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Estimating the Effects of Economic Complexity and Technological Innovations on CO_2 Emissions: Policy Instruments for N-11 Countries

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Abstract: Every year, the problem of environmental degradation becomes more severe globally. It is widely believed that technological innovation and economic complexity are understood as structural transformations toward a more sophisticated and knowledge-based means of production as a viable way to fight against climate change. However, the studies integrating these two elements into the same environmental policy framework are still scant. With this in view, this study investigates the dynamic linkage between economic complexity, technological innovations, economic growth, and nonrenewable energy on CO_2 emissions in the N-11 nations. This study uses data from 1980 to 2020. It applies the recent method of cross-sectional autoregressive distributed lags (CS-ARDL). The cointegration method shows a strong association among the variables. The findings of the CS-ARDL show that technological innovations are negatively related to environmental degradation, while nonrenewable energy deteriorates the environment by escalating CO_2 emissions. This study fails to validate the EKC in the N-11 nations. In addition, economic complexity is helping these economies to achieve environmental sustainability by lowering environmental pollution. Based on the findings, this work recommends that the N-11 countries restructure their industrial sectors with low-carbon energy sources. For this purpose, these countries should increase their research and development budgets. This will help in launching environmentally friendly energy sources in their economic development model.

Keywords: economic complexity; CO_2 emissions; technological innovations; economic growth; N-11 nations

1. Introduction

World economies are expanding their economic setup by using and preserving natural resources. In achieving economic stability, climate change has been considered a hurdle [1–3]. Higher industrial output further degrades the ecological atmosphere, which is unsuitable for achieving sustainable development goals (SDGs). The Next Eleven (N-11) countries are in transition mode and are aiming to increase their exports with more trade partners. For economic sustenance, these countries need to use energy sources of coal, gas, and oil [4,5]. As a result of these economic activities, the emissions of greenhouse gasses (GHGs) take place, which deteriorates environmental quality. Climate change is a global problem, and nations strive to mitigate the negative impacts through various agreements and treaties.

Today, the world's economies are enhancing their external relations to boost economic growth. These activities are increasing energy consumption and degrading the environment. The economic complexity (EC) index measures the export structure of an economy. The technology and knowledge in the manufacturing sector are the basic definitions of the EC. In other words, EC measures the knowledge and technology in a country's exports [6,7]. Hence, various degrees of EC show the intricacy and diversity of different nations [8]. This diversity of EC in different countries can affect the environmental quality in two ways; for more production and manufacturing, the countries need to explore and utilize more natural resources and energy. In this situation, the dependence on fossil fuels can be reduced for sustainable development [9]. Conversely, EC may stimulate business and research and development (R&D) and increase efficiency and competitiveness. These changes further bring structural changes and make ways for sustainable development. R&D stimulates economic growth through technological advancements for society and brings clean technologies [10]. Therefore, EC brings environmentally friendly technologies and provides sustainable energy in the economic sectors [11,12].

The Next Eleven (N-11) countries consist of 11 emerging nations. Rapid population and economic growth have increased the energy consumption of these countries. As a result, these countries have tried to lower energy costs and restructure their energy systems (IEA). The N-11 countries are at a junction for their future energy usage because these governments are calling for a reduction in the use of imported gas by increasing renewable energy. Currently, the N-11 countries are facing an elevated level of environmental pollution. Figure 1 shows the trend of CO_2 emissions from 1980 to 2020. Carbon emissions have been increasing for over three decades in the N-11 countries [13]. To attain the Paris Agreement's set target, these countries need to define their emission-reduction target. Currently, these countries are degrading their environmental quality through their energy sources and use. It shows that these countries still need to critically examine the climatic targets set in the Paris Agreement. Thus, emissions will continue to rise unless these countries take adequate measures. Despite the low cost of renewable energy, these countries significantly consume and depend on nonrenewable energy sources contributing to the carbon emission ratio. Figure 2 indicates the carbon emissions in units of million tonnes from these countries [13].

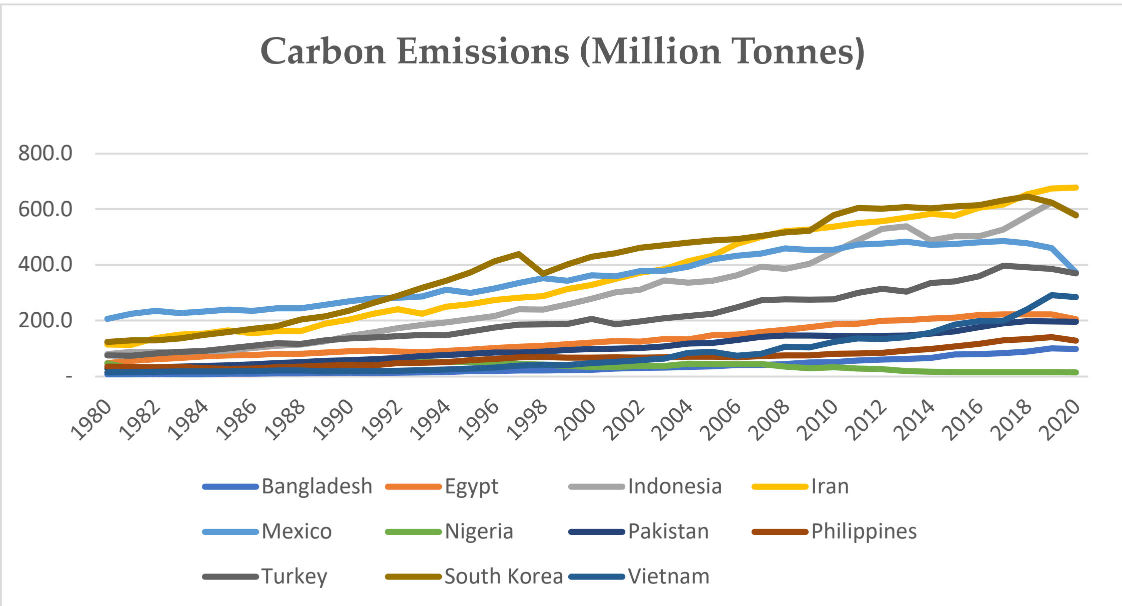

Figure 1. Trends of CO_2 emissions in the Next Eleven countries.

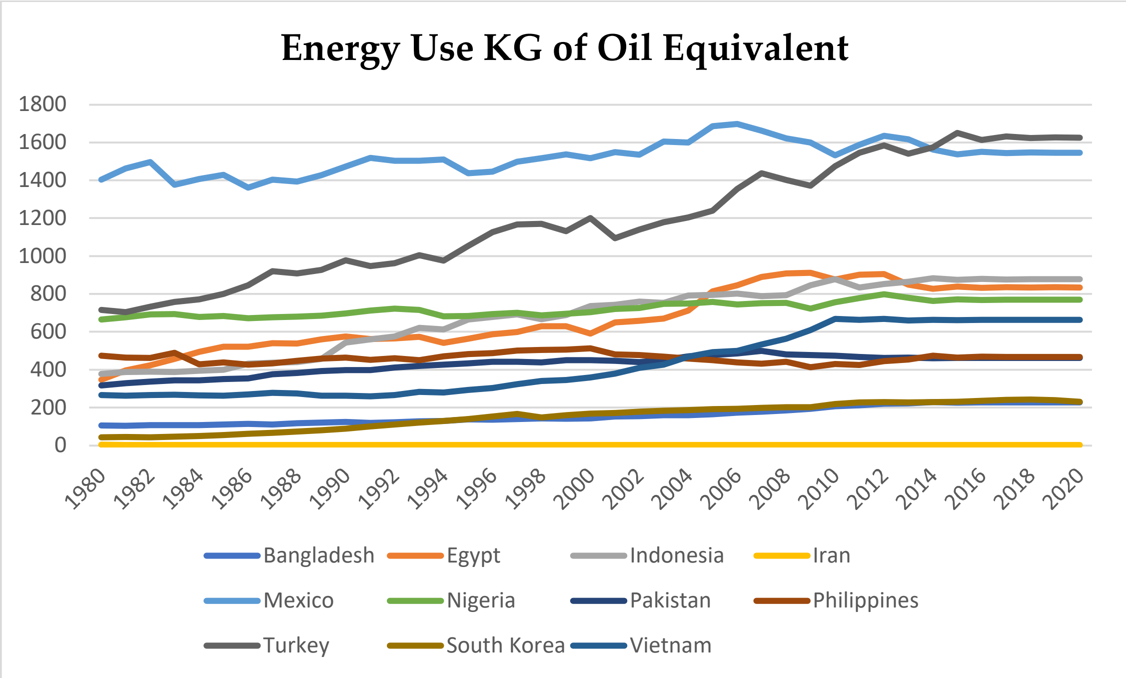

Figure 2. Trends of nonrenewable energy use in N-11 countries.

The literature has presented three possible theoretical justifications for the Gross Domestic Product (GDP) contamination association. Firstly, it is measured on the revenue flexibility for air quality. Secondly, it is associated with increased profits from efficient technologies, and thirdly, it is associated with economic activity based on economic complexity [14].

Along with the economic complexity of the service sector, policymakers and scholars have identified that innovations are the key factor in economic prosperity. Moreover, efficient technologies can be used against environmental problems around the world. According to endogenous growth, a country's economic development is ensured by the internal forces of human capital. Human capital increases economic growth through efficient technologies in the production process [15]. Technological advancements are due to economic motivations, which can be affected by the performance of the public and private sectors. Therefore, technological innovations are necessary to protect environmental resources as well as the promotion of economic expansion. This economic expansion further helps to develop and install modern technologies. Innovative technologies can reach marketplaces by diffusion, innovation, and invention [16].

Even though several studies have been conducted to explore the connection between environment and income, various spaces still need to be explored and can be solved. Therefore, this work investigates the impacts of technological innovations and economic complexity on CO_2 emissions in the N-11 countries. This work highlights the importance of the endogenous theory by presenting technological innovations as an endogenous factor. The study also assesses the roles of innovations and economic complexity in environmental degradation in the N-11 countries.

Economic complexity is vital for developing nations because it moves from agricultural economies toward industrial-based and information-based economies. Substantial movements in international trade, resource use, production process, and social and economic conditions are considered economic complexity [17]. This condition requires technological advancements because transitioning from fossil fuels to renewable energy requires some innovations. As a result, following the works of Adebayo et al. [17] and Ali et al. [18], this work takes economic complexity and technological advancements as determinants of environmental pollution in the N-11 nations.

Because of the importance of patent applications and industrial value added to environmental quality, this research work differs from past studies in the context of the N-11 nations. Additionally, this work adds to the literature by taking the value to add the industrial sector as a measure of economic complexity in the N-11 countries. Moreover, this work also investigates the environmental Kuznets curve (EKC) theory in the N-11 nations. The short- and long-run associations among the variables are determined by the cross-sectional autoregressive distributed lag (CS-ARDL) approach.

The structure of this article is as follows: the next section provides the literature review; the third section consists of data description, theoretical foundation, model, and methodology; the fourth section presents the results and discussion. The last section provides the conclusion and the policy implications of the study.

2. Literature Review

2.1. Carbon Emissions and Economic Growth

Several studies are available in the literature that examined the association between GDP and CO_2 emissions. For example, Awosusi et al. [19] utilized the annual data for 1990–2018 and applied quantile regression. The study found that economic growth degrades the environment in the panel of NIC nations. The study validated the EKC. Adebayo et al. [20] found the same findings for Turkey that economic growth is not environmentally friendly. Akadiri et al. [21] applied the same technique to the data of 1990–2019 from the BRICS countries and found that economic growth increases CO_2 emissions. He et al. [22] analyzed the 1990–2018 data for ten energy transition economies and found that economic growth degrades the environmental quality. Xu [23] conducted a study for Brazil and took the load capacity factor as a proxy for environmental quality. The data analysis from 1970–2017 showed that GDP drives air pollution in Columbia. For Indonesia, Ahmed et al. [24] conducted a study by analysis of the data from 1971–2014. The study also found that environmental degradation is due to economic growth. However, contrarily, some research found that economic growth can be a tool to deal with CO_2 emissions. For example, the study by Usman et al. [25] showed that a 1% increase in GDP lowers CO_2 emissions. The study of Rjoub et al. [26] estimated the data from 1970–2018 in Sweden and found that economic growth decreases CO_2 emissions. Other studies also found that economic growth contaminates environmental quality [1,27–32].

2.2. Carbon Emissions and Innovations

Technological advancement is considered to be a crucial factor contributing to a nation's economic progress. The research by Schumpeter [16] proved the theoretical background that technological advancement can reach the market in three ways, namely, diffusion, innovation, and invention. The scholar believed that research and development (R&D) could create the pathway for invention and innovation in any society. The execution and acceptance of a particular innovation can be described as diffusion. Therefore, these three variables contribute positively to the environment and the economy. Endogenous growth theory considers technological innovations to be a function of growth. Inconsistent results have been published by studies that calculate the impacts of innovations on CO_2 emissions. For example, the work of Kihombo et al. [33] studied the impact of innovations on carbon emissions over the years of 1990–2018. The results indicated that innovations have been mitigating carbon emissions over the years. For a global panel data set of 1990–2018, Kirikkaleli et al. [2] analyzed the impact of technological innovations on CO_2 emissions. The study found a positive role in abating carbon emissions. The study by Chen and Lee [15] investigated a panel of 96 countries and found that technological innovations are environmentally friendly. Similarly, the work of Khan et al. [34] analyzed the quarterly data from 2005Q1 to 2018Q4 and found that technological innovations mitigate CO_2 emissions. Gyamfi et al. [35], also found that technological innovations are lowering CO_2 emissions in Portugal. Adebayo et al. [36] found that technological innovations are increasing CO_2 emissions in Japan.

2.3. Carbon Emissions and Nonrenewable Energy Consumption

Energy is essential for economic growth, but its negligent use can create havoc on the environment. Nonrenewable sources of coal, oil, and gas are the foremost contributors to environmental degradation and pollution. Therefore, energy should be used responsibly. Several studies have found that the reckless use of energy can harm environmental quality [19,37]. Hanif et al. [38] showed that fossil fuel consumption degrades the environment. A study by Lotfalipour et al. [39] analyzed the annual data from 1967–2007 by applying ARDL and found that fossil fuels are lowering environmental quality in Iran. Dogan and Seker [40] analyzed the panel data of European countries and found that nonrenewable energy is contaminating the environment. Khan et al. [34] analyzed the panel data of 1990–2015 of OECD nations. The study indicated that nonrenewable energy is degrading the environment. Similarly, the work of Wada et al. [41] analyzed the data from 1971–2016 in Brazil and found that fossil fuels are degrading the environment.

2.4. Carbon Emissions and Economic Complexity

Economic complexity means transitioning from an agricultural-based economy to an industrial, production economy where more complex goods are produced, and this index has recently been added to the environmental literature. Economic complexity can play a crucial role in lowering environmental pollution in several ways. Most countries are moving from energy-intensive secondary industries toward service-based economies. A shift in an economy can be measured by its transition from an industrial-based economy toward a service-based economy. Even though there are many factors that measure the structure of an economy, these factors benefit from the developments in an economy. The economic complexity in any economy allows for an increase in industrial production, which then allows it to move toward a service-based economy. Agriculturally based and then industrial economies produce environmental pollution but shifting toward service-based businesses can help to mitigate environmental pollution. Therefore, changes in an economy's structure and its institutional framework help lower environmental pollution.

According to Kaufmann et al. [42], each country's manufacturing and EC require more natural resources linked to climate. Very few studies have probed the impact of EC on environmental quality. Doğan et al. [43] found that EC degrades the environment in low- and middle-income countries. High-income countries have a cleaner environment due to EC. Boleti et al. [44] investigated the data of 88 nations and found that EC enhances the environmental quality of the nations under investigation. Neagu et al. [45] found a long-run connection between energy use, environmental degradation, and EC in European nations. Other studies also found the detrimental role of EC on the environment in the G-7 nations [46–48]. There was also some disparity, demonstrated by the fact that EC sometimes improves environmental quality [49–51]. Chu [52] pointed out that EC degrades the environment, but stable institutional quality can control this impact.

Based on the mentioned studies, it is evident that there are mixed findings on the associations of economic complexity, economic growth, innovations, and nonrenewable energy. These inconsistent findings show the importance of further research for other countries. Moreover, this article applies the CS-ARDL method to find out the short- and long-run coefficient values for effective policymaking in the N-11 countries.

3. Data, Theoretical Foundation, Model, and Method

3.1. Data

This research analyzes the factors of environmental degradation via the proxy of CO_2 emissions. The factors of CO_2 emissions are economic growth (GDP), technological innovations (TI), nonrenewable energy (NRE), and economic complexity (EC). The annual data from 1980–2020 were analyzed (40 observations). Nonrenewable energy is included in the model to avoid the problem of omitted variables. The log form of all the data was checked for consistent results [4]. Table 1 shows the description and source of data taken for empirical analysis.

Table 1. Data description and their sources.

Parameters	Symbol	Unit	Source
Carbon Emissions	CO_2	Million tons	BP [53]
Technological Innovations	TI	Number of patents (resident + nonresident)	WDI
Gross Domestic Product	GDP	Constant USD	WDI
Economic Complexity	EC	Average complexity of the products (exports)	Economic complexity index
Nonrenewable Energy	NRE	KG of oil-equivalent per capita	WDI

3.2. Theoretical Foundation

Romer's endogenous growth model and the production function were applied, and it is stated as follows:

$$Y = f\ (TI, J, K) \tag{1}$$

where Y shows income, and the output consists of technological progress, shown by (TI); J and K are the country's capital stock. Technological innovations measure technological progress (B). Economic growth has a distinct role in an economy, but it requires energy consumption, which creates greenhouse gases (GHGs) and contaminates the environment. Therefore, economic growth can be linked with environmental pollution (CO_2). The function of CO_2 will be as follows:

$$CO_2 = f\ (Y) \tag{2}$$

Since the factor of technology and capital define the output (economic growth), the function of CO_2 is as follows:

$$CO_2 = f\ (TI, K) \tag{3}$$

where, because a country's economic growth can impact CO_2 emissions, TI and K can influence CO_2 emissions. Capital can be classified into two categories: polluting and nonpolluting. The polluting capital will be from nonrenewable energy, and the nonpolluting capital will be from renewable energy. This is indicated in Equation (4).

$$K = K_e + K_{ne} \tag{4}$$

where K_e denotes the degrading environmental capital; hence, the function of CO_2 will be as follows:

$$CO_2 = f\ (NRE, TI) \tag{5}$$

where nonrenewable energy use is represented by NRE. Economic activity can also be included in the model because production activities are for economic growth. The function can be written as follows:

$$CO_2 = f\ (NRE, TI, GDP) \tag{6}$$

It is suggested that when an economy moves from an agriculturally based economy to a manufacturing-based economy, it consumes more energy and degrades its environment. However, when a manufacturing-based economy moves toward a service-based economy, its energy consumption significantly lowers, and the environmental quality starts to improve. According to EKC, it is important to consider the economic complexity in an economy when measuring environmental quality. EC can be the best explainer of EKC. According to EKC, at the preindustrial level of an economy, income and pollution move together, but after reaching a threshold level (industrial production), pollution starts to decrease. This study follows the works of Ali et al. [18] and Ali et al. [53] for empirical analysis and model structuring. Therefore, the equation form of this work is as follows:

$$CO_2 = f\ (NRE, TI, GDP, EC) \tag{7}$$

In Equation (7), NRE, TI, GDP, EC, and CO_2 represent nonrenewable energy use, technological innovations, economic growth from [53], and economic complexity [54]. To check the validity of EKC, this includes the square form of GDP. Equation (8) is as follows:

$$CO_2 = f\ (\text{NRE, TI, GDP, EC, GDPs}) \tag{8}$$

Moreover, this work took the log form of the data to eliminate the problems of normality [55], and the log form equation is as follows:

$$lnCO_{2t} = \beta_0 + \beta_1\, lnNRE_{it} + \beta_2\, lnTI_{it} + \beta_3\, lnGDP_{it} + \beta_4\, lnEC_{it} + \beta_5\, lnGDPs_{it} + \epsilon_{it} \tag{9}$$

3.3. Cross-Sectional Dependence Test

The methodology starts with introducing the cross-sectional dependence (CD) test. A CD test informs one about any dependence among the countries of panel data. These test results further guide the econometric techniques for cointegration and long-run coefficient values. This work continues with the application of CD by Pesaran (2015) [55]. Therefore, the equation for this test is as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\partial_{ij}^{t}\right) \tag{10}$$

where T and N represent time and cross-sections. ∂_{ij}^{t} is an association of errors.

3.4. Slope Homogeneity Test

The nature of the panel data was introduced by [56]. The equation for this test is:

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - K}{\sqrt{2K}}\right) \tag{11}$$

$$\tilde{\Delta}_{\text{adj}} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - E\left(\tilde{Z}_{iT}\right)}{\sqrt{var\left(\tilde{Z}_{iT}\right)}}\right) \tag{12}$$

3.5. Unit Root Test

If the existence of CD is validated among the data, then it is important to conduct second-generation unit root tests. For this purpose, cross-sectionally augmented IPS (CIPS) and cross-sectionally augmented DF unit root tests can be applied. These tests will determine the order of CO_2, NRE, TI, GDP, and SCH integration.

3.6. Cointegration Test

This work moved forward to investigate the cointegration among CO_2 emissions, nonrenewable energy, technological innovations, GDP, and economic complexity. For this purpose, the work applies [57]. The test effectively provides robust results in the presence of CD in the data. The equations for this test are as follows:

$$G_t = \frac{1}{N}\sum_{i=1}^{N}\frac{\partial_i^!}{SE\partial_i^!} \tag{13}$$

$$G_a = \frac{1}{N}\sum_{i=1}^{N}\frac{T\partial_i^!}{\partial_i^!(1)} \tag{14}$$

$$P_t = \frac{\partial^!}{SE(\partial^!)} \quad (15)$$

$$\partial^! = \frac{P_a}{T} \quad (16)$$

$\partial^! = \frac{P_a}{T}$ represents the ratio of correction, yearly.

3.7. Short-Run and Long-Run Analysis

Among the available econometric techniques of fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS), this research selects the CS-ARDL approach by Chudik and Pesaran [58] to gain short- and long-run coefficient values. CS-ARDL provides authentic results while considering the CD in the data. Therefore, this study has opted for a methodology that could address potential endogeneity issues. For instance, the CS-ARDL approach was applied, which is robust in the presence of misspecification bias, serial correlation of error terms, cross-sectional dependency, nonstationarity, and the endogeneity bias problem. First-generation tests cannot perform this. Therefore, the equation for this test is as follows:

$$\Delta EF_{i,t} = \varnothing_i + \sum_{I=0}^{p_w} \varnothing_{ij} \Delta EF_{i,t-1} + \sum_{I=0}^{p_z} \varnothing_{ij} AEV_{i,t-I} + \sum_{I=0}^{p_z} \varnothing_{ij} Z_{i,t-I} + \varepsilon_{i,t} \quad (17)$$

Z_i = (ΔEF_t AEV_t) represents the cross-section averages, and AEV shows a set of explanatory variables.

3.8. Robustness Check Test

To cross-check the findings and ensure robustness, this work continues to apply the augmented mean group (AMG), FMOLS, and DOLS methods. This test is valid because it captures the heterogeneity and cross-section dependence problems [59].

4. Results and Discussion

This section consists of the results of the methods used for the analysis. For this purpose, the CD, slope homogeneity test, unit root tests, cointegration test, CS-ARDL test, and robustness check tests are presented sequentially. First, it is important to check for cross-sectional dependence in the panel data of the N-11 countries. Table 2 presents its findings.

Table 2. Results of cross-sectional dependence analysis.

Variable	Test Statistics	Prob	Abs (corr)
CO_2	45.048 ***	0.000	0.949
TI	31.372 ***	0.000	0.661
EC	23.937	0.000	0.531
GDP	42.021 ***	0.000	0.885
NRE	21.691 ***	0.000	0.694

Note: *** explains the level of significance at 1%.

The panel data of carbon emissions, technological innovations, economic complexity, economic growth, and nonrenewable energy have cross-sectional dependence. This means that any shock in country variable will disturb the other countries' data. This CD may be due to the similar socio-economic policies of the N-11 nations. The next step is to check the slope homogeneity property of the data, and Table 3 shows its results.

Table 3. Slope test.

	Value	*p*-Value
Delta	25.499 ***	0.000
adj	28.002 ***	0.000

Note: *** explains the level of significance at 1%.

The *p*-value is significant. This means that panel data suffer from heterogeneity problems. Therefore, the second-generation unit root test is suitable for finding the panel data's unit root. For this purpose, this study applies two unit root tests, CIPS and CADF. Table 4 shows the findings.

Table 4. Unit root test.

Variable	CIPS		CADF	
	At Level	1st Difference	At Level	1st Difference
CO_2	−1.670	−5.169 ***	−2.041	−3.648 ***
TI	−2.360 **	−5.690 ***	−2.041	−4.298 ***
EC	−1.578	−5.194 ***	−1.860	−4.256 ***
GDP	−2.456 ***	−4.286 ***	−2.187 **	−3.228 ***
NRE	−2.328 **	−5.565 ***	−2.245 **	−4.114 ***

Note: *** and ** explain the level of significance at 1% and 5%, respectively.

The panel data are integrated at first difference. This means that carbon emissions, technological innovations, economic complexity, economic growth, and nonrenewable energy are moving together in the long run. This outcome further encouraged this study to conduct the cointegration test. For this purpose, the Westerlund test was applied. This test is efficient in controlling the panel data. This test provides efficient results by considering the CD in the data. Table 5 shows its findings.

Table 5. Westerlund test.

	G_t	Ga	P_t	Pa
Test statistics	−2.446 ***	−9.566 ***	−6.717 ***	−5.794 ***
Robust *p*-values	0.000	0.000	0.000	0.000

Note: *** explain the level of significance at 1%.

Table 5 shows that the values of Ga, Pt, and Pa are significant at 1% and 5%. This outcome shows that the panel data of the N-11 countries are cointegrated strongly in the long run. Carbon emissions, technological innovations, economic growth, economic complexity, and nonrenewable energy are cointegrated in the long run. The CS-ARDL approach was applied to know the coefficient values of independent variables. The CS-ARDL approach provides short-run and long-run coefficient values. This test also provides the error correction term (ECT), which shows the stability of the model. Table 6 shows the findings of the CS-ARDL method.

Table 6. CS-ARDL.

Short-Run	Coefficient	ST ERROR	Z-Value	PROB
$\Delta lnTI$	−0.020 *	0.010	−1.92	0.054
$\Delta lnEC$	−0.068 ***	0.021	−3.21	0.000
$\Delta lnGDP$	−0.073	0.016	−4.60	0.000
$\Delta lnGDPs$	0.042 **	0.017	2.55	0.011
$\Delta lnNRE$	0.612 ***	0.154	3.96	0.000
Long-run results				
$lnTI$	−0.012 **	0.006	−1.97	0.048
$lnEC$	−0.038 ***	0.011	−3.34	0.000
$lnGDP$	−0.041 ***	0.008	−4.59	0.000
$lnGDPs$	0.026 ***	0.009	2.59	0.009
$lnNRE$	0.355 ***	0.093	3.82	0.000
ECM	−0.691 ***	0.056	−12.44	0.000

***, ** and * explain the level of significance at 1%, 5 and 10%, respectively.

The results shows that economic growth is lowering the CO_2 emissions in the N-11 countries. This means that a 1% increase in GDP lowers CO_2 emissions by 3.06% in the long run. This outcome shows that the N-11 countries are on the right track and that their economic progress is environmentally friendly. This finding is different from the findings of Kirikkaleli et al. [5] and Adebayo et al. [20]. The N-11 countries are adopting sustainable energy policies, and economic growth significantly lowers the pollution burden. The value of the square of GDP is positive. This means that after reaching some threshold level, economic growth will degrade environmental quality. This means that the N-11 countries will compromise their environmental quality to achieve future economic growth. This finding is vital for policymakers to implement strict environmental regulations to keep the environment clean in the future. This result cannot validate the EKC in the N-11 nations. Moreover, this finding is different from the findings of Ali et al. [18].

The role of nonrenewable energy is negative for CO_2 emissions in the N-11 countries. This means that a 1% increase in energy use will raise CO_2 emissions by 0.93% and 0.50% in the short and long run. This finding correlates with the results of He et al. [22] and Pata and Isik [57]. This result is justifiable because the N-11 countries are in transition mode and are working toward becoming progressive countries. In this endeavor, these countries are using nonrenewable energy sources and degrading their environment [60].

The findings also confirm that technological innovations (TI) are lowering CO_2 emissions. This means that a 1% increase in innovations reduces 0.02% carbon emissions in the short and long run. Adebayo et al. [61] also found the findings that technological innovations improve energy efficiency and reduce energy intensity. As a result, TI improves the air quality. The N-11 countries are increasing their research and development to increase energy efficiency. Therefore, the number of patents in these countries rose rapidly. This work found the positive impact of EC on CO_2 emissions. This means that a 1% increase in economic complexity lowers CO_2 emissions by 0.068% and 0.038% in the short and long run. The observation of the international energy agency (IEA) that the tertiary sector is good for the environment is correct. Service-based economies mitigate CO_2 emissions. It becomes good when an economy moves from agricultural to industrial and then to a tertiary base. As income increases, people start to care about their environment. Economic structural revolution further encourages innovations because economic complexity has assisted these economies to mitigate climate change. Therefore, these countries are moving toward sustainability. These findings contradict the findings of Ali et al. [62], which revealed that economic complexity is degrading the environment in Pakistan. The robustness check is presented in Table 7.

Table 7. Robustness check.

Variable	AMG	FMOLS
lnTI	−0.02 ***	−0.07 **
lnEC	−0.03 **	−0.09 ***
lnGDP	−0.59 ***	−1.61 ***
lnGDPs	0.14 **	0.33 ***
lnNRE	0.92 ***	1.29 ***

Note: ** and *** explain the level of significance at 5%, and 1%, respectively.

The robustness check results of AMG and FMOLS indicate similar findings to that of CS-ARDL.

Causality Test

After checking the robustness of the results, this work moved forward to learn the causal effect among the variables. For this purpose, the Dumitrescu Hurlin Panel causality test was applied. This test provides authentic results while considering the problems of panel data. Table 8 shows its findings.

Table 8. Causality Test.

Null Hypothesis	W-Stat.	Prob.
EN → CO_2	2.30764	0.7985
CO_2 → EN	3.94754 ***	0.0108
GDP → CO_2	4.90798 ***	0.0001
CO_2 → GDP	4.80766 ***	0.0002
GDP2 → CO_2	4.82822 ***	0.0002
CO_2 → GDP2	4.66154 ***	0.0004
EC → CO_2	5.73630 ***	4×10^{-7}
CO_2 → EC	4.03640 ***	0.0075
TI → CO_2	3.16310	0.1468
CO_2 → TI	9.69363 ***	0.0000
GDP → EN	4.41762 ***	0.0014
EN → GDP	4.25887 ***	0.0029
GDP2 → EN	4.39632 ***	0.0015
EN → GDP2	4.24143 ***	0.0031
EC → EN	4.47578 ***	0.0010
EN → EC	5.04872 ***	4×10^{-5}
TI → EN	2.84707	0.3128
EN → TI	6.83893 ***	4×10^{-11}
GDP2 → GDP	3.96788 ***	0.0100
GDP → GDP2	3.87206 ***	0.0146
EC → GDP	2.98563	0.2290
GDP → EC	5.32711 ***	8×10^{-6}
TI → GDP	3.04599	0.1980
GDP → TI	4.90728 ***	0.0001
EC → GDP2	2.86070	0.3038
GDP2 → EC	5.30554 ***	9×10^{-6}
TI → GDP2	3.07250	0.1853
GDP2 → TI	4.96537 ***	7×10^{-5}
TI → EC	2.94875	0.2495
EC → TI	4.26908 ***	0.0027

*** shows significance at 1% level.

There is a feedback causal association between GDP, carbon emissions, economic complexity, and energy use. Moreover, economic complexity and energy use are causing each other. One-directional impact goes from CO_2 to energy use, from CO_2 to technological advancements, from energy use to technological progress, from economic growth to economic complexity, from economic growth to technological progress, from industrial value to technological progress.

5. Conclusions and Policy Implications

This work investigates the impacts of economic complexity, technological innovations, nonrenewable energy use, and economic growth on CO_2 emissions in N-11 countries. For empirical analysis, this work adopts the second-generation methodologies. The annual data for 1980–2020 are analyzed and the findings confirm that economic growth is improving air quality in the short and long run, but its square term is degrading the environment. This outcome is crucial for the N-11 nations because the EKC was not validated. Moreover, technological advancement is environmentally friendly in these nations. During the research period of 1980–2020, the number of patents significantly increased in the N-11 nations.

Based on the findings, the following suggestions are recommended for the N-11 countries. These countries need to increase the number of patents because it will increase energy efficiency and reduce carbon emissions in the N-11 countries. As the N-11 nations are heading toward more economic growth, their investment should also be toward ecofriendly and innovative industry technologies. Economic complexity is environmentally friendly because CO_2 emissions can be lowered by increasing tertiary-sector processes. Therefore, this study suggests service-based growth for the Next Eleven countries. In this regard, it is recommended that service sector-based trade, service sector-based companies, and international collaborations to increase services should be enhanced in the N-11 nations. A service-based economy holds a basic position in any country because it enhances employment opportunities and wealth creation. Therefore, these countries should enhance service-based growth by creating public–private engagement. Policymakers should make national policies for service-based growth for sustainable development. In doing so, the current hurdles in regulations should be addressed to form a service-based economy.

The industries should not only be capital-intensive, but also green-intensive sectors. The findings also show that the industrial sector in the N-11 countries contaminates environmental quality. This may be because the N-11 nations need to restructure their energy resources in industries. The traditional energy resources are emitting greenhouse gases and creating environmental damage. These countries must launch renewable sources in industries on an emergency basis and should try to enhance the service-based sectors to boost economic growth. These countries have diverse backgrounds and almost the same environmental degradation rate. These countries have to increase their research and development budgets. Past research has documented that the shift from a manufacturing-based economy toward a service-based economy reduces energy consumption, which helps lower emissions of GHGs. At the same time, these countries must introduce renewable energy sources at domestic levels for a cleaner environment.

This research work enhances the literature by including the roles of economic complexity, economic growth, and technological innovations on CO_2 emissions for N-11 countries. Future research can include other factors of technological innovations and financial risk to present interesting findings for other groups of countries.

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