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Research and Development Expenditure & Environmental Sustainability: A Comparative Study for Developed and Developing Nations

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Abstract

Research and Development Expenditure (RDE) is one of the critical factors in economic growth that supports innovation, science, and new ideas. RDEs are frequently made toward developing solutions that lower emissions and boost efficiency, resulting in a long-term reduction in carbon dioxide (CO2) emissions. However, a thorough study of its impact on environmental sustainability is scarce and sparse. This paper compares and examines the relationship between expenditure on research and development and carbon dioxide emission, followed by other factors, such as Electricity Consumption and Exports of goods and services for 1996-2020 in developing and developed countries. The findings indicate that RDE and CO2 emissions in developing and developed countries have a negative relationship. As the share of electricity use rises, CO2 emissions will increase in developing and developed nations. However, when considering how exports impact CO2 emissions, developing nations' impacts differ from those of developed countries.

Keywords *Research and Development Expenditure, Carbon dioxide emission, Electricity Consumption, Exports, Environment*

Introduction

Environmental pollution is one of the most severe global issues of the modern era. It is one of the few issues that has worsened recently, although governments have been working to tackle it for many years. The world economy has been expanding rapidly, which is the fundamental cause of pollution. Rising economic growth and industrialization in emerging economies have fuelled the irresponsible consumption of fossil fuels (Yawen et al.,2021). According to theory, using various carbon-intensive natural resources, mainly fossil fuels, is closely related to the relationship between gross domestic product (GDP) and Carbon dioxide emission (CO2e). In developed economies, the interaction between development and the environment is nuanced.

On the one hand, developed countries have policies and regulations to protect the environment and are generally more environmentally concerned than developing countries. However, developed nations also tend to have higher economic development levels, which can harm the environment.

The problem of ensuring sustainable development while preserving the environment is one that many developing countries must overcome. In many developing nations, environmental degradation results from the pressure to satisfy an expanding population's basic requirements while competing in the global economy. One of the leading causes of environmental damage in developing nations is overpopulation. An increasing population strains resources, which results in overuse. Additionally, an expanding population produces more pollution and trash. Environmental deterioration is mainly fuelled by economic development. Developing nations frequently engage in unsustainable activities like clear-cut logging,

mining, and oil exploitation to catch up to the developed world. As a result of these activities, the ecosystem may suffer from habitat loss, pollution, and climate change.

Economists have extensively examined the environmental impact of Carbon dioxide emissions with various indicators and econometric techniques. Several of these indicators include government spending (Le & Ozturk, 2020), urban population (Abbasi et al., 2020), innovation (Usman & Hammar, 2020), monetary policy (Qingquan et al., 2020), the usage of electricity (Zhang, 2019), GDP (Akadiri et al., 2020), energy consumption (Ucan et al., 2014), information and communication technologies (Mirza et al., 2020), and international trade (Boamah et al., 2017).

Research and Development (R&D) activities can be the execution of a modern and significantly better product (goods and services) or process, a new marketing system, or modern organization technique in business activities, workplace organization, or peripheral relations (Usman & Hammar, 2020). According to specific experts, the innovation process or research-based engagement is pro-cyclical. For instance, (Barlevy, 2004) asserts that businesses typically seek to reap short gains from creative endeavors that result from R&D expenditure. Such a decision was driven by the long-term profit increases in R&D participation only during economic peaks Moreover decreases during economic troughs. According to (Comin & Gertler,2006), productivity, embodied, and disembodied technological innovations are intimately related. R&D exhibits pro-cyclical behavior, total factor productivity exhibits pro-cyclical behavior over the medium term, and the relative price of capital exhibits countercyclical behavior. Similar conclusions were drawn (Artuc & Pourpourides, 2014) from their study that capital investment shocks can predict fixes in R&D activities. When the economy is booming or a bust, increased capital investment fosters innovation and vice versa. (Francois & Ellis, 2009) the study is just one of many that emphasize pro-cyclical innovation. Technological developments influence growth in R&D investment. However, participating in research investment activities is a long-term process with an unknown application, and declining returns are anticipated to predominate in new information. For the following reasons, the current study is focused on assessing the possible effects of RDE on environmental quality for developed and developing countries.

The accelerated warming of the earth's atmosphere has necessitated addressing environmental deterioration. 2018 is the fourth-ever warmest year since the 1880s, accompanied by extreme climatic conditions (United States Environmental Protection Agency, n.d.). The (UNEP, n.d.) report also indicates that the emission of Greenhouse Gases (GHG) has increased consistently since the 1970s, reaching a record level of 53.5 GtCO2e—when all emission types are taken into consideration. This means a significant 1.3% increase over and above the peak level of global emissions in 2016. By genre, the primary greenhouse gases (GHGs) are carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and the fluorinated gases (F-GHGs) listed by the United Nations Framework Convention on Climate Change (UNFCCC) —hydrofluorocarbons (HFCS), perfluorocarbons (PFCs), and Sulphur hexafluoride (SF6) (United States (U.S.) EPA, 2012). Countries have implemented significant environmental pollution control measures at various levels over the years due to rising energy production and consumption trends. Although non-renewable resources like coal, gas, and oil are the primary sources of global CO2 emissions (Ahmed et al., 2021), understanding how environmentally friendly RDE affects carbon emissions throughout our chosen economies is still an intriguing question.

Review of Literature

In recent research, many studies have focused on environmental sustainability, considering various economic variables. A review of the literature for this study has been thematically summarized as

Per capita Income and CO2 Emissions.

Several studies have examined the validity of the Environment Kuznets Curve (EKC) hypothesis, i.e., an inverted U-shaped relationship between per capita income and CO2 emissions. Can and Gozgor (2017) found that the EKC hypothesis is valid in France. Anser et al. (2019) also confirmed the existence of the EKC for Latin America and the Caribbean economies. Alharthi et al. (2021) also confirms the validity of the EKC hypothesis for the panel of MENA economies and Pata (2018) in Turkey.

Several determinants of CO2 emissions have been examined within the framework of the Kuznets curve. Can and Gozgor (2017) found that energy consumption positively impacts CO2 emissions in France. Pata (2018) found that economic growth, coal consumption, financial development, import, industrialization, and urbanization positively impact CO2 emissions in Turkey. In contrast, export and noncarbohydrate energy consumption decrease emissions in the long run. Anser et al. (2019) found that industrial growth and fossil fuel consumption significantly contribute to carbon emissions in Latin America and the Caribbean Economies. They also suggest that advanced technology-based industrial growth can increase the potential to produce goods competitively with lower carbon emissions.

Alharthi et al. (2021) examined the impact of renewable and non-renewable energy consumption on CO2 emissions in MENA economies under the Environmental Kuznets curve (EKC) framework. Their results suggest that renewable energy consumption significantly reduces emissions, while non-renewable energy consumption increases CO2 emissions. They also found that the impact of renewable energy consumption on emissions increases with higher quantiles.

Energy consumption and Carbon Dioxide emissions

The relationship between energy consumption and CO2 emissions has been extensively studied. Ucan et al. (2014) investigated the relationship between renewable and non-renewable energy consumption and economic growth in 15 European Union countries. Their results suggest a long-run equilibrium relationship between real GDP, renewable and non-renewable energy consumption, greenhouse gas emissions, and research and development. They also found unidirectional causality between non-renewable energy consumption and economic growth. Similarly, Ibrahim & Ajide (2021) investigated the tripartite impacts of renewable, non-renewable, and trade openness on environmental quality for the G-7 countries. They found that renewable energy significantly lessens the prevalence of carbon emissions and that the effects of technological progress captured by research and development and eco-innovation significantly reduce CO2 emissions. However, the impacts of non-renewable energy and trade openness contribute to a surge in CO2 emissions.

Wada et al. (2021) explored the nexus between energy, export, import, population, and economic growth on environmental quality in Brazil. Their results suggest a stable long-run equilibrium association amongst energy consumption, real GDP per capita, actual per capita trade, export per capita, real import per capita, population growth, and CO2 emissions. They also found that shock to energy use, real GDP per capita, real exports per capita, real imports per capita, and population growth cause changes in environmental quality, both in the short-run and long-run periods, with significant implications for ecological conservation in Brazil. These studies highlight the importance of renewable energy and technological progress in mitigating CO2 emissions while emphasizing the negative impacts of non-renewable energy and trade openness on environmental quality.

Innovations and Environmental Quality

Petrovica and Lobanovb (2020) found that in 16 OECD between 1981 and 2014, the growth of R&D investments by 1% reduces CO2 emissions by 0.09%–0.15% on average. Adedoyin and Alola (2020) found a negative and significant long-run equilibrium relationship between ecological footprint and renewable energy consumption. Khan et al. (2020) found that public-private partnership investment in energy and technological innovation helps to lower consumption-based carbon emissions in China. Usman and Hammar (2020) found that financial development and renewable energy utilization significantly accelerate environmental quality. The increase in technological innovation activities, economic growth,

and population size detrimentally affect environmental quality in the long run. Khan et al. (2021) found that financial developments are a significant positive determinant of the renewable energy sector in the Belt and Road Initiative countries. Weimin et al. (2021) found that the positive shocks of innovation disrupt the deleterious repercussions of CO2 emissions, while the adverse shocks deteriorate the environmental quality. Khattak et al. (2021) found that REC (Percentage of the total energy used) and RGST (positive shocks) had a mitigating influence on environmental pollution, while EXP, Gross Domestic Product (Y), Foreign direct investment (FDI), and RGST (adverse shocks) facilitated environmental pollution in BRICS economies. Finally, Luo et al. (2021) found a negative and significant influence of green investment and technology innovations and a significant positive effect on energy consumption (fossil fuel based), population growth, trade, and FDI inflow on CO2 emissions in the selected Asian countries.

FDI and Environmental Sustainability

FDI has been identified as a significant contributor to economic growth in many countries. However, the impact of FDI on the environment has been a subject of debate in recent times. Studies have shown that an increase in FDI inflows can lead to environmental degradation, resulting in negative impacts on the sustainability of the environment (Haibo et al., 2017). This finding suggests that FDI alone is not sufficient to promote ecological sustainability. Instead, there is a need for strong governance and quality institutions to regulate the conduct of businesses financed through FDI flows. Alshubiri et al. (2021) investigated the impacts of financial depth and FDI on green and non-green energy consumption in OPEC members. They found that FDI increased non-green energy consumption and decreased green energy consumption. However, increasing financial depth had the opposite effect, increasing green energy consumption while decreasing non-green energy consumption. Financial depth can promote ecological sustainability when combined with FDI. Similarly, Yawen et al. (2021) examined the relationship between expenditure on higher education (HEEXP) and carbon dioxide and found that HEEXP disrupted CO2 emissions. In the long run, CO2 emissions positively interacted with FDI, GDP, Total population (POP), and emissions, indicating that FDI could significantly promote ecological sustainability when combined with other factors such as higher education expenditure.

Research Gap

The study mentioned above's geographic focus is on a few selected nations, most of which have used comparable econometric methodologies to examine the link between CO2 emissions and R&D expenditure. Environmental Kuznets Curve relationships have been used in numerous research to analyze various relationships. A promising direction is a requirement to consider the diversity of carbon emission sources, such as coal, oil, and gas.

Also, none of the studies compare developing and developed nations considering the impact of Research and Development expenditure on environmental sustainability. In this scope, this study is relevant.

Research Question

Worldwide, developing and developed countries must contend with the severe problem of environmental degradation. However, depending on the rate of economic development and population increase, the scope and impact of this issue may vary. By performing a comparative analysis of the relationship between R&D expenditure and CO2 emissions across numerous developed and developing countries, this research seeks to close the knowledge gap. Examining this connection will help us better comprehend how the environmental issues developed and developing nations face differ and how they might be resolved to reduce CO2 emissions.

Research Objectives

- To understand the relationship between Research and Development expenditure, export of goods and services, and electric power consumption with environmental sustainability in developing nations.

- To understand the relationship between Research and Development expenditure, export of goods and services, and electric power consumption with environmental sustainability in developed nations.
- To compare the relationship between Research and Development expenditure, export of goods and services, and electric power consumption with environmental sustainability in developing and developed nations.

Research Methodology

A descriptive and analytical research methodology is used in this study. Four countries have been chosen, for developed and underdeveloped countries. This research considers Argentina, China, Egypt, and India as developing countries, while Canada, France, Germany, and the United States are considered developed nations. These nations were chosen for this study based on their parity of per capita income.
In the study, the following variables have been used.

Carbon dioxide emissions, the combustion of fossil fuels and cement production produce carbon dioxide emissions. They consist of gas flaring and carbon dioxide created when solid, liquid, and gas fuels are consumed. (World Bank Data, n.d.).

Research and Development Expenditure (% of GDP) refers to research and development (R&D) expenditures expressed as a percent of GDP. The four main sectors—business enterprise, government, higher education, and private non-profit—cover capital and ongoing expenses. Basic research, applied research, and experimental development are all included in R&D (World Bank Data, n.d.).

Electric power consumption reflects the production of power plants and combined heat and power plants less any losses incurred during transmission, distribution, transformation, and internal use. (World Bank Data, n.d.).

Exports of goods and services refer to the value of all goods and other market services offered to the rest of the world. The costs associated with goods, shipping, insurance, travel, royalties, license fees, and other services like government, financial, informational, communication, construction, and building-related services are included. They do not include transfer payments, factor services, investment income, or employee remuneration (World Bank Data, n.d.).

Data Sources and variables

All variables' data are taken from world bank data for 1996-2020. Following is the table showing the variable's names along with units and notations as

Table 1 Data Sources and Description

Variable	Notations	Units	Source of Data
Carbon Dioxide Emission	CO2	metric tons per capita	World Bank
Research and Development Expenditure	RDE	Billion US Dollars	World Bank
Electricity Consumption	EC	Watt-hour	World Bank

Exports of Goods and services	EX	Billion US Dollars	World Bank

Empirical Model

Data for the study are a combination of cross-sectional and time series data. So, in this case, the study employs the panel data model. The model is given as follows:

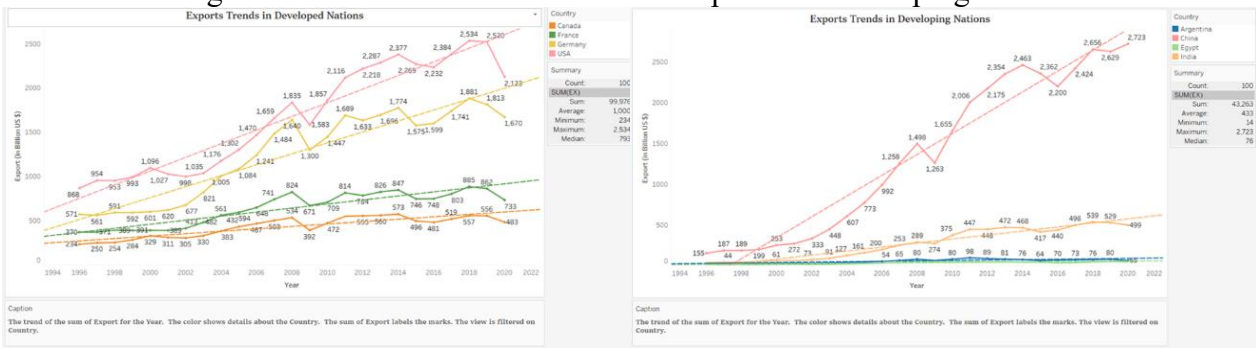
Model: $CO2it = \beta_o + \beta_1 RDEit + \beta_2 ECit + \beta 3EXit + Vit$

Here, CO2 is Carbon dioxide emission, an indicator of environmental sustainability; β0 is the intercept; β1, β2, and β3 are the coefficients; RDE is the Research and Development Expenditure; EC is the Electric Power Consumption, EX is the Exports of goods and services, and Vit is the error term. This study employs the equation's fixed and random effect models and then does the Hausman test to determine which model fits this study best. The relationship between the dependent and independent variables in developing and developed countries and comparisons between developing and established nations are examined in this study using R software for panel data analysis.

Descriptive Analysis for Developed and Developing Nations

A comparative descriptive analysis of different indicators used to compare developed and developing countries, using statistical data to identify trends over time.

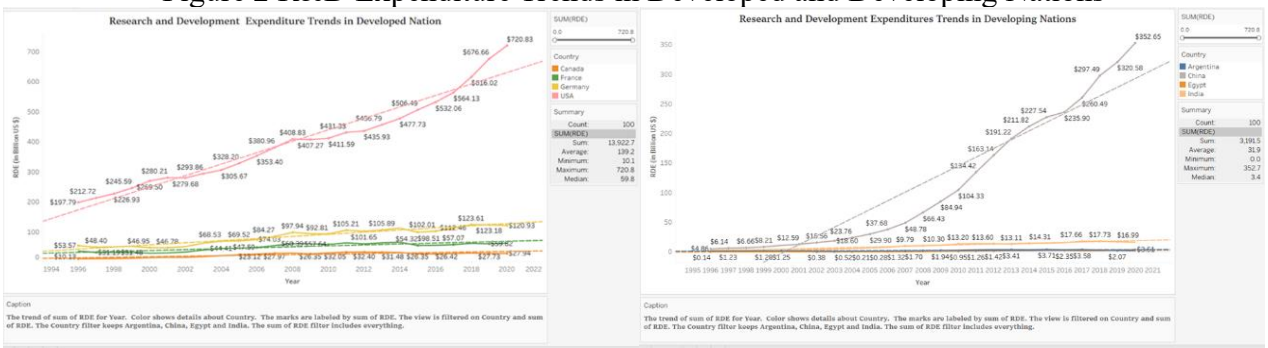
Figure 1 CO2 Emission Trends in Developed and Developing Nations



Source: Created by Author

As shown in Figure 1, CO2 emissions have declined, showing a decreasing trend line in developed countries. In developing nations, an upward trend can be seen because CO2 emissions have increased.

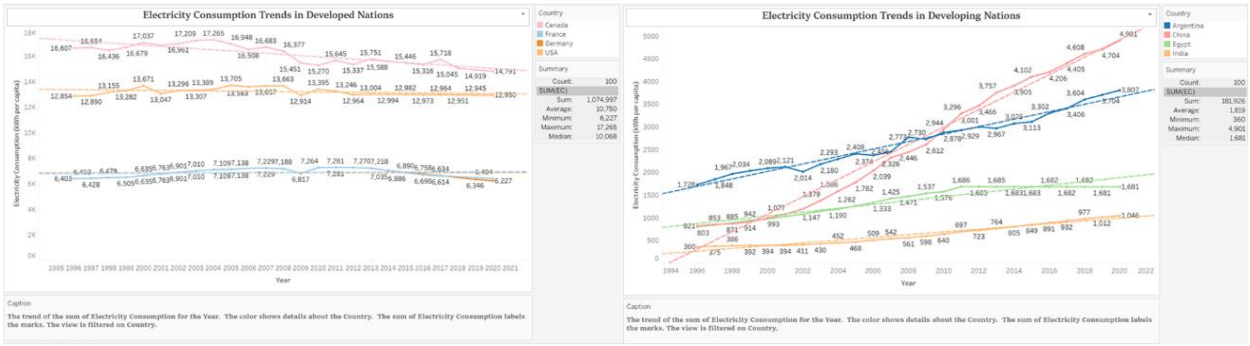
Figure 2 R&D Expenditure Trends in Developed and Developing Nations



Source: Created by Author

R&D expenditure has increased, showing an upward trend in developed and developing nations, as shown in Figure 2.

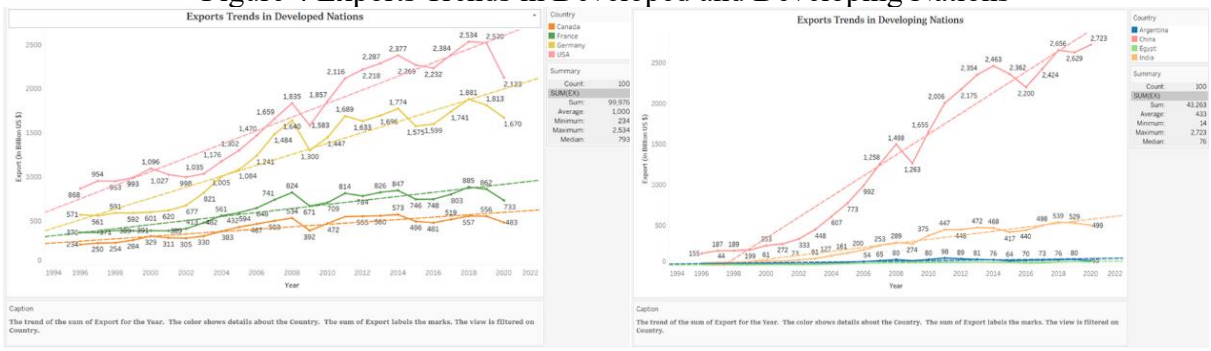
Figure 3 Electricity Consumption Trends in Developed Nations and Developing Nations



Source: Created by Author

Because of the fall in electricity usage, developed countries' trend lines are diminishing. Developing countries show an upward trend because of the rise in electricity usage, as shown in Figure 3.

Figure 4 Exports Trends in Developed and Developing Nations



Source: Created by Author

As a result of increased exports, developed and developing countries exports have an upward trend line shown in Figure 4.

Empirical Data Analysis and Discussion

This study uses panel data and provides empirical results. The Hausman test was used to choose between fixed and random effects models.

Data Analysis for Developing Nations

Table 2 Results of the Hausman Test for Developing Countries

Hausman Test		
data: Y ~ X		
chisq = 105.11	df = 3	p-value < 2.2e-16
Source: Calculated by Author		

Table 3 Results of Fixed Effect Model for Developing Nations

Coefficients:	Estimate	Std. Error	t-value	Pr(>|t|)

XRDE	-6.539	1.048	-6.236	1.307e-08 ***
XEC	0.455	0.062	7.308	9.174e-11 ***
XEX	2.098	0.137	15.208	< 2.2e-16 ***
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				
Total Sum of Squares:	104980000			
Residual Sum of Squares:	3997900			
R-Squared:	0.961			
Adj. R-Squared:	0.959			
F-statistic:	783.021 on 3 and 93 DF	p-value: < 2.22e-16		
Source: Calculated by Author				

As the p-value is less than 0.05 in the Hausman test, shown in Table 2, and rejects the null hypothesis that the preferred model is random effects, the method used here will be a fixed effect method. Data and panel data analysis shown in Table 3 indicate that RDE impacts CO2 emission negatively and substantially (significant at a 5% significance threshold). This suggests that as RDE increases by 1 billion U.S. Dollars, CO2 emissions decrease by 6.539 metric tons per unit, holding constant the effects of the other variables. As the proportion of electricity consumption rises, so will the amount of CO2 emission. This shows that while keeping the effects of the other variables constant, CO2 emissions increase by 0.455 metric tonnes per unit as E.C. increases by 1 watt per hour. The study demonstrates a positive and significant (significant at a 5% significance level) relationship between EX and CO2 emission. This implies that while keeping the effects of the other variables constant as EX increases by 1 billion us dollars, CO2 emissions increase by 2.098 metric tonnes per unit.

Data Analysis for Developed Nations

Table 4 Result of the Hausman Test for Developed Countries

Hausman Test
data: Y ~ X

chisq = 2894.3	df = 3	p-value < 2.2e-16
Source: Calculated by Author		

Table 5 Results of Fixed Effect Model for Developed Nations

Coefficients:	Estimate	Std. Error	t-value	Pr(>|t|)
XRDE	-8.549	0.989	-8.637	1.555e-13 ***
XEC	0.584	0.092	6.322	8.853e-09 ***
XEX	-1.273	0.182	-6.993	4.024e-10 ***
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				
Total Sum of Squares:	142020000			
Residual Sum of Squares:	17199000			
R-Squared:	0.878			
Adj. R-Squared:	0.871			
F-statistic:	224.973 on 3 and 93 DF	p-value: < 2.22e-16		
Source: Calculated by Author				

As the p-value is less than 0.05 in the Hausman test, shown in Table 4, and rejects the null hypothesis that the preferred model is random effects, a fixed effect method has been used to analyze. According to panel data analysis in Table 5, RDE has a negative coefficient of -8.549, meaning that every billion U.S. dollars of RDE added to the equation causes an 8.549 metric tonne reduction in CO2 emissions. At the 0.001 level, this indicator is statistically significant (p-value = 1.555e-13). EC has a coefficient of 0.584; a rise in E.C. (measured in watts per hour) is thought to increase CO2 emissions by 0.584 metric tonnes. At the 0.001 level, this indicator is also statistically significant (p-value: 8.853e-09). A one-unit increase in EX (measured in billions of U.S. dollars) is correlated with a 1.273-metric-ton reduction in CO2 emissions, according to the coefficient for EX, which is -1.273. At the 0.001 level, this indicator is also statistically significant (p-value = 4.024e-10).

Data Analysis for Comparison of Developing and Developed Nations

Data analysis comparing developing and developed countries are required to comprehend the differences between these two groups in terms of carbon emissions, R&D expenditures, energy consumption, and economic development of the differences between these two groups in terms of carbon emissions, R&D expenditures, energy consumption and economic development, data analysis comparing developing and developed countries is required. While developed countries have lower carbon emissions, more significant R&D expenditures, and higher economic growth and trade levels, developing countries typically have higher rates of carbon emissions. Data analysis can offer insights to guide policy decisions toward this goal because both groups experience particular difficulties in achieving sustainable development.

Table 6 Comparison of Developing and Developed Nations

	Developing Nations	Developed Nations
Coefficients	Estimate	Estimate
XRDE	-6.539	-8.549
XEC	0.455	0.584
XEX	2.098	-1.273
Source: Calculated by Author		

The results from Table No. 6 indicate a negative relationship between RDE and CO2 emission in developing and developed countries, which suggests that if the expenditure on R&D increases, CO2 emissions will decrease. The results revealed that the estimated RDE coefficient for developed countries was more negative (-8.549) than for developing countries (-6.539), showing that as RDE rises, CO2 emissions fall more in developed for developing countries (-6.539), showing that RDE rises, CO2 emissions fall more in developed countries than in developing countries. In developing and developed countries, CO2 emissions will increase as the share of electricity used does. However, when examining how exports affect CO2 emissions, developing countries' effects differ from those of developed countries. As EX rises, CO2 emissions rise more rapidly in developing countries than developed countries; the calculated coefficient for EX was positive for developing countries (2.098) and negative for developed countries (-1.273).

Conclusions and Policy Implications

Change begins with one question and is just about asking one right question. This study focuses on the comparative study of developed and developing countries, examining whether spending on research and development assists environmental sustainability. The study results revealed that the estimated coefficient

for research and development expenditure was more damaging for developed countries than for developing countries. As research and development expenditure rises, carbon dioxide emissions decrease more in developed than developing countries. The estimated electricity consumption coefficients for both developed and developing countries were positive, showing that both groups' rising electricity use is associated with rising carbon dioxide emissions. However, the effect was more pronounced in developed countries. As exports grow, carbon dioxide emissions in developing countries rise more than in developed countries, according to the estimated coefficient for export, which was more favorable for developing countries and negative for developed ones. That is why developing and developed countries have different benchmarks to judge this scenario.

To attain environmental sustainability, the study's findings have significant policy implications for developed and developing nations. While developing nations should focus on their research and development expenditure to accomplish sustainability objectives, developed nations should continue research and development expenditure to accomplish sustainability; developed nations should continue to invest in research and development to reduce carbon dioxide emissions. Developed and developing nations should prioritize energy efficiency by implementing renewable energy sources and energy-saving technologies. Economic development and environmental sustainability should be balanced in developing nations, and policymakers should consider adopting measures to cut export-related carbon emissions. Collaboration and technical aid from developed countries can help developing nations achieve sustainability objectives.

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