1126 | YES |
|                                                                 | t-stat    | 3.3845 | 2.3479 | −1.8282 | 2.3049 | 2.4997 | −2.5494 | −1.9367 |     |
| Egypt                                                           | Coeff.    | 0.1659 | 0.1298 | −0.139  | 0.1181 | 0.0928 | −0.0999 | −0.0772 | YES |
|                                                                 | t-stat    | 3.2962 | 2.9253 | −2.8597 | 2.9156 | 3.7623 | −1.6861 | −1.7355 |     |
| Indonesia                                                       | Coeff.    | 0.1492 | 0.159  | −0.1389 | 0.0913 | 0.154  | −0.0909 | −0.1543 | YES |
|                                                                 | t-stat    | 2.9064 | 3.2381 | −3.4454 | 3.9963 | 2.7183 | −3.3784 | −3.6542 |     |
| Iran                                                            | Coeff.    | 0.1468 | 0.0947 | −0.1201 | 0.08   | 0.1163 | −0.1778 | −0.1152 | YES |
|                                                                 | t-stat    | 2.6999 | 2.3645 | −3.8289 | 3.8511 | 3.2819 | −1.3028 | −1.895  |     |
| Mexico                                                          | Coeff.    | 0.1209 | 0.1469 | −0.1118 | 0.0969 | 0.1392 | −0.1409 | −0.1555 | YES |
|                                                                 | t-stat    | 3.8174 | 3.7178 | −2.8295 | 2.9396 | 3.8564 | −3.7795 | −1.6314 |     |
| Nigeria                                                         | Coeff.    | 0.1297 | 0.0806 | −0.1552 | 0.1584 | 0.1066 | −0.0971 | −0.1631 | YES |
|                                                                 | t-stat    | 3.0559 | 3.566  | −1.1304 | 3.4753 | 3.9165 | −1.3895 | −1.4294 |     |
| Pakistan                                                        | Coeff.    | 0.0773 | 0.0997 | −0.1454 | 0.1032 | 0.122  | −0.1694 | −0.1137 | YES |
|                                                                 | t-stat    | 2.9981 | 2.5048 | −2.9214 | 3.3442 | 3.0818 | −3.5512 | −1.6012 |     |

Table 11. Cont.

| Country     | Variables | FO     | TO     | GTI     | NRR    | Y      | ET      | Y2      | EKC |
|-------------|-----------|--------|--------|---------|--------|--------|---------|---------|-----|
| Philippines | Coeff.    | 0.1445 | 0.1138 | −0.0943 | 0.154  | 0.1189 | −0.1397 | −0.1079 | YES |
|             | t-stat    | 3.2057 | 2.3598 | −1.0235 | 3.0951 | 2.9416 | −3.9613 | −1.848  |     |
| Turkey      | Coeff.    | 0.1754 | 0.0967 | −0.119  | 0.1409 | 0.1054 | −0.097  | −0.1138 | YES |
|             | t-stat    | 2.4374 | 2.6189 | −1.1    | 3.1654 | 3.7832 | −3.3893 | −3.0386 |     |
| South Korea | Coeff.    | 0.0818 | 0.1471 | −0.1245 | 0.1619 | 0.1577 | −0.1763 | −0.1205 | YES |
|             | t-stat    | 2.5727 | 2.9681 | −1.2324 | 2.2883 | 2.0367 | −1.6788 | −2.4579 |     |
| Vietnam     | Coeff.    | 0.1564 | 0.1084 | −0.1455 | 0.0925 | 0.108  | −0.101  | −0.1641 | YES |
|             | t-stat    | 3.4883 | 3.8372 | −3.5921 | 3.4323 | 3.7326 | −3.1751 | −1.6851 |     |

## 6. Discussion

Foreign direct investment (FDI) frequently entails the exchange of cutting-edge technologies and management strategies, leading to enhanced resource utilization and a diminished ecological footprint in industries that adopt environmentally sustainable technologies [125]. Innovation driven by foreign direct investment (FDI) can also contribute to the advancement and widespread use of environmentally friendly technologies [126]. Foreign direct investment (FDI) plays a crucial role in facilitating the transfer of technology to locally owned companies in the host country. This, in turn, encourages technological progress among domestic competitors in the market. In addition, employees at these firms have the chance to gain knowledge about the technology, and a few may even utilize this knowledge to initiate their own business endeavors [127]. The dissemination of technology occurs through different channels, such as foreign direct investment, trade, and licensing [128]. Foreign direct investment (FDI) plays a vital role in addressing financial challenges and promoting the exchange of knowledge and technology, which are essential for meeting the growing energy needs in developing countries [129].

In contrast, several studies indicate that foreign direct investment (FDI) may have negative impacts on the environment, especially in developing countries where environmental regulations are less strict. This can potentially lead to the formation of pollution hotspots [130,131]. On the other hand, there are studies that suggest that FDI can have a positive impact on environmental sustainability [130]. These studies highlight how FDI can encourage the adoption of green energy sources, improve energy efficiency, and foster technological innovations in operational practices [125]. In developed countries, the positive environmental impact of FDI is frequently accredited to the adoption of environmentally friendly production technologies and management practices [1]. As societies progress and experience economic growth, there is often an increased recognition of the importance of environmental issues. This leads to a growing desire for cleaner technologies and sustainable practices [1].

Foreign direct investment (FDI) has the potential to lead to negative environmental impacts, especially in developing countries with less-strict environmental regulations, which could potentially result in the establishment of areas with high levels of pollution [132]. Foreign direct investment (FDI) can occasionally result in an increase in the utilization of natural resources to support economic activities. This, in turn, can have negative consequences such as environmental degradation and the depletion of ecosystems [133]. In countries where environmental regulations are lacking or enforcement systems are ineffective, the environmental impact of foreign direct investment (FDI) can be exacerbated. Some multinational corporations (MNCs) might take advantage of lax regulations to engage in practices that harm the environment. Foreign direct investment (FDI) can also involve the relocation of industries that have negative environmental impacts from developed

countries to developing countries, with the aim of taking advantage of lower production costs. This can result in the transfer of environmental challenges to the receiving nations. However, foreign direct investment (FDI) has the potential to contribute to environmental sustainability by integrating green energy, improving energy efficiency, and advancing technology in operational procedures. As countries experience economic growth, there is often an increased awareness of environmental issues, which results in a demand for cleaner technology and sustainable practices. Therefore, it is of utmost importance to establish and enforce effective environmental policies, specifically in relation to foreign direct investment (FDI), to ensure the successful integration of green technology in the country where it is being implemented [41].

For trade openness, the study unveiled a positive linkage with the measurement of environmental quality. The study findings suggest trade liberalization intensifies the environmental adversity that is domestic production, with the inclusion of fossil energy and inefficient technology eventually amplifying environmental degradation. The destructive effects of TO on environmental quality has been supported by the existing literature such as [49,134–136]. Trade liberalization frequently promotes an emphasis on economic development driven by exports, potentially resulting in the extensive utilization of natural resources to meet the demand for exports. As a result, there may be negative consequences such as deforestation, overfishing, and depletion of resources [137]. The Pollution Haven Hypothesis suggests that companies, especially those with significant pollution levels, may choose to relocate their operations to countries with more relaxed environmental regulations in order to reduce production costs. As a result, there could be an increase in pollution and environmental degradation in countries that have less-strict environmental regulations [138]. Increased trade operations frequently lead to higher levels of production and transportation, which in turn require more energy. This can worsen air and water pollution, greenhouse gas emissions, and overall environmental degradation, especially when the energy comes from non-renewable and polluting sources [139,140]. However, foreign direct investment (FDI) can also contribute to environmental sustainability by integrating green energy, enhancing energy efficiency, and promoting technological advancements in operational procedures. Reducing harmful emissions is of utmost importance, and one effective way to achieve this is by enhancing the affordability and accessibility of low-carbon technology [141]. When countries adopt climate policies, they experience a boost in the importation of low-carbon technologies and an increase in green foreign direct investment (FDI) inflows. This trend is particularly noticeable in emerging market and developing economies [137].

Furthermore, the production and disposal of goods involved in international trade can have a significant impact on waste generation. Unfortunately, in certain instances, improper waste management practices can result in the pollution of land, water, and air, thereby exacerbating the degradation of environmental quality [142]. Agriculture that heavily relies on trade, particularly in dry regions, can result in the excessive use of water resources for irrigation, which can lead to issues such as soil salinization, depletion of underground water sources, and harmful effects on ecosystems [143]. Ultimately, this has a detrimental impact on both the quantity and quality of water resources. It is crucial to implement effective environmental policies, particularly in the areas of trade and agriculture, in order to encourage the adoption of green technology and sustainable practices in the host country [144]. Implementing effective irrigation management techniques and ensuring proper drainage are crucial steps in addressing the issue of salty soils and preventing salinization [145]. In addition, improving the efficiency of irrigation channels, implementing methods to capture and treat salty drainage water, establishing desalting plants, and promoting the cultivation of salt-tolerant crops are among the solutions that can be employed to effectively manage soil salinization [145].

The coefficients of NRR have been exposed as positively statistically significant with EF and EVI, while for EPI and ESI, the coefficient of NRR has been exposed as negatively statistically significant at a 1% level, which has been found in all three model estimations.

The study findings suggest that extraction of natural resources has an adverse impact on EQ. Our study findings are supported by the literature offered by [35,146–148]. There are some possible ways that NRR has played a destructive role in degrading environmental quality: First the extraction of resources may have substantial adverse effects on the environment, such as deforestation, habitat degradation, soil erosion, and water contamination [38,149]. Consider mining operations, which have the potential to inflict substantial damage onto forests and ecosystems. Likewise, the process of extracting oil and gas may have adverse impacts on the quality of water and air, eventually may result in substantial environmental damage, resulting in the depletion of biodiversity and disturbance of ecological equilibrium [150,151].

The extraction of natural resources can result in substantial adverse environmental consequences, including but not limited to deforestation, habitat degradation, soil contamination, and water contamination [152]. Furthermore, an excessive reliance on natural resource revenues can impede economic diversification, thereby diminishing the potential for sustainable development. Sometimes, the existence of ample natural resource revenue can result in adverse outcomes, including the “resource curse” or “Dutch disease.” This occurs when currency appreciates due to the influx of natural resource revenue, reducing the international competitiveness of other exports. Consequently, the progress of economic diversification and overall development may be impeded [152]. Corruption, political instability, and social unrest can result from ineffective management of natural resources rent; these phenomena exacerbate social inequalities and undermine democratic governance [153]. Moreover, relying extensively on revenue generated from natural resources might restrict the expansion of economic activities and hinder the achievement of long-term, environmentally friendly development [154]. Several countries that largely dependent on revenue from natural resources may inadvertently neglect the development of other crucial sectors, such as agriculture, industry, and services [155]. The economy’s excessive reliance on natural resources may render it vulnerable to fluctuations in resource pricing and demand, leading to economic instability and hindering long-term development [38]. Furthermore, the existence of natural resources rent might lead to a condition known as the “resource curse” or “Dutch disease” [153]. This occurs when there is an excess of natural resource revenue, leading to a strengthening of the currency and reducing the competitiveness of other exports on the global market. As a result, other sectors of the economy may suffer adverse effects, impeding the process of economic diversification and general advancement. Furthermore, mismanagement of the income derived from natural resources may lead to corruption, political volatility, and societal turmoil [156], which signifies profits derived from natural resources may lead to corruption and the pursuit of economic gains via unproductive means by both government officials and commercial businesses, which may lead to a dearth of transparency, responsibility, and equitable allocation of resources, hence exacerbating socioeconomic disparities and undermining democratic government [147].

## 7. Conclusions and Policy Suggestions

### 7.1. Conclusions

This research was driven by the necessity to comprehend the intricate connection between financial openness, natural resources, and carbon neutrality in N-11 countries. This research is important as it offers valuable insights into how environmental tax and environmental innovation can help drive carbon neutrality in N-11 countries. Furthermore, it is anticipated to enhance the current body of knowledge regarding the correlation among financial openness, natural resources, and carbon neutrality. It aims to offer policymakers valuable perspectives on crafting policies that foster sustainable economic development and environmental conservation in N-11 nations.

In conclusion, the discourse on the environmental implications of foreign direct investment (FDI) and trade openness underscores the complex interplay between economic development, technological innovation, and environmental sustainability. While FDI of-

ten brings about technological transfers and managerial advancements that can enhance resource efficiency and promote the adoption of environmentally friendly practices, its impact on the environment varies significantly depending on the regulatory framework and enforcement mechanisms in place. Studies indicate that in countries with lax environmental regulations, FDI may lead to negative environmental outcomes such as pollution hotspots, resource depletion, and ecosystem degradation. Similarly, trade openness, while facilitating economic growth and international cooperation, can exacerbate environmental degradation through increased production, energy consumption, and waste generation. However, both FDI and trade openness have the potential to contribute positively to environmental sustainability when coupled with effective environmental policies, investment in green technology, and the promotion of sustainable practices. Therefore, it is imperative for policymakers to strike a balance between economic development and environmental protection by implementing stringent environmental regulations, promoting clean technology transfer, and fostering sustainable development practices in both domestic and international contexts.

This research significantly enhances the field of environmental economics and policy by thoroughly examining the connection between foreign direct investment (FDI), trade openness (TO), and environmental quality (EQ) in developing nations, filling a noticeable gap in the existing literature.

This study delves into the impact of FDI and TO on EQ, addressing a notable gap in current research. Although each element has been thoroughly researched individually, there is a lack of systematic study focusing on their combined effects. The study provides a comprehensive understanding of the intricate dynamics at play in the interconnections between economic activity and environmental outcomes.

This academic study compiles data from various sources, emphasizing the positive effects of foreign direct investment on technological innovation and the adoption of eco-friendly energy, while also acknowledging the adverse environmental effects linked to trade liberalization. The study offers a well-rounded perspective, helping readers grasp the intricacies of the subject matter.

The study examines the impact of natural resources rent (NRR) on environmental degradation. This finding illuminates the mechanisms underlying the resource curse phenomenon, offering valuable insights for policymakers looking to mitigate its negative impacts. An in-depth examination of how economic activities, environmental policies, and sustainability outcomes interact addresses research gaps effectively. This study offers decision-makers and stakeholders practical insights into the trade-offs involved in pursuing sustainable development amidst globalization challenges.

This study makes a significant contribution to the literature by investigating the combined impacts of FDI and TO on EQ, gathering evidence from different perspectives, demonstrating the link between NRR and environmental damage, and providing a comprehensive understanding of the challenges faced by developing nations in achieving sustainable development goals. This work is a significant addition to the field of environmental economics and policy.

## *7.2. Policy Suggestions for Future Development*

The crux of the matter is that the N-11 nations must establish robust environmental legislation to effectively handle the impact of financial openness and trade on environmental quality. This may include implementing more stringent regulations on pollution, mandating environmental impact studies for new projects, and enhancing monitoring and compliance systems.

Environmental taxes have shown their effectiveness in other situations as well, including reducing emissions and promoting sustainable industrial practices. The N-11 nations should contemplate increasing environmental levies as a means to dissuade environmentally detrimental activities and finance initiatives related to green technologies.

If this statement is actually accurate and innovation does indeed lead to improved environmental results, it logically follows that regulations should be implemented to promote further study and development of such environmentally friendly technologies. For instance, this may include tax benefits or, on the other hand, financial support provided to corporations who allocate resources towards the pertinent technology and advancements, perhaps extending to scholarly investigations on environmental breakthroughs.

Strategies might be developed to promote and support the import and export of environmentally friendly technology and services, in order to counterbalance the negative effects of trade liberalization. Possible measures might include reducing tariffs on environmentally friendly items and providing financial assistance to enterprises engaged in their production.

Financial transparency should be increased in order to encourage sustainability in financial practices. An effective approach to improve this would be promoting the use of green bonds or implementing rules that encourage sustainable investing practices. It is crucial to ensure that these investments are of high environmental standards.

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