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Asymmetric Effects of Economic Growth on Carbon Emissions of Developed Countries: Evidence From Nonlinear Panel Autoregressive Distributed Lag Model

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ABSTRACT

This study explores the asymmetric impact of economic growth on carbon emissions in developed countries by utilizing the panel data for the period 1990 to 2019. The current investigation considers the growth of developed countries to be an essential determinant of CO2 emissions. This study is the first of its kind to reveal the asymmetric connections between GDP and CO2 emissions by using the Westerlund panel co-integration and nonlinear panel auto-regressive distributive lag model. The findings support the fact that the impact of economic growth on CO2 emissions is significantly asymmetric. In the long run, positive GDP shocks will increase CO2 emissions in developed economies. Also, the positive shocks to GDP are correlated with CO2 emissions and other variables in a unidirectional way, except for renewable energy. Based on the given results quite a few policy recommendations were proposed in the concluding portion.

KEYWORDS: *Gross domestic product, Effects of asymmetries, Co-integration of the Westerlund panel, ARDL's Nonlinear panel.*

1. Introduction

Economic growth is a long-term process providing the potential output in any country. It is important for every nation and in this race to disastrously exploit natural resources. Economic growth increases the standard of living in any community. It guarantees a better quality of life. For a long time, the relationship between sustainable economic growth and ecological performance has been a strong discussion. Therefore, many studies have examined the association between economic growth and environmental degradation, yielding a variety of conclusions, including indications of an inverse association in some circumstances. The Environmental Kuznets Curve (EKC) model predicts an inverted-U connection. This model shows that pollution and degradation of natural resources increase rapidly in the initial phases of development. While this connection returns and pollution fall after a specific level of development. Thus, a shift in the connection has been viewed because of enhancing cooperation at a certain point in economic development, communities are more concerned with fresh air and strong forests with increased profits. Scholars, as well as policymakers, have reacted differently to the Environmental Kuznets curve theory, resulting in diverse results and confusing conclusions (Kahuthu, 2006).

Humanity faces two main challenges: sustainable growth and environmental protection. However, as land pollution raises concerns regarding the climate crisis, which is mostly caused by carbon dioxide emissions, the environment has become a more pressing concern for developed and emerging nations (Kasman & Duman, 2015; Uddin et al., 2017). Carbon dioxide (CO_2) emissions are the most significant portion of the GHGs. The causal relationship between the effect of CO_2 emissions on the gross domestic product (GDP) and electric usage has attracted the attention of researchers for decades (J. B. Ang, 2007; Saidi & Hammami, 2016).

Nowadays, Environmental degradation is a highly important environmental concern and attracting the attention of international organizations, academics, and politicians in the same way (Acheampong, 2018; Shaw et al., 2018). However, power usage is a fundamental input in the growth model and helps the manufacturing of products, lowering CO_2 emissions by waste reduction will harm economic development (Mardani et al., 2019). As a result, determining the causal relationship between these factors is crucial for developing a suitable economic plan in emerging regions (Wagner et al., 2001). For example, a positive link seen between parameters studied means that an efficient program would have a detrimental implication and improve the natural atmosphere (Carfora et al., 2019). As a result, implementing a growth strategy, particularly in a carbon industry has the potential to accelerate environmental degradation.

Furthermore, energy plays a crucial part in the economic performance of the country. However, it is a serious environmental issue (Apergis & Garćıa, 2019). Global energy use has increased by fifty percent in the last two decades relative to 1995. Improving energy usage is a major risk to environmental sustainability due to its negative effects on environmental conditions (Danish et al., 2019). In addition, numerous primary components, including the energy sector are predicted to increase fuel consumption. (Espa & Holzer, 2018). Holding the economic growth of the developing nations is a critical test in setting ecological goals. In particular, economic growth is the main force required for the BRICS economies (Shao et al., 2019). For instance, China provides more than twenty percent of the world's Gross domestic product, while it unclean the atmosphere by supplying above forty percent of overall CO_2 discharges (Dong et al., 2017). Such realities have real consequences for regulating GHG and air pollution (Reilly, 2012).

There might be a few focal points for expanding interest in energy efficiency. For example, by reducing fossil fuel by-products, reducing dependency on the FFs, improving energy security, surviving power deficiencies, and causing mechanical rivalry by reducing operating costs, reducing weight on the environment (European Commission - The Joint Research Centre, 2015). Furthermore, energy efficiency is a crucial element of BRICS economies' green advancement policies, which expect to minimize CO_2 emissions by improving the use of electricity (Bayar & Gavriletea, 2019). Additionally, achieving feasible progress goals often includes the use of enhanced energy (Shahbaz et al., 2019). In this way, renewable and efficient energy is a major consideration for developed and developing countries to promote rapid economic growth, meet the power disparity, as well as decrease the impacts of greenhouse gas discharges.

Different aspects of environmental change have been investigated in the latest literature on environmental quality. Some research, for instance, considered the need for the use of atomic energy to mitigate ecological corruption(Dong, Sun, Jiang, et al., 2018), while some thought that FDI was an important explanation for natural changes (Pao & Tsai, 2011; Shao et al., 2019). Exchange receptivity (Haug & Ucal, 2019; Shao et al., 2019), a monetary shock of events (Haug & Ucal, 2019; Pata, 2018), and common assets were other natural elements (Danish et al., 2019). Despite this, the most recent evaluations do not appear to address the importance of business expansion in both advanced and emerging nations for carbon reduction.

The present study fills the research gap by modeling the role of economic growth in affecting the environmental quality of selected developed countries. Based on the preceding discussion, the current study objectives can be summarized as follows: The main objective of this research is to investigate the short and long-term symmetric and asymmetric effects of GDP on carbon dioxide emissions in selected developed countries. In the present case, we examine whether the impact of GDP on CO_2 is encouraging or negative and whether it is considerable or insignificant. The research's second objective is to examine the path of causality with the variables in the case of emerged countries separately. Conspicuously, in a nonlinear approach, this examination uses the pooled mean gathering (PMG) method. For all countries on the panel, the PMG strategy offers comparable long-term boundaries but heterogeneous short-run limits. By using this technique unexpectedly to study GDP, and environmental panel details, this analysis is unique. It offers co-integration tests in a panel data system independently of the positive and negative sections of explanatory and contingent variables.

The remaining parts are arranged as follows the first part presents the introduction. The second part contains a thorough analysis of the literature. Part three introduces the data and variables. In addition, Part 4 presented the econometric model and methodology. The practical analysis and the detailed findings are discussed in Part 5. Finally, part six summarizes the conclusions and makes policy recommendations based on the results of the analysis, as well as making some suggestions for future studies.

2. Literature review

The literature review focuses on the relationship between emerged economies' GDP, FF, RE, and CO2 emissions, concentrating on selected developed countries. This section cites reviews that explore the relationship between GDP, FF, RE, and CO2 and addresses symmetric methods. Further examinations are then highlighted to consider the asymmetric relationship between selected variables.

2.1. Symmetric relationship between emissions GDP, FF, RE, and CO_2 emissions

The linear relationships between GDP, FF, RE, and CO_2 emissions have been modeled by numerous surveys. For example, within a certain time, (Ran et al., 2020) determined the relationship between environmental deregulation and carbon emissions in China. The results indicated that while atmospheric diversification has a good effect on environmental pollution when employing spatial panel and dynamic threshold models, China's current environmental centralization approach may be detrimental to energy consumption regulation. Also, (Umar et al., 2020) using multiple econometric approaches within a multivariate framework, researchers looked at the impact of growth in the economy and natural resources on CO_2 emissions in China. Economic growth and natural resources have a beneficial influence on China's CO2 emissions, according to the findings. The short and long-term relationship between environmental quality indices and economic expansion was investigated by (Chen & Taylor, 2020). The finding suggested that Singapore's post-industrial growth may have led to the formation of pollution havens in the area and had important consequences for sustainable regional development and pollution emission governance. (Pegkas, 2020) explored tourism, energy, and the weather have all had an impact on Greece's economic growth. The data show that increasing fuel efficiency and financial expansion improves harmful emissions, but there is a long-term positive connection between tourism, investment, energy consumption, pollution, and economic growth.

In the sense of the Indian economy, (Zameer et al., 2020) also explored the link between innovation, environment, and economic growth. The study revealed that in the long term, using ARDL bound testing and vector error correction model (VECM) techniques, trade openness, energy use, and economic growth positively guide CO_2 emissions. (Nathaniel, 2020) examined the environmental effects of the use of oil, urbanization, commerce, and economic development captured by the ecological footprint. The results showed that environmental deterioration is growing through urbanization and economic development. (OKUMUŞ & BOZKURT, 2020) examined the complicated links between the growth of the economy and ecological deterioration sequence across groupings of nations having various degrees of development in the context of the environmental

Kuznets curve (EKC) theory. The data showed that the energy usage coefficient is positive and statistically significant in all nation categories, but that the EKC hypothesis is supported for the lower medium and higher middle-income groups of countries, but not for the low and high-income groups. (Ntarmah et al., 2020) also looked at the complicated link between loan availability, wealth creation, as well as the environment from the standpoint of the sub-regional economies. Economic growth impacted carbon pollution in Central African nations and not in the East, Southern, or West African subregions, according to the study, which used the panel vector autoregressive (panel VAR) model. The findings of (Abdollahi, 2020) show that in industrialized nations, energy usage, environmental deterioration, and economic growth all have an impact.

Although, there is a unidirectional causality between the growth of the economy and atmospheric pollution, as well as contamination of the environment and energy use. (Abdouli & Hammami, 2020) observed that GDP growth, FDI inflows, environmental quality, and financial success all have an impact on CO_2 emissions for Middle Eastern nations. The data revealed a unidirectional causal relationship between energy consumption and GDP growth. Furthermore, these countries employ economic measures that promote economic progress while also protecting the environment. (Pata & Aydin, 2020) proposed that countries should consider the different ways of consumption of renewable energy because of environmental difficulties. Also, the outcome of RE is environmentally friendly. (Mahjabeen et al., 2020) stated that in D-8 nations the renewables development series, as well as the power sustainability performance series are important. The authors investigated whether the usage of renewable energy boosts economic growth and environmental degradation by the use of FMOLS tests, while the ARDL panel statistics indicate substantial co-integration. (Doğan et al., 2020) concluded that in OECD countries environmental deterioration might be mitigated by improving economic quality and using renewable energy. The interplay among energy usage, productivity expansion, and ecological pollution in countries is complicated, as studied by (Ozcan et al., 2020). He shows the secret to advancing sustainable development by life rather than guiding a trade-off process. (Taşkın et al., 2020) investigated the influence of renewable energy on economic development in a range of nations by bringing environmental degradation into the discussion. Inside the Developed nations, there is a link connecting renewable and non-renewable energy use and economic development was examined by (Behera & Mishra, 2020). The authors analyzed that by using Panel ARDL methods, nonrenewable energy consumption and economic growth have a short-term causal relationship, as does capital stock.

According to certain research, there is a link between resource depletion and GDP. According to (Nordhaus, 1992), rather than posing a long-term threat to the environment, to protect and enhance energy efficiency, economic development appears to be required. Meanwhile, concerns about the detrimental consequences of economic expansion on the environment are growing. Discussions about (Grove, 1992) had also prompted a flurry of research on the notion of ecologically growth and prosperity. As a result of this study, many people believe that the tradeoffs between development and ecological quality are not policy constant. Such imbalance may be greatly reduced with the proper rules in place (Antle & Heidebrink, 1995; Press & Journal, 2010; Selden, 1994). This is especially important for provisional nations that are in danger of enacting socioeconomic reforms which are incompatible with the long-term sustainable development goals.

The climate, resource usage, and economic activity are all linked in a complex way. They argue even though resource use provides instant economic benefits, it has long-term negative consequences for the environment (Kolstad & Krautkraemer, 1993). But on the other side, economic development has a net negative impact on environmental sustainability and appears to be dependent on the quality of various contaminants (Birdsall & Wheeler, 1993; Hettige et al., 1992). For instance, certain air contaminants with relatively substantial health and environmental impacts, different gases among other pollutants, show an environmental Kuznets curve connection with growth in the economy.

(Selden & Song, 1994) investigated many air pollutants and found comparable results with the inverted-U curve.

According to (Shafik & Bandyopadhyay, 1992), environmental impacts have been discovered to rise real Consumption. While (Goldemberg, 1998) believes such environmental calamities may be averted simply by completing the instructions taken by developed countries for years. The industrialized have implemented innovative and productive technologies initially as in the developmental phase. However, (Panayotou, 1997) discovered that when a nation's economic content is reduced, the strength of its institutional arrangements may make a difference. Future levels of wealth are expected to accelerate environmental changes. More solid property ownership under the legal system, greater contract compliance, plus effective environmental regulations are all policies that assist straighten the inverted-U Hypothesis and lessen the cost of greater competition. (Claessens & Feijen, 2006) used this method to demonstrate how better governance would lead to greater environmental changes in the financial sector. It has long been assumed that enhanced accounting processes drive efficiency advancements throughout the electricity generation sector, resulting in significant emissions reductions (Kumbaroğlu et al., 2008). According to (Dasgupta et al., 2001), environmental authorities in industrialized nations may directly utilize banking system dynamics through systematic programs of businesses' sustainability effect. According to (Lanoie et al., 1998), if markets are aware of a polluter's sustainable development, they will provide advantages towards reducing emissions. Simultaneously, (Dasgupta et al., 2006) investigate investors' reactions to the release of lists of firms in Korea that refuse to follow national environmental regulations. They discover that companies that feature on these lists have seen a substantial drop in their stock value. As a result, the findings suggest that a good world economy could be sufficient to motivate firms to reduce Carbon emissions. For such reasons stated above, we think financial institutions may play a significant role in generating possibilities for tackling global hazards. Marketplaces are aimed specifically at resource allocation and determining a fair price for products. In this regard, the state should assist industries by establishing a clear management system that ultimately making benefits climate mitigation.

It should also encourage and incentivizes the development of emerging innovations that contribute toward a lower greenhouse society. Furthermore, financial markets are essential as they allow businesses to reduce their debt ratio as well as generate funding for long-term energy-efficient technology development. However, for sustained economic and financial growth, a strong institutional foundation is required (Cropper & Griffiths, 1994; Jones & Manuelli, 2001). Economies as solid financial structures show usually richer and more capable of regulating pollution. As a result, an inverted U-shape could emerge from a collection of nations with varying degrees of institutional power. They show that pollution rises in poor low-income countries and falls in wealthy countries with higher institutions as they develop. (John & Pecchenino, 2017) propose models of inverted U-shaped pollution–income curves. The price of carbon rises when the optimal shift out of a corner's answer has no emissions reductions having significant environmental investments. Poor nations make use of the most polluting technologies which causes emissions to rise in parallel with income (Stokey, 1998). The marginal utility of consumption decreases as income and consumption rise and finally environmentally friendly technology will be the best option. Emissions will decrease when environmental quality choices remain high sufficiently. (Torras & Boyce, 1998) contributed to the volume of dynamic knowledge by highlighting the importance of macroeconomic arrangements inside the Kuznets curve. In the research of air and water response variables using data from nineteen to forty-two nations.

Researchers observed when a greater equal division of resources adds favorably through its Environmental Kuznets relationship. They claim such tendency is related to the growing power of individuals who surrender power and are more likely to face the consequences of emissions. They discovered how education, democratic freedoms, as well as civil freedoms had a particularly high impact on ecological sustainability among low-income nations. Their study focused on the disparities between lower and higher-income nations. (Panayotou, 1997) also demonstrated the effectiveness of legal frameworks in moderate nations may significantly minimize ecological damage. For a further explanation, a more thorough institutional review appears to be needed. Income is closely attributed to factors like the geographical strength of growth and imported goods rather than being the cause (Wagner et al., 2001). (Sadath & Acharya, 2019) based on developing countries, direct pollution mitigation initiatives and the content of cost-effective use of energy resources will support the world in climate change reduction efforts. In southeast Asian economies, the link between carbon dioxide emissions, energy usage, plus economic expansion was examined (Nosheen et al., 2019).

The link between carbon dioxide emissions, financial development, energy usage, and economic expansion was examined. The inverted U-shape relationship between GDP and natural resources was studied by the authors. The influence of industrial prosperity, international trade, and electricity generation on growing carbon dioxide concentrations in the atmosphere was studied using the ARDL and FMOLS panels (Waqih et al., 2019). The findings revealed the existence of the Pollution Heaven Hypotheses and the Inverted U Curve in the short term. Also, in the long-term panel data analysis, the absence of Emission Heaven theories and the existence of an inverted U Curve.

2.2. The asymmetric relationship between GDP, FF, RE, and CO_2 emissions

The non-linear ARDL technique was used to investigate by (Musibau et al., 2020), the asymmetric influence of economic expansion on the atmosphere of Nigeria. The findings revealed the relationship between the variables chosen, significant asymmetries predominate. (Şentürk et al., 2020) looked at the asymmetric link among per-capita Carbon dioxide emissions and per capita Gross domestic product for Annex I countries, non-Annex countries, and the UNFCCC. By using panel smooth transition models (PSTR) the results indicated asymmetries remain in the short and long term. Economic growth's positive and negative shocks have different indications and severity on Carbon emission.

Because of the asymmetric impacts of financial growth, (Omoke et al., 2020) has significant asymmetric impacts on greenhouse gas emissions for Nigeria. The findings showed an asymmetrical relationship between financial development and carbon pollution. The asymmetric heterogeneous link between electricity consumption with income development was underlined in nineteen chosen African nations, and asymmetries were pointed out (Kouton, 2019). (Isik et al., 2018) looked at the symmetric as well as asymmetric relationships between the growth of tourism, renewable energy consumption, and income development. The data demonstrate how the causal renewables and sustainable development relationship embraces theories of renewables growth in Spain, China, Turkey, and Germany. Whereas the Italian and U.S. models show a bidirectional relation using the Granger causality model of the bootstrap panel. (Mahmood et al., 2019) has looked at the asymmetric impacts of trade on Corban emission for Tunisia. The creators noticed that the positive exchange shocks extended outflows entirely, while the negative shocks had unfavorable yet insignificant discharge impacts. The asymmetric effects of exchange and FDI on CO_2 outflows in Turkey were explained by (Haug & Ucal, 2019) and showed that the two elements had asymmetric impacts. The implications of EG, EC, and FD on ecological efficiency in China were examined by (Ben et al., 2019). In the short run, CO_2 emissions were asymmetrically influenced by all the factors selected. Be that as it may, the drawn-out effects on CO_2 emanations of FD and EG were also asymmetric. On the other hand, the asymmetric effect of ecological guidance on CO_2 emissions in China was announced by (S. Khan et al., 2019).

The literature audit suggests that numerous variables of environmental changes be investigated in the surviving literature on the quality of the climate in developing countries. Numerous studies, for example, highlighted the position of growth (Gokmenoglu, et al., 2019; Wang et al., 2011), on other hand, some studies determined energy growth as the essential engine of ecological debasement (Balsalobre-Lorente, Driha, et al., 2019; Salman et al., 2019; Wu et al., 2020). Mostly, many types of research highlighted the significance of increasing environmental quality of RE (Danish et al., 2019; Dong et al., 2017; Onishi et al., 2012), several findings clarified the significance of decreasing environmental degradation by NU consumption (Dong, Sun, Jiang, et al., 2018) and foreign direct investment being as a leading reason for ecological adjustments (Pao & Tsai, 2011; Shao et al., 2019) and (Danish et al., 2019). Similarly, the relevance of GDP for lowering greenhouse gas emissions in selected poor nations was not considered in this study. The study's real goal is to address this research vacuum by emphasizing the significance of GDP in improving the current sustainability of chosen industrialized nations.

In the available evaluations for industrialized nations, linear models have also been employed to explore the link between growth, renewables, as well as the environment. Dynamic Ordinary Least Square method (Gokmenoglu, et al., 2019; Dong, Sun, Jiang, et al., 2018), FMOLS (Dong, Sun, & Dong, 2018; Shao et al., 2019), and ARDL (Dong, Sun, Jiang, et al., 2018; Pata, 2018). In many research, time-series data vector error correction modeling (Shaw et al., 2018), and the Garch model were used (B. W. Ang & Zhang, 2000; Pao & Tsai, 2011). Because systemic shifts and short-run shocks look through the asymmetry reasoning, (Po & Huang, 2008) questioned the usage using linear regression to evaluate the goals of the business interactions. According to (Kouton, 2019), time-series data cannot adequately remove asymmetric influences due to adynamic statistical strength. As a result, NPARDL is used in this work to highlight the asymmetric interaction between chosen variables in panel data from industrialized countries, with an emphasis on heterogeneities for the countries studied. In this behavior, the actual study gives the literature a particular attempt. Also, public conduct among the countries chosen is envisaged.

Economic development, fossil fuels, renewables, and Carbon dioxide all have a part in environmental protection mitigation. The complexity, however, includes factors that have changed because of nations' appropriate lighting resources and strategic frameworks for resolving climate-related uncertainties. The major objective of our research is to offer econometric approaches which will enable everyone to analyze the nonlinear and asymmetric co-integration of air sustainability, and productivity expansion, with CO_2 in several developed and developing countries between 1990 and 2019. Asymmetry and nonlinearity methods, as well as favorable and unfavorable changes in one external variable, do not affect another variable (Baz et al., 2019; Shahbaz et al., 2017; Tugcu & Topcu, 2018). Several factors influence the nature of a nonlinear relationship between the variables, including monetary, social, legislative, cultural, as well as international relations, and technological development offers either positively or negatively variance through economic growth usage, that does not have the same impacts on energy performance. In this case, we make utilize (Shin et al., 2012). It adds to the research on this ecological production as well as a power connection, a nonlinear autoregressive distributed lag model was developed. To determine the overall order of integration or the unknown serial correlation dates within the sequence. According to our literature review, we employ the unit root test (Kim & Perron, 2009). Asymmetrical and nonlinear econometric approaches have not been examined between economic growth and carbon dioxide emissions in specific developed and developing countries, as per the literature review.

3. Data and Methodology

The major goal of this research is to figure out which way correlation runs and to assess the relationship between GDP, FF, RE, and CO_2. We used a balanced panel data set for this, and we got the secondary source data from the World Development Bank (WDB). Annually data on all observations are collected. For empirical evaluation, we employ a time-series panel data set that has been divided into developed countries for analysis.

The countries and their codes are described in detail in the "Tables." The nations included in each sample are chosen depending on data availability. Furthermore, the study spans the years 1990 through 2019. All variables have a 29-year data period. CO_2 is used as a dependent variable, GDP is used as an independent variable, and FF and RE are used as control variables. To prevent correlation, we transformed CO_2 and GDP into logarithmic form.

Table 1: List of Selected Developed Economies and Codes

Country	Code	Country	Code
Italy	ITA	Japan	JPN
Germany	DEU	Netherlands	NLD
Canada	CAN	Sweden	SWE
France	FRA	Norway	NOR
Spain	ESP	Portugal	PRT

Note: This table shows a list of chosen developed nations, together with their WDI country codes.

According to the latest environmental literature, CO_2 emissions have been used as an environmental measure because they account for a large proportion (80 percent) of global GHG emissions (Allard et al. 2018). The emissions of CO_2 are measured in kilotons. Gross domestic product (GDP), fossil fuel consumption (FF), and renewable energy were included as independent variables (RE). In the current research, GDP is usually an agreed measure, and we estimated the asymmetric effects of GDP to fill the literature void. After analysis, we refer to the constant US$ 2010 GDP. RE is calculated as the share of RE in the overall consumption of energy consisting of solar, geothermal, wind, fuel, and other renewable energy resources (Cheng et al. 2019). Furthermore, in table 2, the variables, definitions, units, and sources are presented.

Table 2: Variables Specification

Variables	Specification	Source	Presentation
Dependent variables			
Carbon emissions	kt	World Bank	CO_2
Independent variables			
Gross Domestic Product	constant 2010 US$	World Bank	GDP
Fossil Fuel Energy	% of Total Consumption	World Bank	FF
Renewable Energy Consumption	% of total final energy consumption	World Bank	RE

3.1. Econometric Model

A few researchers have concentrated on the relationship with mixed results between GDP, FF, RE, and CO_2 emissions. The current review aims to identify the asymmetric effect of GDP in selected countries on CO_2 emissions. The method employed by (Dong et al., 2017) has been broadened; it now includes GDP as a major CO_2 emission factor and describes the overall model as follows:

$$CO_2 = f(GDP, FF, RE) \quad \textbf{(1)}$$

$$CO_{2it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 FF_{it} + \beta_3 RE_{it} + \varepsilon_{it} \quad \textbf{(2)}$$

Where CO_2 represents emissions of carbon dioxide, GDP is a gross domestic product, RE and FF are consumptions of renewable energy and fossil fuel; for this study, εt speaks to the error word, "i" represents a country and "t" characterize the duration (1990-2018). As a control variable, we implemented FF and RE. In this analysis, we want to use GDP that binds CO_2 to better explore the possible asymmetric relationship. This is on the basis that the interest side effects for the CO_2 level could be better recognized by this variable than the GDP as increases sought after driven income may have more straightforward effects on environmental degradation.

$$CO_2 = f(GDP^+, GDP^-, FF, RE) \quad (3)$$

$$CO_{2it} = \beta_0 + \beta_1 GDP_{it}^+ + \beta_2 GDP_{it}^- + \beta_3 FF + \beta_4 RE + \varepsilon_{it} \quad (4)$$

Here, our model is broken down into positive and negative series; GDP+ and GDP- reflect growth as well.

3.2. Econometric Methodology

To achieve our goal, we use the following econometric procedure: After model development, to examine cross-sectional dependency, we use the Psarian (2004) CD test. Second, we employ Pesaran's CIPS, IPS, and CADF panel unit root tests, that enable both cross-sectional dependence and sequential correlations. After confirming the unit root, we run the Westerlund cointegration tests. Fourth, will go through the NPARDL approach in depth before determining the direction of causality using the Dumitrescu and Hurlin causality test.

3.2.1. Cross-sectional dependence

Panel data disturbances are frequently considered to be cross-sectional independent, especially when high cross-section dimensions are present. Because of industrialization and involvement across international economies, CSD frequently occurs among panel data. According to (Lau et al., 2019), when CSD is ignored during estimation it might result in a loss of effectiveness as well as inaccurate test statistics. To use relevant panel econometric methodologies, we must first determine whether cross-sectional dependence exists across the selected nations. To put it another way, panel econometric approaches that fail to account for cross-sectional interdependence may produce inaccurate conclusions. We employed the cross-section dependency (CSD) test popularized by (Pesaran, 2007) to determine whether there is any cross-sectional dependence for carbon dioxide emissions, GDP, renewables use, as well as consumption of fossil fuels. The null hypothesis of CSD is cross-sectional independence, while the alternative hypothesis is cross-sectional interdependence. The test statistics are given as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i=1}^{N} \rho ij \right), N(0,1) \quad (5)$$

3.2.2. The panel Unit Root Test

To further understand the characteristics of stationarity, various unit root tests were performed on the panel data. It is critical to examine the data's stationarity before estimating, as estimation of non-stationary data produces inaccurate conclusions. The CADF and CIPS unit root tests were used in Pesaran (2007) to seek stationarity and analyze panel data heterogeneity (Kouton, 2019). Pesaran created the enhanced CADF and CIPS unit root test using a standard framework (Pesaran, 2007). We employ the panel unit root test to avoid the high risk of CSD since it considers the topic of cross-sectional dependence. The CADF and CIPS are common checks in the present literature, which makes the CSD. The CADF test is tested using the conventional DF regression. The test is based on OLS's evaluation of the progressive equation:

$$\Delta y_{it} = \alpha_i + \beta_i y_{it-1} + \delta_i y_{t-1} + \sum_{j=0}^{k} \delta_{ij} \Delta y_{it-j} + \sum_{j=0}^{k} \Delta y_{it-j} + \varepsilon_{it} \quad (6)$$

Within Eq. (6), yit−1 and Δyit− j represent each cross-sectional unit, a cross-sectional average of lagged level, and the first difference, individually. The following CIPS statistics apply paradoxically to the median of individual CADF insights:

$$CIPS = \frac{(1)}{N}\sum_{i=1}^{N} ti(N.T) \quad (7)$$

The null hypothesis for the CADF, IPS, and CIPS tests is that the root unit is indistinguishable, while the alternative is that one unit in the panel is stationary at any rate. The unit root analysis also identifies whether GDP, FF, RE, and CO_2 emissions shocks are permanent or transitory, but they also suggest whether the variables should be broken down. Nevertheless, a drawn-out affiliation holds between the episodes, and any aggravation in the system would have transitory impacts. Without co-integration, every external shock might have long-term consequences and should be considered.

3.2.3. Co-integration test for the panel

Following the stationarity test, we employ panel co-integration approaches. If the statistic has a unit root, co-integration testing is beneficial since it prevents misleading regression. Fixed effects, random effects, and instrumental variable estimators are common panel data techniques that fail to account for the cross-sectional dependency of error components, resulting in inaccurate conclusions (M. K. Khan et al., 2020). For established and emerging countries, this study utilizes the (Westerlund, 2007) co-integration technique to assess the relationship between carbon emissions (CO_2) and their drivers, such as GDP, renewable energy usage, and fossil fuel consumption. When the error terms are cross-sectional dependent, this test is extremely helpful and long-lasting (Kapetanios et al., 2011). Furthermore, there are no limitations to the test due to similar factors. We utilize this co-integration approach because of the data's cross-sectional dependency. The null hypothesis of Westerlund's (2007) co-integration test is that the variables are not co-integrated, whereas the alternate theory is that they are. Using group statistics, the presence of co-integration within a cross-sectional region is examined, whereas the existence of co-integration within the entire sample is investigated using panel statistics.

We tested for symmetric co-integration before testing for asymmetric co-integration. CSD is a concern that should be discussed during co-integration training. The Westerlund co-integration (2007) test is used to stay away from potential CSD. This test looks for CSD in panel data and detects co-integration in the panels using an error correction model.

$$\alpha i(\mathrm{L})\mathrm{y}_{\mathrm{it}} = \delta_{1\mathrm{i}} + \delta_{2\mathrm{i}}\mathrm{t} + \alpha_{\mathrm{i}}(\mathrm{y}_{\mathrm{it-1}} - \beta_i^{'}\,\mathrm{x}_{\mathrm{it-1}}) + \gamma_{\mathrm{i}}(\mathrm{L})'\mathrm{v}_{\mathrm{it}} + \mathrm{e}_{\mathrm{it}} \quad (8)$$

Where $\delta_{1\mathrm{i}} = \alpha_{\mathrm{i}}(1)\phi_{2\mathrm{i}} - \phi_{1i} + \alpha_{\mathrm{i}}\phi_{2\mathrm{i}}$ and $\delta_{2\mathrm{i}} = -\alpha_{\mathrm{i}}\phi_{2\mathrm{i}}$ The test statistics are given below:

$$G_t = 1/N\sum_{i-1}^{N}\hat{\beta}_i / SE(\hat{\beta}) \quad (9)$$

$$G_a = 1/N\sum_{i-1}^{N}\mathrm{T}\hat{\beta}_i / \hat{\beta}_i(1) \quad (10)$$

$$P_t = \hat{\beta} / SE(\hat{\beta}) \quad (11)$$

$$P_a = \mathrm{T}\hat{\beta} \quad (12)$$

The mean group data is signified by Gt and Ga, while the panel data is denoted by Pt and Pa. The Westerlund test (2007) evaluates the speed with which a shift to long-term equilibrium occurs. By changing the values of Pa, we may estimate the error correction component in equation (9).

3.2.4. Nonlinear Panel Auto-regressive distributed lag model

Mostly considering the framework of the current investigation, we construct the NPARDL model, as stated by (Salisu & Isah, 2017). For four reasons, this method is appropriate in this situation. To begin with, this method is appropriate for big-time panels with tiny cross-sections. But next, a most essential argument which helps in the detection of nonlinear asymmetries, is the study's major goal. Third, as with exports and imports, this takes into consideration the data's inherent heterogeneity. Finally, it is more appropriate when the integration order is less than I (1).

So, the short-and long-run nonlinearities are found in this system. The panel shapes of the nonlinear panel auto-regressive distributed lag model remain similar, as mentioned in the time series setting. NPARDL is a modified version of the forecasting model which accounts for the heterogeneous as well as complex nature of the data from the panels. It is ideal for estimating large T panels. The pooled mean group (PMG) predictor and the mean group (MG) predictor are the two most prevalent techniques for estimating a dynamic heterogeneous panel data model. We utilize the PMG method to calculate the long-run coefficient since the short-run coefficient for all nations in the panel is diverse (Bangake & Eggoh, 2012). By following (Bahmani-Oskooee & Fariditavana, 2016) and (Pesaran & M.H., 2004), by using a linear auto-regressive distributed lag model, I can calculate the short-run effects of the independent variables by presenting a short-run dynamic adjustment procedure. First, the symmetrical analysis of the ARDL panel is defined as:

$$CO_{2it} = \alpha_{0i} + \alpha_{1i} CO_{2i,t} + \alpha_{2i} GDP_{t-1} + \alpha_{3i} FF_{t-1} + \alpha_{4i} RE_{t-1} + \sum_{j=1}^{N1} \lambda_{ij} CO_{2i,t-j} + \sum_{j-0}^{N2} \gamma_{ij} GDP_{t-j} + \sum_{j-0}^{N3} \eta_{ij} FF_{t-j} + \sum_{j-0}^{N4} \alpha_{ij} RE_{t-j} + \varepsilon_{it} \tag{13}$$

i =1, 2, 3, ……N; t = 1, 2, 3, ……T. Where CO_{2it} is the logarithmic corban emissions on every cross-sectional unit I over time t; FF_t , as well as RE_t, refer to fossil fuel and renewable energy, respectively, at time t; i is the sampled unit, and t is the time number. The amount and significance of the short-run impacts are determined by estimating Equation (13) and the sign and significance of the coefficients related to the first separated variables are given to the long-run impacts. I found co-integration among the variables adjacent to them. This is done to legitimize long-run impacts. The variables of order zero (I(0)), or order one (I(0)) could be combined (1). To consider the word error correction, re-specify the equation (13) as follows:

$$\ln CO_{2it} = \varphi_i v_{i,t-1} + \sum_{j-1}^{N1} \lambda_{ij} \ln CO_{2i,t-j} + \sum_{J-0}^{N2} \gamma_{ij} \ln GDP_{t-j} + \sum_{j-0}^{N3} \eta_{ij} \ln FF_{t-j} + \sum_{j-0}^{N4} \alpha_{ij} \ln RE_{t-j} + \varepsilon_{it} \tag{14}$$

Where $v_{i,t-1} = \ln CO_{2i,t-1} - \phi_{oi} - \phi_{1i} \ln GDP_{t-1} - \phi_{2i} \ln FF_{t-1} - \phi_{3i} \ln RE_{t-1}$ are the symmetric correction terms for each unit; the factor ϕ_i is the error-correcting speed of the fitting term for each unit. The factor $\phi_{0i}, \phi_{1i}, \phi_{2i}, \phi_{3i}$ is calculated as $-\frac{\alpha_{0i}}{\alpha_{1i}}, -\frac{\alpha_{2i}}{\alpha_{1i}}, -\frac{\alpha_{3i}}{\alpha_{2i}}$ respectively.

The ARDL way of dealing with co-integration is extended to the undecomposed model in the strategy of this analysis. In both equations (13) and equations (14), there is no decomposition effect of GDP into positive and negative shocks. The symmetrical effects on the emission of carbon are seen. The asymmetric effects of panel ARDL are referred to as the nonlinear panel ARDL when analyzing the symmetric effects. So, symbolized here is the asymmetric representation of equation (13):

$$CO_{2it} = \alpha_{0i} + \alpha_{1i}CO_{2i,t-i} + \alpha_{2i}^{+}GDP_{t-1}^{+} + \alpha_{2i}^{-}GDP_{t-1}^{-} + \alpha_{3i}FF_{t-1} + \alpha_{4i}RE_{t-1} + \sum_{j=1}^{N1}\lambda_{ij}CO_{2i,t-j} + \sum_{j=1}^{N2}(\gamma_{ij}^{+}GDP_{t-j}^{+} + \gamma_{ij}^{-}GDP_{ij}^{-}) + \sum_{j=0}^{N3}\eta_{ij}FF_{t-j} + \sum_{j=0}^{N4}\delta_{ij}RE_{t-j} + \varepsilon_{it}$$

(15)

Where GDP^{+} and GDP- refer to positive and negative growth. The long-run (elasticity) coefficients for positive GDP and negative GDP, FF, and RE are added as:

$$\alpha_{GDP}^{+} = -\frac{\alpha_{2i}^{+}}{\alpha_{1i}} \quad (16)$$

$$\alpha_{GDP}^{-} = -\frac{\alpha_{2i}^{-}}{\alpha_{1i}} \quad (17)$$

$$\alpha_{FF} = -\frac{\alpha_{3i}}{\alpha_{1i}} \quad (18)$$

$$\alpha_{RE} = -\frac{\alpha_{4i}}{\alpha_{1i}} \quad (19)$$

Long-term CO_2 elasticity to positive GDP, negative GDP, FF, RE. As described below, positive, and negative shocks are measured as positive and negative shocks of the partial sum of GDP decomposition:

$$GDP_t^{+} = \sum_{j=1}^{t}\Delta GDP_j^{+} = \sum_{j=1}^{t}\max(\Delta GDP_j, 0)$$

(20)

$$GDP_t^{-} = \sum_{j=1}^{t}\Delta GDP_j^{-} = \sum_{j=1}^{t}\min(\Delta GDP_j, 0)$$

(21)

where GDP_t^{+} and GDP_t^{-} are the partial sum process of expands (+) and diminishes (-) in GDP since $GDP_t = GDP_0 + GDP_t^{+} + GDP_t^{-}$. It is conceivable to re-specify equation (15) and adds the error correction term as follows:

$$CO_{2it} = T_i\varphi_{i,t-i} + \sum_{j=1}^{N1}\lambda_{ij}CO_{2i,t-j} + \sum_{j=0}^{N2}(\gamma_{ij}^{+}GDP_{t-j}^{+} + \gamma_{ij}^{-}GDP_{ij}^{-}) + \sum_{j=0}^{N3}\eta_{ij}FF_{t-j} + \sum_{j=0}^{N4}\delta_{ij}RE_{t-j} + \varepsilon_{it} \quad (22)$$

The error correction term ($\varphi_{i,t-i}$) represents the long-term equilibrium found in the NPARDL model, while its associated Ti parameters are the adjustment term velocity that estimates the time system required to converge in the presence of a shock to its long-term equilibrium. Because the connection involving GDP, renewables power usage, fossil fuel consumption, as well as CO_2 emission may alter in the immediate future for each cross-section, the PMG methodology is used. In the long term, therefore, a similar pattern regarding any connection between these factors appears possible. It is also worth mentioning that alternate approaches, like FMOLS and DOLS, are being applied. These methods, on the other hand, simply focused on the long-term connection between variables, disregarding short-run fluctuations. This viewpoint also backs up the notion as PMG is the right tool for the job. The PMG method for estimation for all countries in the panel is used for homogeneous long-run coefficients (Bangake & Eggoh, 2012).

4. Results and Discussion

In this part, we examine the effects of GDP on CO_2 emissions using several econometric approaches, with fossil fuel and renewable energy as control variables. This part is divided into further four sections. To begin, we use various unit root tests CADF, CIPS, and the IPS unit root test to evaluate data stationarity. We use Westland's co-integration test in the second step to see if there is a long-term link between the parameters. The third phase involves using the short- and long-term correlations between variables using the Non-Linear panel ARDL (PMG) methodology. The D-H causation approach is used in the last step to determine the causality relationship, which is either one-way or two-way among the variables.

4.1. Cross-Sectional Dependency test

The first approach is to look for cross-sectional dependency in the panel of developed nations. The cross-sectional dependency test findings are shown in table 3. The results of the cross-section dependence test reveal that the cross-sections are interdependent as seen by the statistically significant test statistics. The findings provide striking evidence of CSD in the quantities of GDP, FF, RE, and CO_2. We investigated the degree to which economic growth is cross-sectionally independent within and across areas. The findings reveal strong evidence of cross-sectional dependence, which should be considered when analyzing cross-country growth.

Table 3: CD test (Pesaran, 2004) results for developed countries.

Developed countries		
Variable	**CD Test**	**P-Value**
LnCO2	10.120	0.000
lnGDP	34.480	0.000
FF	6.880	0.000
RE	25.050	0.000

Note: Estimated by CD test.

Appropriate estimation and prediction approaches for panel data models with cross-sectional dependency are a topic in and of itself, as explored by (Ahn et al., 2001; Pesaran, 2006). The development of panel unit root tests with cross-sectional dependency is also underway.

4.2. Panel unit root tests

Before proceeding with any econometric approach, we used panel unit root tests to establish whether the series is stable or has a unit root after validating the presence of CSD. For selected developed nations, we use the Pesaran (2007) CIPS, CADF, and IPS unit root tests to check if either series is stationary or has a unit root. The null hypothesis asserts that the series is stationary or has no unit root and the alternative hypothesis argues that the series is non-stationary or has a unit root. Furthermore, the three measures show symptoms of order heterogeneity. The unit root occurs with and without a pattern for all variables at different phases, as shown in Table 4. Nonetheless, all orders are made on the foundation of the first difference. All orders are I (1), indicating that the fundamental need for NPARDL evaluation has been addressed.

We pick whether the econometric methodology is appropriate for our model after performing the unit root tests and analyzing the results. In this circumstance, we can use the OLS methodology if all of the variables are I (0). And on the other hand, we may apply the panel ARDL bound testing technique if the variables are I(0) and I(1) mixed nature of stationarity (Ali et al., 2015; Bahmani-Oskooee & Fariditavana, 2016). We infer that GDP, GDP positive, GDP negative, and FF are all integrated of order zero I(0) based on the panel unit root test findings. When we run Pesaran CIPS (2007) unit root tests, CO_2 is integrated of order I(1) in developing nations at 1 percent, 5 percent, and 10 percent levels of significance. When we test Pesaran CADF and IPS in developed and developing countries, we get inconsistent results with I (1) and I (0).

Table 4: Results of panel unit root tests for Developed Countries

Variables	Level		1^{st} Difference		
	Intercept	**Intercept trend**	**Intercept**	**Intercept trend**	**Order**
Pesaran CIPS (2007)					
CO_2	-2.925	-4.046	-5.363 ***	-5.426 ***	I(1)
GDP	-2.048	-3.035**	--	--	I(0)
GDP^+	-1.230***	-1.527***	--	--	I(0)
GDP^-	-1.343***	-1.301*	--	--	I(0)
FF	-2.819***	-3.155***	--	--	I(0)
RE	-1.203	-2.575	-5.481	-5.875	I(1)
Pesaran CADF (2003)					
CO_2	-2.114	-3.306	-4.237 ***	-4.270***	I(1)
GDP	-2.172	-2.665	-2.881***	-3.042 ***	I(1)
GDP^+	-1.340***	-1.748***	--	--	I(0)
GDP^-	-1.748***	-1.670***	--	--	I(0)
FF	-1.734	-2.298	-3.953***	-4.060***	I(1)
RE	-0.603	-1.657	-3.792***	-3.990***	I(1)
IPS (2003)					
CO_2	-0.157	0.167	-8.359***	-6.978***	I(1)
GDP	2.667	-0.858	-8.026***	-6.358***	I(1)
GDP^+	1.202	1.397	-5.278***	-4.987***	I(1)
GDP^-	8.247***	5.054***	--	--	I(0)
FF	0.134	1.562	-7.115***	-5.779***	I(1)
RE	9.732	5.148	-6.2754***	-8.387***	I(1)

*Note: The presence of unit root is the null hypothesis. The significance levels are *** p0.01, ** p0.05, and * p0.1.*

The table shows the results of the panel unit root test at the level and first difference. For the panel unit root approaches, we used CADF, CIPS, and the IPS unit root test. The null hypothesis (H0) states that none of the variables are stationary. while the alternative hypothesis (H1) states that they are stationary. In addition, the probability numbers indicate whether we should reject or accept the null hypothesis.

4.3. Wasteland's co-integration test

The following panel of developed economies must be checked for co-integration, or simply a long-run connection, among variables after the panel unit root test. The findings of linear co-integration are shown first in Table 5, indicating that the null hypothesis cannot be rejected. Carbon emissions, GDP, renewable energy usage, and fossil fuel consumption all have a long-run linear connection, according to the data. The data is broken down into two types of statistics (Gt, Ga) and panel statistics (Pt, Pa). Although board statistics are centered on the incorporation of error correction system data, the compilation of insights does not indicate data from the term for error correlation with cross-sectional units (Malik et al., 2020). This conclusion is consistent with previous assessments of the BRICS economies, which found a link between energy growth, energy use, and CO_2 emissions (Dong et al., 2017; Pao & Tsai, 2011). If the statistics recognizing the shocks or volatility of GDP, FF, RE, and CO_2 emissions are comparable, symmetrical co-integration indicates that any shock to the system (i.e., GDP, FF, RE, and CO_2) will not damage the economy and climate. Although linear co-integration is improved among GDP, FF, RE, and CO_2 discharges in the Westland co-integration test, we are now continuing with the asymmetrical co-integration test. GDP, RE, FF, and carbon emissions are all strongly co-integrated, according to the nonlinear co-integration results given in the second section of table 10.

Table 5: Wasteland's co-integration results (Developed countries)

Statistic	Value	Z value	P-value
Sec 1st : Symmetric results			
Gt	-3.817	-6.508	0.000
Ga	-13.828	-3.046	0.001
Pt	-34.432	-23.094	0.000
Pa	-36.469	-16.123	0.000
Sec 2nd: Asymmetric results			
Gt	-2.912	-2.868	0.002
Ga	-9.520	0.160	0.563
Pt	-8.592	-2.746	0.003
Pa	-11.773	-2.448	0.007

Note: Estimated by Westerlund's co-integration model.

Linear models are unable to capture cyclical changes, but nonlinear or asymmetric models can. As a result, both yielded distinct results (Akram et al., 2020). The collections show a covered or nonlinear co-integration between GDP, FF, RE, and CO_2 discharges. Explaining similar outcomes between linear and nonlinear co-integration experiments to detect frequent variances, but nonlinear or asymmetric approaches allow similar changes. Nonetheless, we conclude that for developed countries, cointegration exists across all variables. As a result, the error is tied to the short-term dynamics in the long run. If any of the cointegration tests yield significant findings, we can assume that there is a long-run relationship between the variables (Siddique & Majeed, 2015).

4.4. Linear panel ARDL

When a long-run connection is demonstrated, it means that while there may be shocks inside the short run that disrupt the circulation in the distribution of values, they will eventually converge with a period in the long run. The estimation of long- and short-run models will be done from now on. The error correction term for the short run has a negative symbol and is significant at a 1%, 5%, and 10% levels. For developed countries, the ECT coefficient's estimated value is .0573921, and its 1% level of significance indicates a somewhat faster and more difficult transition to equilibrium. In a year, it is estimated that 5% of the discrepancy will have converged to the long-term equilibrium. Table 6 shows that at a 1 percent level, economic growth has a positive significant connection with carbon emissions. This means that a 1% rise in economic production will result in a 0.638373 increase in carbon emissions in the near run, confirming Zhang et al. (2021) conclusions that economic development promotes environmental damage in a comparable period. Conversely, renewable energy reduces carbon emissions, but it is significant.

Table.6 Results of panel ARDL Short Run

CO2 is a Dependent variable

Variable	Coefficient	Std. Err.	z	Prob.
GDP	1.356	0.201	6.740	0.000
FF	0.996	0.402	2.480	0.013
RE	-0.255	0.039	-6.590	0.000
Log Likelihood=	700.403			

The model is estimated by PMG.

Over the same period, economic development causes more environmental harm. On the contrary, Renewable energy reduces pollution and is insignificant at 1%, 5%, and 10% levels. Economic growth was found to have a coefficient of 1.356816, and fossil fuel had a coefficient of .9968886, whereas renewable energy had a value of -.2553464 in Table 7 for developed countries. In the long term, the result shown in the table is that economic growth has a significant impact on CO2 emissions at a 1% level of relevance. Economic growth has a positive long-term impact on the economy, with a percentage rise in economic growth resulting in a 1.3568 increase in carbon emissions. The results show that, despite the enormous volume of economic activity in the nations studied, emissions from processing and manufacturing businesses, as well as home activities, are still high. However, renewable energy has a negative and significant effect on CO_2. The evidence of a quick transition from nonrenewable to clean energy consumption, which is better for the environment and like Rjoub et al. (2021) for Turkey.

Table 7. Results of linear Panel ARDL Long Run

CO_2 is a Dependent variable

Variable	Coefficient	Std. Err.	z	Prob.
Ect	-0.057	0.067	-0.040	0.008
Constant	-1.722	1.992	-0.860	0.387
GDP	0.638	0.135	4.710	0.000
FF	0.892	0.216	4.120	0.000
RE	-0.146	0.047	-3.080	0.002

The model is estimated by PMG.

Furthermore, fossil fuels had also a long-term impact on CO2 emissions for the countries studied. The data show that FF has a positive and significant long-term connection with carbon emissions.

Non-Linear Panel ARDL model

Since all variables at the first difference are stationary, we precede with the dynamic estimation procedures. Table 8 shows the short-run results of the nonlinear panel ARDL for developed countries. Whereas table 9 shows the long-run results of the nonlinear panel autoregressive distributive lag model for developed countries. The PMG estimate approach is used to achieve the findings. The PMG results and the cointegration connection obtained by the error correction term (ECT) are shown in tables 8 and 9. The co-efficient of the ECT is negative and significant across all nations, showing a long-term relationship between the variables. Similarly, in the long run, we may expect GDP, FF, and RE to follow similar patterns.

The coefficient of the error correction term reflects how rapidly the system adjusts to the long-run equilibrium. In other words, the ECT's coefficient measures how quickly a system of interconnected variables may be brought back to long-run equilibrium. Furthermore, the system is dynamically stable and converges to the long-run equilibrium when the absolute co-efficient of the ECT is less than one. The presence of nonlinear co-integration between GDP and CO_2 emissions is also revealed

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by the finding of the error correction component. This section, as previously said, exhibits nonlinear co-integration and suggests that the equilibrium between GDP, FF, RE, and CO_2 discharges was asymmetric. The results were separated into three groups.

Relation between GDP-CO_2 emissions

The data points to an unequal link between GDP and CO_2 emissions in developed countries. In addition, table 8 shows that a positive shock to GDP and RE has a negative and negligible influence on CO_2 emissions in the short term, whereas other variables have a positive and inconsequential impact, except for FF, which has a direct and statistically significant impact on the CO_2 emissions in developed countries. Table 8 shows that in the PMG short-run model, RE has an inverse and statistically negligible influence on CO_2 emissions in developing countries, whereas other factors have a positive and statistically insignificant impact on CO_2. GDP has an unbalanced effect on CO_2 emissions in the near run. The PMG long-run outcomes in industrialized nations show a favorable and statistically significant influence of positive shock to GDP. A 1 percent level of a significant negative shock to GDP, FF, and RE in CO_2 emissions, which can be regarded as a sign of economic progress. In industrialized nations, a 1% increase in positive GDP shocks raises CO_2 emissions by.409 percent, whereas a 1% rise in negative GDP shocks increases CO_2 emissions by 3.441 percent. Table 9 indicates that in the PMG long-term model, a negative shock to GDP has a negative and statistically negligible influence on CO_2, but other factors have a positive and substantial impact on CO_2 emissions in the case of developing nations. Negative GDP shocks, on the other hand, have a higher impact on CO_2 emissions than positive GDP shocks. This outcome differs from that of (Danish et al., 2019). Industrialization is taking place in developed nations, and the industrial sector is a major source of GDP. During the time of economic development, GDP will degrade the quality of the environment.

Given the strong correlation between GDP and CO_2 emissions in developed economies, as a result of the findings GDP cannot grow without taking into consideration. This means that as GDP rises, CO_2 emissions will rise as well. As the economy grows, so does the energy demand. Another viewpoint is that rising economic activity (consumption, manufacturing, and investment) raises energy demand.

Table 8. Results of Non-linear Panel ARDL Short Run

CO2 is the dependent variable

Variable	Coefficient	Std. Err.	z	Prob.
GDP+	0.409	0.030	13.320	0.000
GDP-	3.441	0.507	6.780	0.000
FF	1.123	0.178	6.300	0.000
RE	-0.562	0.115	-4.870	0.000
Log Likelihood	707.552			

The model is estimated by PMG.

The relationship between Fossil Fuel-CO2 emissions

The symmetric relation between FF and CO_2 emissions in developed economies is justified, therefore, A 1 percent shift in FF raises CO_2 pollutants by 1.123 percent over a long time. FF affects CO_2 emissions. Notably, the long-term GDP and RE coefficients are considerably higher than the FF coefficients, showing the value of GDP and RE in developed countries. This means that, while GDP, FF, and RE will all reduce pollution, GDP and RE will be the most important factors in reducing CO_2 pollutants in developed nations.

Relationship between renewable energy and CO2 emissions

The findings provide light on the uneven link between RE and CO_2 emissions in industrialized nations. That is, RE will cut CO_2 emissions in wealthy nations in the long term. A one percent change in RE, for example, reduces CO_2 emissions by 0.562 percent. This is a reasonable conclusion for (Sharif et al., 2020), who observed that RE has a long-term beneficial influence on CO_2 emissions. The current study's findings are consistent with those of (Dong et al., 2017, 2018), who find comparable results in the instance of China, namely that a 1% shift in RE shocks boosts CO_2 emissions by 0.882 percent in the long run. Given that RE decreases CO_2 emissions, this tendency demonstrates that the long-term impact of RE on CO_2 emissions is asymmetric.

Table 9. Results of Non-linear Panel ARDL Long Run

CO2 is a dependent variable

Variable	Coefficient	Std. Err.	z	Prob.
Ect	-0.174	0.083	-2.090	0.036
Constant	-0.352	0.182	-1.930	0.053
GDP+	-0.038	0.324	-0.120	0.907
GDP-	0.379	0.504	0.750	0.452
FF	0.800	0.163	4.910	0.000
RE	-0.037	0.071	-0.520	0.600

Note: Model is estimated by PMG.

Furthermore, the long-term coefficient has a greater absolute value than the short-term coefficient, implying that the reduction in the influence of RE on CO_2 emissions will be reinforced over time. The findings back up the necessity for renewable energy to reduce CO_2 emissions and improve environmental standards in wealthy countries. The CO_2 emissions of renewable energy are lower over time than those of fossil fuels (Dong et al., 2017). After examining the data of NPARDL, we conclude that the connection between GDP, FF, RE, and CO_2 emissions is asymmetric.

Dumitrescu-Hurlin (DH) pairwise panel causality test

The analysis relates the unidirectional or bidirectional causation between the variables in the last stage, which is based on the D-H panel causality test. It is crucial to think about the causalities between the independent variables as well as the short- and long-run connections between them. This test relies on the ongoing Dumitrescu-Hurlin (DH) pairwise panel causality test set up by (Dumitrescu & Hurlin, 2012). This technique also involves two measurements, i.e., measurements of Wbar insights and Zbar.

The Wbar measurement yields normal insights from the test, while the Zbar measurement speaks to the regular normal distribution (Bayar & Gavriletea, 2019). Finally, the heading of causality can allow policymakers to monitor effective monetary arrangements in the selected developed and developing countries alongside natural systems. The implications of the D-H panel causality test are given in table 10 for developed countries. From the coefficients of significant levels of the desired variables, the way an indication of causality can be recognized. The causality course demonstrates that carbon emissions are caused by GDP and the other way around. If any developed countries do not take any CO_2 emission combat measures in the long run, the EKC is intended to turn from the altered U-molded bend to the N-formed bend. This finding is consistent with Katircioglu's outcome (Heidari et al., 2015). In essence, there is a bidirectional causal link between renewable energy and CO_2 emissions.

Table 10. Results of Pairwise Dumitrescu Hurlin Panel Causality Tests for Developed countries

Direction of causality	W-Stat.	Zbar-Stat.	Prob.	Causality
$GDP \rightarrow CO_2$	6.08224	9.67919	0.0000	Yes
$CO_2 \rightarrow GDP$	1.34430	0.50531	0.6133	No
$GDP^+ \rightarrow CO_2$	6.80063	11.0702	0.0000	Yes
$CO_2 \rightarrow GDP^+$	1.45721	0.72392	0.4691	No
$GDP^- \rightarrow CO_2$	8.11199	2.92020	0.0035	Yes
$CO_2 \rightarrow GDP^-$	6.26748	1.41507	0.1570	No
$FF \rightarrow CO_2$	5.75480	9.04518	0.0000	Yes
$CO_2 \rightarrow FF$	4.00835	5.66380	1.E-08	No
$RE \rightarrow CO_2$	8.07635	14.7564	0.0000	Yes
$CO_2 \rightarrow RE$	3.07635	3.85899	0.0001	Yes

Note: Estimated by pairwise DH panel Causality.

The presence of a two-way causality test was established by Dumitrescu and Hurlin between the CO_2 and RE. The Dumitrescu-Hurlin Panel's causality test reveals that in industrialized nations, there is uni-directional causation between GDP and CO_2, natural fossil fuel and CO_2, and energy and CO_2 that is ecologically favorable.The findings demonstrate that any change in CO_2 levels would affect the economy's GDP to shrink or increase. The CO_2-to-GDP input relationship shows that varieties in production may also have a generous effect on the examples of energy usage. The findings indicate that the greater the usage of energy assets, the greater the growth of the economy of all developed nations.

Conclusion

This analysis aims to analyze the asymmetric relation between GDP, FF, RE, and CO_2 emissions in developed countries over the period 1990-to 2019. In the panel setting, we apply the NPARDL model to achieve our examination goals. The empirical collections determine that the influence of the selected variables on CO_2 emissions in developed economies is asymmetrically heterogeneous and that RE reduces CO_2 emissions. In developed countries, however, GDP, RE, and FF are essential causative factors for CO_2 emissions. In this analysis, we apply the NPARDL using the PMG approach. A linear analysis is performed for the nonlinear investigation, resulting in the linear panel frameworks, considering the CSD, CIPS, and panel co-integration tests. The consequences show that environmental and economic policies should be included in the investigation of asymmetries in the relationships between GDP and CO_2 emissions in developed countries. The unit root tests show that all the series are stationary at the first difference, while the Westerlund linear co-integration test (2007) discovers the co-integration between the variables. The findings support the asymmetrical structure of both the long-term and short-term impact of GDP on CO_2 emissions. Positive GDP shocks have dramatically increased CO_2 emissions in developed economies in the long run. More precisely, a 1 percent positive-sum fluctuation in GDP brings about a 0.409 percent rise in long-term CO_2 contaminants, and a 1 percent change in positive GDP shocks decreases short-term CO_2 emissions by .037 percent. Also, the results indicate a correlation between RE and CO_2 emissions in developed economies. A 1 percent fluctuation in the RE decreases CO2 emissions in the long run by 0.562 percent. Provided that RE lowers CO_2 emissions, the short-term effect of RE on CO_2 emissions is also negative. The heterogeneous effects among developed countries are also formalized by the consequences.

Recommendation on Strategy

As a result of our empirical findings, we suggest that developed countries produce more quality adjustment commodities. In consequence, when economies speed up the transition from a primary to a tertiary system, more advanced technologies become available. It could have a positive impact on the environment, while at the same time; it could have negative consequences on air quality. The findings formalize the energy, development, and environmental relationship; thus, green techniques should be adopted by developed economies to ensure environmental hazards, boost RE, and advance the use of renewable energy to decrease CO_2 emissions. To achieve the global environmental goals of the Paris understanding and the fulfillment of SDGs, developed countries should advance RE by preparing successful RE approaches and should cooperate to update RE. Shared ventures should be upheld to help spread knowledge and creativity and advance energy-productive advances. Investments in RE resources should be increased to suit the energy required for industrialization and reduce contamination of the atmosphere. Also, when formulating energy, climate, and growth policies, policymakers should consider the asymmetric behavior of GDP. The study's results are for developed countries only; the collections can therefore not be extended to other countries. Also, future studies should think of the nonlinear behavior of energy, development, and environmental nexus based on this study's asymmetric results. The asymmetric NPARDL used in this study can be implemented to capture locational asymmetries in a single quartile regression system (Dong et al., 2017).

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