RESEARCH ARTICLE

Nexus between energy use, industrialization, forest area, and carbon dioxide emissions: New insights from Russia

Asif Raihan[1*], Almagul Tuspekova[2]

[1]Institute of Climate Change, Universiti Kebangsaan Malaysia, Bangi 43600, Malaysia, asifraihan666@gmail.com
[2]Faculty of Social Sciences and Humanities, Universiti Kebangsaan Malaysia, Bangi 43600, Malaysia, tuspekova.almagul@gmail.com

*Corresponding author: Asif Raihan, asifraihan666@gmail.com
Received: 06 September, 2022, Accepted: 30 September, 2022, Published: 01 October, 2022

Abstract
Greenhouse gas (GHG) emissions, especially carbon dioxide (CO_2) emissions, contribute significantly to global climate change, which in turn threatens the environment, development, and sustainability. The current study examines the nexus between Russia's energy consumption, industrialization, and forest cover in terms of the country's total CO_2 emissions. The Autoregressive Distributed Lag (ARDL) bounds testing technique and the Dynamic Ordinary Least Squares (DOLS) methodology were used to examine time series data from 1990 to 2020. Evidence of cointegration between the variables was found using the ARDL bounds test. An increase of 1% in energy consumption and industrialization is predicted to result in an increase of 1.3% and 0.23% in CO_2 emissions in Russia. In addition, it has been estimated that a 1% increase in forest area might lead to a 4.29% reduction in CO_2 emissions in the long run. This article proposed policies to reduce emissions in Russia and assure environmental sustainability through the use of renewable energy sources, green industry, and sustainable forest management.

Keywords: Climate change; CO_2 emissions; Environment; Renewable energy; Forest; Sustainability

Introduction

A large extent of greenhouse gases (GHGs) and carbon dioxide (CO_2) are present in the atmosphere, contributing significantly to global warming in the 21st century. These gases are mostly produced by human activities like the burning of fossil fuels and the degradation of forests (Raihan et al., 2021a). Climate change brought on by continued CO_2 emissions is predicted to have catastrophic impacts on all aspects of human society (Isfat & Raihan, 2022). To protect long-term growth and decrease the negative effects of climate change, reducing CO_2 emissions and improving the quality of the environment have become global concerns (Raihan & Tuspekova, 2022a). Russia is the fourth-largest CO_2 emitter in the world, and most of its emissions come from the burning of fossil fuels like gas, oil, and coal, therefore the country's contributions to global warming are significant. Around 4.6% of global emissions come from Russia's around 2 billion tonnes of CO_2eq (carbon dioxide equivalent) released annually. At 11 tonnes per person per year, carbon dioxide emissions are more than double the global average. Russia's commitment to combating climate change, however, was confirmed when the country ratified the Paris Agreement in April 2015. The Russian government established its long-term climate strategy in October 2021, with goals of achieving net-zero greenhouse gas emissions by the year 2060 and reducing emissions by 80% compared to 1990 levels by the year 2050. Policymakers in Russia are increasingly aware of the need for a holistic understanding of Russia's climate change vulnerability in order to find a middle ground between policies aimed at mitigating climate change and achieving sustainable development, and the implementation of measures that achieve both. The greatest challenge in making progress toward both goals at once is navigating the tension that arises while trying to reduce pollution while also fostering economic growth (Begum et al. 2020). Therefore, there is a significant debate over whether or not the goals of sustainable development and enhanced environmental quality (emissions reduction) are incompatible (Raihan & Tuspekova, 2022b). Russia's main sources of CO_2 emissions need to be investigated in order to provide a solution to the important topic of how Russia may cut CO_2 emissions, which arises.

Russia's GDP of USD 1.78 trillion in 2021 made it the eleventh largest economy in the world (World Bank, 2022). However, oil and gas exports are crucial to Russia's economy. In terms of natural gas, Russia has the greatest reserves in the world; in terms of coal, it has the second largest; and in terms of oil, it has the eighth largest. It ranks high among natural gas producers and exporters, third among oil producers, and second among oil exporters.

In 2021, oil and natural gas income accounted for 45 percent of Russia's federal budget, demonstrating the country's reliance on these commodities. The amount of crude and condensate produced in Russia reached 10.5 million barrels per day in 2021, accounting for 14% of the global supply. Additionally, industrialization in Russia has provided a new avenue for economic growth, contributing roughly 30% to GDP (World Bank, 2022). Steel production, railroads, mining, and chemical processing all played significant roles in Russia's industrialization. Russia is a modern, industrial power that can and will have an effect on the global economy. However, Russia's economy relies heavily on fossil fuels, which results in high energy consumption and carbon dioxide emissions. This means that industrialization is becoming an increasingly formidable obstacle to sustainability and carbon reduction in Russia. It is of great worry to the government that emissions are intensifying, especially those coming from the energy sector and industrialization. Therefore, this study attempts to investigate the effects of Russia's energy consumption and industrialization on carbon dioxide emissions.

Approximately one-fifth of yearly global CO_2 emissions come from agriculture, forestry, and other land use (AFOLU); and land use, land-use change, and forestry (LULUCF) activities making them the second-largest source of CO_2 emissions and a significant contributor to global climate change (IPCC, 2014). Urbanization, industrialization, settlements, mining, and agriculture have all contributed to the loss of forest cover (Jaafar et al., 2020). Alterations to land use, such as the cutting down of trees, can result in significant amounts of carbon dioxide emissions and climate change (Raihan et al., 2018). But forests are important because they act as carbon sources and sinks, altering the balance of the global climate (Raihan et al., 2021b). Carbon sequestration, the process by which forests remove CO_2 from the air and store it in tree biomass and soil, is an important climate change mitigation strategy (Raihan & Tuspekova, 2022c). About 300 billion metric tonnes of carbon dioxide are sequestered annually by forested areas, with an additional 3 billion metric tonnes of CO_2 expected to release into the atmosphere as a result of increased deforestation (Raihan et al., 2022a). Russia is the world's most forested country, accounting for more than 20.1% of the world's total forest area. Nearly half of Russia is covered by forests (World Bank, 2022). This has significant implications for the country's carbon balance. Therefore, studying the forest's potential to reduce carbon dioxide emissions in Russia is essential.

The problem of the environment-growth nexus is brought up by the fact that Russia has had a hard time in recent decades attaining rapid economic expansion without badly harming the environment. Despite its widespread interest among modern scholars, the connections between CO_2 emission and its causes have received scant attention in Russia. While most CO_2 research considers the BRICS (Brazil, Russia, India, China, and South Africa), only a minority of these studies include Russia. It is challenging to construct an accurate picture of the relationship between CO_2 and its drivers for Russia using only panel research due to the known limitations of panel analysis. For this reason, the current assessment employs econometric techniques to investigate the dynamic effects of economic growth, energy use, industrialization, and forest area on CO_2 emissions in Russia, with the intention of filling the resulting research gap. This study is valuable because it contributes to the advancement of both theoretical and practical knowledge in modern Russian literature and policy. This is the first study to evaluate the potential of forest areas to lower CO_2 emissions in Russia, and that is the main innovation of this research. In addition, the most up-to-date and thorough data that was available throughout a 31-year period (1990-2020) was included in this investigation. The study's findings provide policymakers with more thorough and insightful information for developing effective policies in the areas of low-carbon economy, promotion of the use of renewable energy sources, green industrialization, and sustainable forest management, all of which would ensure reductions in emissions in Russia. Further, the study's results may help other developing countries adopt climate change mitigation and adaptation methods and implement effective environmental sustainability strategies.

Methodology

Data

This study conducted an empirical examination of the dynamic effects of economic growth, energy use, industrialization, and forest area on CO_2 emissions in Russia using the DOLS approach of cointegration developed by Stock and Watson (1993). Time series data for Russia from 1990 to 2020 were retrieved using the World Development Indicator (WDI) dataset. In this analysis, CO_2 emissions served as the dependent variable, whereas GDP growth, energy consumption, industrialization, and forest cover all played the role of explanatory variables. Kilotons (kt) are used to measure carbon dioxide emissions, while Gross Domestic Product (in constant Russian rubles), energy consumption (in kg of oil equivalent per capita), industrialization (in the percentage of GDP), and forest area (in square kilometers) are the standard units of measurement for the other variables. To ensure that the data follows a normal distribution, the variables were transformed into the logarithm form. Table 1 displays the variables together with their logarithms, measurement units, and data sources. Figure 1 also shows the annual trends of CO_2 emissions, GDP growth, energy consumption, industrialization, and forest area in Russia.

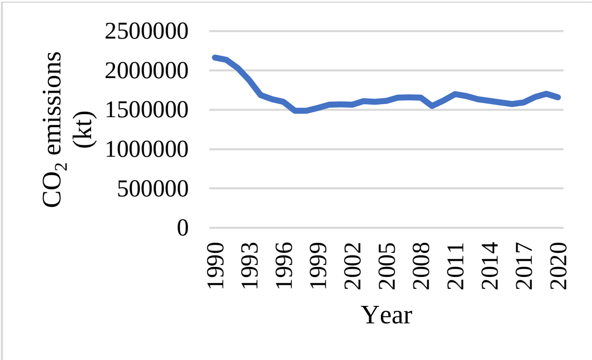
Empirical model

The emission of carbon dioxide is thought to increase in tandem with a growing economy and increased demand for energy. The following function is created within the context of the conventional Marshallian demand function (Friedman 1949) at time t, assuming the market clearance situation where CO_2 emissions equal economic growth and energy use.

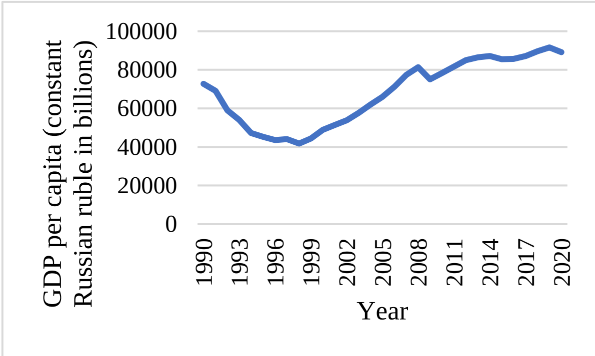
$$CO_{2t} = f\,(GDP_t;\ EU_t) \qquad (1)$$

Table 1. Variables accompanied by their logarithmic representations, measurement units, and data sources

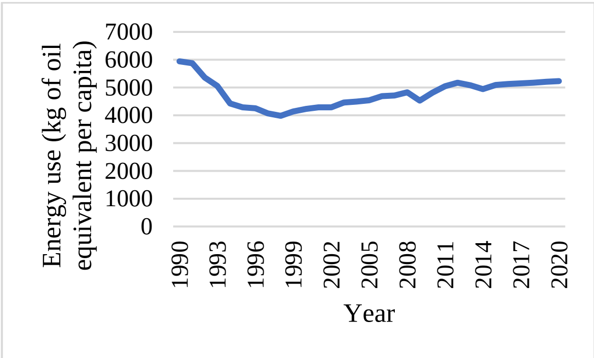
Variables	Description	Logarithmic forms	Units	Sources
CO_2	CO_2 emissions	LCO2	Kt	WDI
GDP	Economic growth	LGDP	GDP per capita (constant Russian ruble)	WDI
EU	Energy use	LEU	Kg of oil equivalent per capita	WDI
IND	Industrialization	LIND	Industry value added (% of GDP)	WDI
FA	Forest area	LFA	Sq. km	WDI



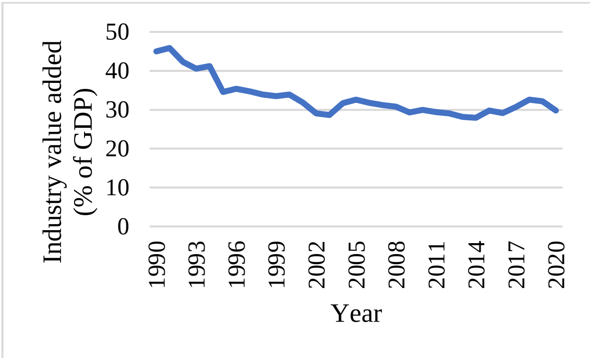
(a) CO_2 emissions



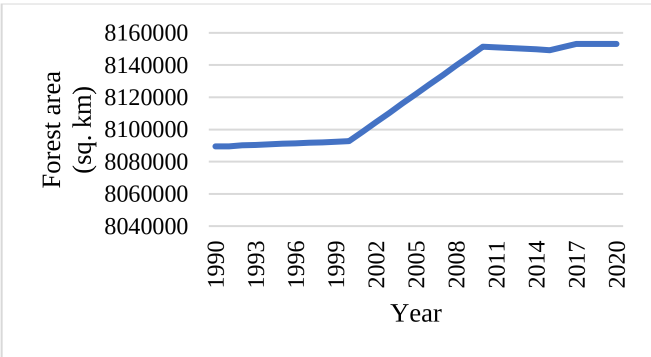
(b) Economic growth



(c) Energy use



(d) Industrialization



(e) Forest area

Figure 1. Yearly changes in the research variables
Source: World Bank (2022)

where CO_{2t} is the CO_2 emissions at time t, GDP_t is the economic growth at time t, and EU_t is the energy usage at time t.

The purpose of this study is to quantify the effects of industrialization and forest area on CO_2 emissions in order to assess their weight on environmental quality. It follows that Equation (1) can be rewritten as:

$$CO_{2t} = f\ (GDP_t;\ EU_t;\ IND_t;\ FA_t) \quad (2)$$

where IND_t is industrialization at time t and FA_t is the forest area at time t

The empirical model is depicted by the equation:

$$CO_{2t} = \tau_0 + \tau_1 GDP_t + \tau_2 EU_t + \tau_3 IND_t + \tau_4 FA_t \quad (3)$$

The econometric model may take the form below, with Equation (3) substituted in for.

$$CO_{2t} = \tau_0 + \tau_1 GDP_t + \tau_2 EU_t + \tau_3 IND_t + \tau_4 FA_t + \varepsilon_t \quad (4)$$

where τ_0 and ε_t are intercept and error term. Besides, τ_1, τ_2, τ_3, and τ_4 signify the coefficients.

Furthermore, the logarithmic procedure of Equation (4) can be finalized as follows:

$$LCO2_t = \tau_0 + \tau_1 LGDP_t + \tau_2 LEU_t + \tau_3 LIND_t + \tau_4 LFA_t + \varepsilon_t \quad (5)$$

Flow chart of the analysis

To investigate the dynamic effects of economic development, energy consumption, industrialization, and forest area on CO_2 emissions in Russia, the present study used the analysis methods illustrated in Figure 2.

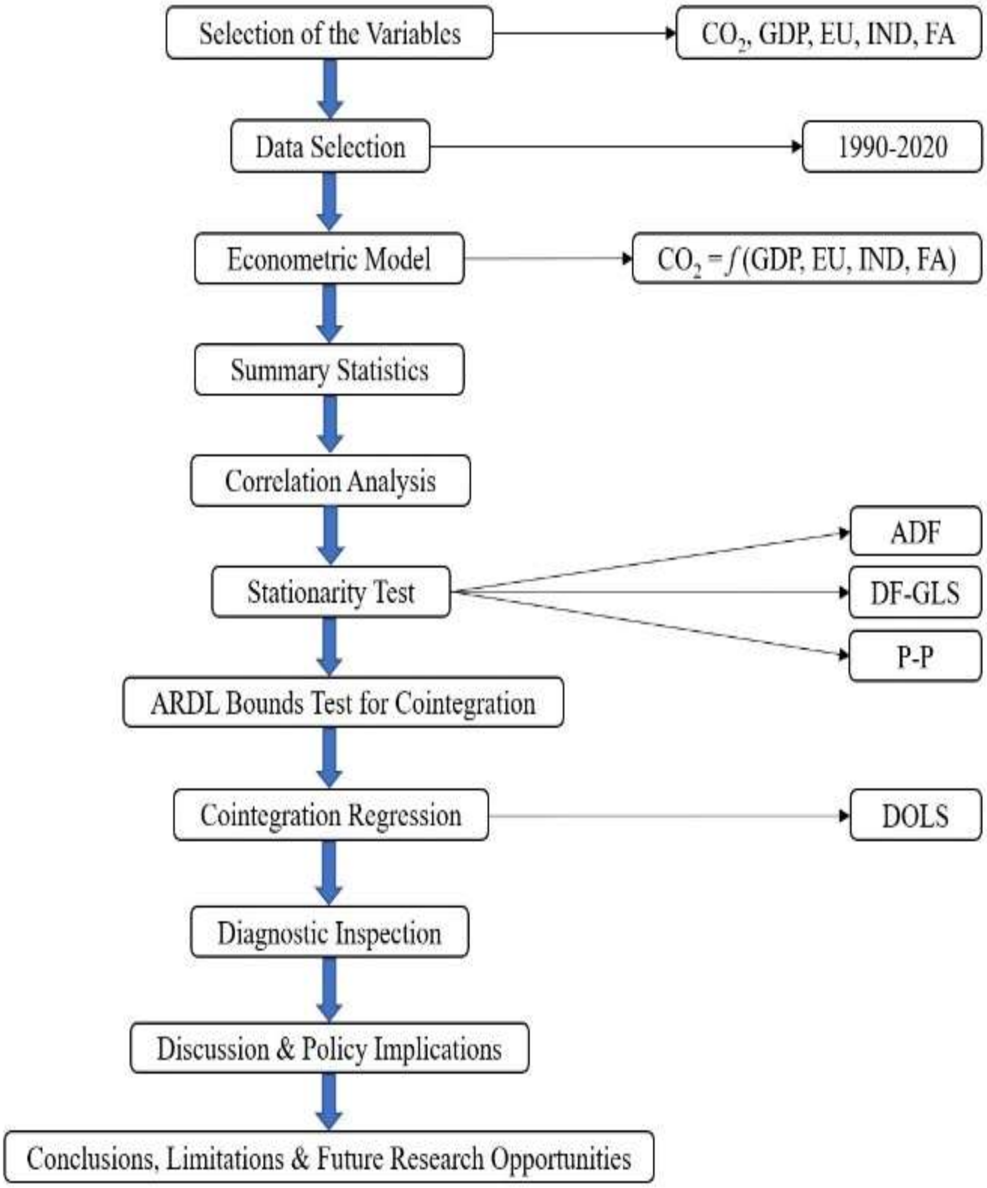


Figure 2. Flow chart of the analysis

Stationarity techniques for data

Using a unit root test is crucial for preventing erroneous regression. By differentiating the variables in a regression, this method ensures that they are stationary and that only stationary processes are used to estimate the equation of interest (Raihan et al., 2022b). For a full understanding of cointegration among variables, the empirical literature recognizes the importance of first defining the sequence of integration. Some research suggests that, due to the unit root tests' varying efficacy depending on sample size, it is essential to use multiple unit root tests when assessing the integration order of the series (Raihan et al., 2022c). Specifically, the Augmented Dickey-Fuller (ADF) test proposed by Dickey and Fuller (1979), the Dickey-Fuller generalized least squares (DF-GLS) test proposed by Elliott et al. (1996), and the Phillips-Perron (P-P) test proposed by Phillips and Perron (1988) were all used to identify the autoregressive unit root. To ensure that no variables went outside the sequence of integration and to back the DOLS technique above conventional cointegration methods, the unit root test was used.

ARDL bounds test

To identify the presence of cointegration between the series, we used the ARDL bounds test suggested by Pesaran et al. (2001). When compared to alternative one-time integer approaches, the ARDL bounds test for cointegration valuation stands out as superior. Since the ARDL bounds test does not require that variables be integrated in a particular order, it can be used when series do not follow a uniform sequence of integration. Second, it has far higher reliability, especially for tiny samples. Finally, it provides a reliable forecast of the long-term model. In Equation (6), the investigation provides a snapshot of the ARDL bounds test.

$$\begin{aligned}\Delta LCO2_t = {} & \tau_0 + \tau_1 LCO2_{t-1} + \tau_2 LGDP_{t-1} + \tau_3 LEU_{t-1} \\ & + \tau_4 LIND_{t-1} + \tau_5 LFA_{t-1} \\ & + \sum_{i=1}^{q} \gamma_1 \, \Delta LCO2_{t-i} + \sum_{i=1}^{q} \gamma_2 \, \Delta LGDP_{t-i} \\ & + \sum_{i=1}^{q} \gamma_3 \, \Delta LEU_{t-i} + \sum_{i=1}^{q} \gamma_4 \, \Delta LIND_{t-i} \\ & + \sum_{i=1}^{q} \gamma_5 \, \Delta LFA_{t-i} + \varepsilon_t \end{aligned} \quad (6)$$

where Δ is the first difference operator and q is the optimum lag length in Equation (6).

Critical values were proposed by Pesaran and Timmermann (2005) based on the F-distribution and the ARDL bounds test. The F-test is used to assess the joint significance of the coefficients of the lagged variables, and the estimating method begins with Equation (6) through the use of OLS. With this method, the present research conducted a test for a potential link between the factors across time. According to the null hypothesis (H_0), the regressors do not exhibit any cointegrating correlations. F-statistics can be compared to upper and lower bounds' critical values, just like in Pesaran et al. (2001). If the F-statistic is above the upper critical value, suggesting the presence of a long-term connection between the variables, the null hypothesis is rejected. However, if the F-statistics are less than the lower critical value, the null hypothesis is accepted. If the observed F-statistics fall between the lower and upper crucial values, the test results are inconclusive.

DOLS cointegration regression

To examine the time series data, the DOLS method (which stands for "discounted" or "extended" ordinary least squares estimation) was used. In the DOLS cointegration test, explanatory variables and the leads and lags of their initial difference terms are incorporated into the covariance matrix of errors, which is then used to regulate endogeneity and calculate standard deviations (Raihan et al., 2022d). The orthogonalization of the error term is shown by the inclusion of the leading and trailing terms of the individual ones. The standard deviations of the DOLS estimator have a normal asymptotic distribution, hence it can be used as a trustworthy test of statistical significance (Raihan & Tuspekova, 2022d). The DOLS method is useful for estimating the dependent variable on explanatory variables in levels, leads, and lags when a mixed order of integration occurs, hence allowing for the integration of individual variables in the cointegrated outline (Raihan & Tuspekova, 2022e). The mixed order integration of individual variables in the cointegrated outline is the primary benefit of the DOLS estimation. Some of the other variables in the regression were also I(1) variables with leads (p) and lags (-p) of the initial difference, while some of the other variables were I(0) variables with a constant term. This estimate eliminates problems of small-sample bias, endogeneity, and autocorrelation by summing the leads and lags among explanatory factors (Raihan et al., 2022e). In any case, after ensuring that the variables are cointegrated, the study employed Equation (6) to estimate the long-run coefficient via the DOLS method.

Results and Discussion

Summary statistics

The outcomes of the summary processes between variables, as well as the results of many normality checks, are displayed in Table 2 (skewness, probability, kurtosis, and Jarque-Bera). Russia's annual data from 1990 to 2020 was sampled 31 times for each indicator. The skewness estimates close to 0 indicate that all of the variables are normal. Furthermore, kurtosis was employed to distinguish between light-tailed and heavy-tailed series by comparing them to a normal distribution. The empirical data shows that all sets are platykurtic, with outcomes less than 3. Moreover, the Jarque-Bera probability calculations show that all of the variables are normally distributed.

Table 2. The statistical summaries of the variables

Variables	LCO2	LGDP	LEU	LIND	LFA
Mean	14.32248	31.82020	8.468984	3.490481	15.91002
Median	14.29660	31.89751	8.480330	3.458845	15.91009
Maximum	14.58725	32.14842	8.689731	3.825699	15.91391
Minimum	14.21292	31.36367	8.289414	3.329756	15.90608
Std. Dev.	1.775874	0.265915	0.103370	0.136920	0.003345
Skewness	0.091417	-0.378472	0.171201	0.142473	-0.016803
Kurtosis	2.556251	1.638359	2.318753	2.353489	1.219451
Jarque-Bera	2.473456	1.134916	0.750893	1.905167	1.096499
Probability	0.782478	0.108575	0.686983	0.131664	0.128960
Sum	443.9968	986.4264	262.5385	108.2049	493.2105
Observations	31	31	31	31	31

Correlation analysis

Table 3 displays the results of the correlation analysis performed on the aforementioned set of variables. The analysis shows that there are correlations between all of the factors. All four of these variables (LCO2, LGDP, LEU, and LIND) show a positive correlation with each other, suggesting that if the value of one grows, the value of the other tends to rise as well. However, LFA has a negative correlation with every other variable, showing that an increase in forest area results in a decrease in the value of every other variable. This investigation proceeded to conduct unit root tests to ensure the variables were stationary based on the results of the correlation analysis.

Table 3. Correlation analysis findings

	LCO2	LGDP	LEU	LIND	LFA
LCO2	1.000000	0.387160	0.762947	0.727599	-0.345612
LGDP	0.387160	1.000000	0.741559	0.890743	-0.420815
LEU	0.762947	0.741559	1.000000	0.631718	-0.494849
LIND	0.727599	0.890743	0.631718	1.000000	-0.726141
LFA	-0.345612	-0.420815	-0.494849	-0.726141	1.000000

Results of unit root tests

Unit root tests have been performed to prove that the DOLS estimation model is preferable to employing only cointegration by ensuring that no parameter exceeds the integration order. Table 4 displays the outcomes of unit root testing with the ADF, DF-GLS, and P-P tests. Level and first-order integration both show that the variable is stationary at the combined levels, hence the DOLS method is superior to the more common cointegration method.

Table 4. Results of ADF, DG-GLS, and P-P unit root tests

Logarithmic form of the variables	ADF		DF-GLS		P-P	
	Log levels	Log first difference	Log levels	Log first difference	Log levels	Log first difference
LCO2	-3.566**	-3.118**	-1.409	-3.338***	-3.406**	-3.323**
LGDP	-0.196	-2.584*	-1.230	-2.438**	-0.858	-2.401*
LEU	-2.080	-3.527**	-1.262	-3.585***	-2.189	-3.461**
LIND	-2.140	-4.064***	-1.098	-4.102***	-3.091**	-5.303***
LFA	-1.423	-2.664*	-1.202	-2.609*	-0.495	-2.773*

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively

Results of ARDL bounds test

After verifying the series' stationarity properties, this study employed the ARDL bounds test for cointegration valuation. Based on the minimum values of Akaike's Information Criterion (AIC), the F-statistic was calculated using a suitable lag period in this investigation. The ARDL bounds test, employed to examine the cointegration relationship, yielded the findings shown in Table 5. If the estimated F-test value is larger than both limits, then a long-run connection between the variables is proven by the results (lower and upper bound). The calculated F-statistic value (6.470895) was found to be more than 10%, 5%, 2.5%, and 1% of the critical upper limit in the order zero and one, thereby rejecting the null hypothesis and confirming the existence of a long-run relationship between the variables.

Table 5. Findings from cointegration with ARDL bounds testing

F-bounds test		Null hypothesis: No levels of relationship		
Test statistic	Value	Significance	I(0)	I(1)
F-statistic	6.470895	At 10%	1.92	2.89
K	4	At 5%	2.17	3.21
		At 2.5%	2.43	3.51
		At 1%	2.73	3.90

The results of the DOLS

The DOLS analysis outcomes are shown in Table 6. Assuming all other factors are constant, a 1% rise in economic growth may result in a 0.02% increase in CO_2 emissions, as the expected long-run coefficient of LGDP is positively significant at the 5% level. The findings suggest that further economic growth in Russia won't have much of an effect on the country's carbon emissions in the long run. The green economy concept has the backing of the Russian economy, which is interested in long-term expansion. Russia, in collaboration with international organizations like the United Nations Environment Programme (UNEP), has established a system of environmental institutions and legislative frameworks to promote equitable and sustainable growth. The estimated long-run coefficient of LEU is positive and statistically significant at the 1% level, which indicates that a 1% increase in energy use leads to a 1.13% increase in CO_2 emissions. Pollution, rubbish production, and environmental damage all rise in tandem with the needs of society as a whole, which in turn is driven by the rising use of fossil fuels and the completion of development projects (Raihan & Tuspekova, 2022f). The growth of Russia's economy is essential to ensuring the country has access to the resources it needs to keep producing energy. Increasing Russia's reliance on renewable energy sources instead of fossil fuels would have many positive effects on the country's economy and environment, including fostering growth and reducing pollution, but it would also position the country to take the lead in the international system and increase competition with more developed nations. In addition, the anticipated long-run coefficient of LIND is notably positive at the 5% level, indicating that every rise of 1% in industry value added is related to an increase of 0.23% in CO_2 emissions. According to the findings, rising Russian emissions can be attributed in part to the country's increasing industry. There is concern that industrialization will increase the use of fossil fuels and cause pollution from industrial effluents, hazardous goods, and heavy metals. During the early stages of industrialization, there is a transition from agriculture to heavy manufacturing based on natural resources. These changes are mostly manifested in the scale and composition of production rather than the rate of technological development. As a result, early industrialization has a greater CO_2 emission rate due to the high demand for energy and the lack of energy-saving equipment (Raihan et al., 2022e). Industrialization may undergo shifts as a result of this evolutionary process, leading to less harmful activities and more environmentally friendly manufacturing.

Table 6. DOLS test results: LCO2 is a dependent variable

Variables	Coefficient	Standard Error	t-Statistic	p-value
LGDP	0.021541**	0.131928	1.632824	0.0157
LEU	1.127779***	0.194210	5.807008	0.0017
LIND	0.232016**	0.101611	2.283375	0.0115
LFA	-4.285113***	0.254562	-16.83333	0.0003
C	37.98929	6.047974	6.281325	0.1047
R^2	0.943708			
Adjusted R^2	0.935048			
Standard error of the estimate	0.023298			
F-statistic	108.9690			
Prob (F-statistic)	0.000000			
Root mean square error (RMSE)	0.021337			
Mean Absolute Error (MAE)	0.017075			

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

The long-run coefficient of forest area is notably negative at the 1% level, suggesting that a 4.29% reduction in CO_2 emissions is the result of a 1% increase in the forest area. However, the research shows that deforestation, forest degradation, and forest fires account for an additional 4.29 percent of CO_2 emissions in Russia for every one percent drop in forest cover. According to the research, forest ecosystems raise the quality of Russia's environment by removing CO_2 from the air and storing it in the flora and soil of forests. Expanding forest reserves and thus increasing forest carbon sinks reduces environmental degradation in the long run, as shown by empirical research. Forest fire accounted for 52.8 million ha of forest loss in Russia between 2001 and 2021, whereas all other causes accounted for 23.2 million ha. Additionally, due to removing land for agriculture and logging, deforestation in Russia occurs at a rate of roughly 2 million hectares each year. Logging, both legal and illicit, is encouraged by foreign investment, demand for resources, export of wood products, and the substantial profits from forest exports. A major issue of contention in the modern climate science community is the importance of restoring, improving, and protecting forests as a means of reducing greenhouse gas emissions (Raihan & Tuspekova, 2022g). Russia joined more than a hundred other countries in signing the first major agreement of the COP26 international climate conference in Glasgow, which calls for an end to deforestation by the year 2030. The most cost-effective strategy for halting environmental decline and slowing global warming is increasing forest carbon sequestration (Raihan et al., 2019). Carbon sequestration, biodiversity conservation, ecosystem rejuvenation, and societal production of products and services are just some of the many benefits of forestry-based mitigation methods (e.g., forest protection, forest conservation, afforestation, reforestation) (Raihan and Said, 2022). Russia's forestry sector has enormous potential to mitigate global climate change by reducing CO_2 emissions and enhancing forest biomass, so increasing the country's carbon sink, through the widespread implementation of forestry-based mitigation techniques. To sum up, improving forest areas may be an effective method to reduce Russia's carbon emissions. In a nutshell, reducing forest fires and felling, and improving forest management may be effective means of reducing Russia's carbon emissions.

Based on the result, energy consumption and industrialization worsen Russia's environmental quality by increasing CO_2 emissions, while expanding the country's forest cover could help the country achieve environmental sustainability by reducing emissions. Furthermore, the signals of the expected coefficients are identical from both a conceptual and a pragmatic vantage point. In addition, several diagnostic tests were used to assess the goodness of fit of the computed model. First, the obtained regression model fits the data pretty well; the R^2 and adjusted R^2 values are 0.9437 and 0.9350, respectively. That means that the explanatory variables may account for 99 percent of the variation in the predictor variables. Finally, the F-statistic proves that the DOLS model is supported by both the dependent and independent variables. The regression model is statistically significant with a p-value of F-statistic of 0.0000. Third, the root mean square error (RMSE) and the mean absolute error (MAE) were successfully used to estimate the accuracy of the model's predictions. The DOLS modeling yielded findings that were a virtually perfect match to the data, as seen by the RMSE and MAE statistics being close to zero and non-negative. Furthermore, Table 7 displays the results of tests for normality, heteroscedasticity, and serial correlation that were performed to verify the robustness of the cointegration valuation. There is no autocorrelation or heteroscedasticity, as shown by the model, and the data are normally distributed. The CUSUM and CUSUMQ tests, which check for model stability by adding up all the residuals from each iteration, were also used in this inquiry. The cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMQ) graphs at the 5% level of significance are shown in Figure 3. The confidence intervals are depicted as red lines, while the residual values are displayed as blue lines. Results reveal that the values of the studied residuals continue to fall within the 95% confidence interval, indicating that the model is robust.

Table 7. Results from diagnostic tests

Diagnostic tests	Coefficient	p-value	Decision
Jarque-Bera test	1.239507	0.2034	Residuals are normally distributed
Lagrange Multiplier test	1.998602	0.4473	No serial correlation exits
Breusch-Pagan-Godfrey test	2.530813	0.1109	No heteroscedasticity exists

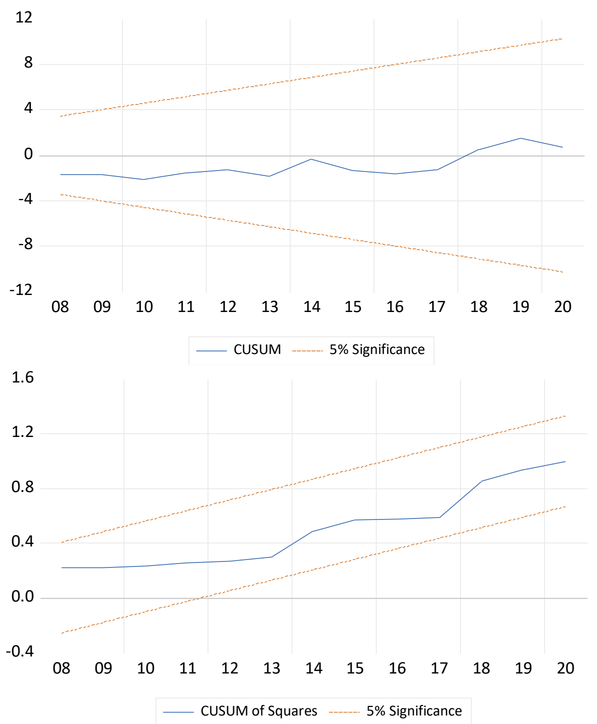


Figure 3. Graphical representations of the CUSUM and CUSUMQ tests (critical boundaries at the 5% level of significance)

The findings of this study suggest that the Russian government should implement an environmental management system to reduce CO_2 emissions and keep economic growth on track. The transition to a low-carbon economy is the best hope for Russia to combat climate change. The study suggested that the government aid markets by adopting strict regulation that boosts emission reduction goals over the long term and consistently backs cleaner output with carbon-reducing technologies. To reduce carbon dioxide emissions from burning fossil fuels for electricity generation and other industrial uses, the Russian government can enact regulations like high carbon taxes, carbon capture and storage, and emission trading schemes. In addition, encouraging the economic move to renewables is vital for reducing environmental impacts associated with economic growth. By replacing traditional energy sources that produce a lot of carbon dioxide, these measures would boost economic growth and increase the use of renewable energy in total energy consumption. Using renewable energy sources for energy production is essential for guaranteeing sustainable development and reducing the effects of climate change. Wind, hydro, geothermal, biomass, and solar energy are only a few examples of Russia's abundance in renewable energy sources, in addition to oil, gas, and coal. However, at the moment, fossil fuels account for the vast majority of Russia's energy consumption, while the country's immense and varied renewable energy resources are underutilized. Due to growing international concern for the environment, it is urgent that Russia make the transition to renewable energies. This will allow for the creation of a more eco-friendly economy. Russia may be able to grow its renewable resources in a decisive manner and create networks of technical assistance with other countries. Increased government funding would do wonders for the spread of renewable energy. Renewable energy can assist to reduce emissions, thus Russia may implement policies to lower the cost of renewable energy while restricting the use of fossil fuels in industry, businesses, and homes. It's possible that the government may use the media to spread the word about its green lifestyle concept and encourage people to adopt low-carbon ways of living and consumption habits.

Findings from this study suggest that industrialization is a critical issue that needs to be emphasized while creating sustainability programs. To maintain economic growth through cleaner production while decreasing CO_2 emissions, the industrial structure must be appropriately modified and optimized. The Russian government should require polluting industries with a track record of endangering public health to implement stringent pollution control measures. Moreover, in order to adopt greener production and industrialization strategies, international investors must adhere to restrictions and constraints. For green industrialization to take place, consumption and production of energy, especially the use of renewable energy, must be sustainable. In addition, the authority may employ administrative measures to strengthen the reformation of heavy and high-emissions firms, all while fostering zero- and low-emissions industries by bolstering industrial diversification. For a more hygienic production system, it is imperative that environmentally sound methods be mandated across the board in industry, and that older, more polluting technologies be phased out entirely. In addition, the government may provide funding to businesses for the purchase of emission-control equipment. Politicians may impose ecological taxes on sectors that don't embrace environmentally friendly technologies. Further, both public and private R&D establishments are required to create cutting-edge technology for reducing pollution and promoting the use of recycled industrial waste as an energy source, thus reducing emissions.

Specifically, this research found that reducing CO_2 emissions through forest development could be a priority for Russian policymakers seeking to create environmentally sound and climate resilient policies. With the goal of lowering carbon dioxide emissions and raising forest biomass through protection and conservation, the Russian government may raise investments while creating stringent forest legislation. By creating commercial forest plantation areas, the government can further encourage private sector participation in sustainable forest management. Forest conservation, forest protection, afforestation, reforestation, sustainable forest management, enhanced natural regeneration, and similar forestry-based mitigation strategies have the potential to strengthen Russia's capacity to mitigate climate change by increasing forest carbon sinks. The Russian government may increase investment and implement strong forest laws and policies to limit CO_2 emissions from deforestation and forest fires. For Russia to preserve its biodiversity, forest fires and deforestation must be prevented at all costs. Last but not least, if Russia's forestry policy were to be put into action as intended, the country might achieve net zero emission status by increasing its national carbon sink, fostering national green growth, and ensuring the sustainable management of its forest ecosystems.

Conclusions

This study utilized time series data from 1990 to 2020 to analyze the dynamic effects of Russia's energy consumption, industrialization, and forest area on the country's CO_2 emissions. In this research, the integration order of the dataset was determined using the ADF, DF-GLS, and P-P unit root tests. In addition, there was long-run cointegration among the variables, as shown by the ARDL bounds test. The DOLS model was used to determine how environmental influences had an impact over time. According to the estimates, a 1% increase in Russia's GDP, energy consumption, and industrialization will lead to a 0.02%, 1.13%, or 0.23% increase in the country's CO_2 emissions. The reduction in carbon dioxide emissions of 4.29% is another way in which an increase of just 1% in forest area improves environmental quality. The findings illuminated the potential for Russia to achieve environmental sustainability through the utilization of renewable sources and forest land. Further, the findings suggested approaches in which Russia could move toward sustainable development by way of bolstering regulatory policy instruments meant to slow down the rate at which the environment degrades. Additional growth variables, such as trade openness, financial development, foreign direct investments, urbanization, institutional quality, globalization, technology innovation, natural resources, ecological footprint, etc., can be taken into account in future studies. However, CO_2 was used in this study to represent environmental deterioration. Carbon emissions from consumer activities are one proxy for environmental degradation; other emissions that could be studied to better

Russia's environment include nitrous oxide (N_2O), sulfur dioxide (SO_2), methane (CH_4), carbon monoxide (CO), ground-level ozone (O_3), hydrogen sulfide (H_2S), and other short-lived climate forces (SLCF). Even though CO_2 emission is not the only source of environmental damage, it was used as a stand-in in the present investigation. Future research for the instance of Russia could include additional environmental contamination indicators, such as water pollution and land pollution.

Funding: Not applicable

Acknowledgments: Not applicable

Conflict of interest: The authors declare no conflict of interest.

References

Begum, R. A., Raihan, A., & Said, M. N. M. (2020). Dynamic impacts of economic growth and forested area on carbon dioxide emissions in Malaysia. Sustainability, 12(22), 9375. https://doi.org/10.3390/su12229375

Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. Journal of the American statistical association, 74(366a), 427-431. https://doi.org/10.1080/01621459.1979.10482531

Elliott, G., Rothenberg, T. J., & Stock, J. H. (1992). Efficient tests for an autoregressive unit root (No. t0130). National Bureau of Economic Research.

Friedman, M. (1949). The Marshallian demand curve. Journal of Political Economy, 57(6), 463-495.

IPCC. (2014). Climate change 2014: Synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 151 pp.

Isfat, M., & Raihan, A. (2022). Current Practices, Challenges, and Future Directions of Climate Change Adaptation in Bangladesh. International Journal of Research Publication and Reviews, 3(5), 3429-3437.

Jaafar, W. S. W. M., Maulud, K. N. A., Kamarulzaman, A. M. M., Raihan, A., Sah, S. M., Ahmad, A., Saad, S. N. M., Azmi, A. T. M., Syukri, N. K. A. J., Khan, W. R. (2020). The Influence of Forest Degradation on Land Surface Temperature–A Case Study of Perak and Kedah, Malaysia. Forests 11 (6): 670. https://doi.org/10.3390/f11060670

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. Journal of applied econometrics, 16(3), 289-326. https://doi.org/10.1002/jae.616

Pesaran, M. H., & Timmermann, A. (2005). Small sample properties of forecasts from autoregressive models under structural breaks. Journal of Econometrics, 129(1-2), 183-217. https://doi.org/10.1016/j.jeconom.2004.09.007

Phillips, P. C., & Perron, P. (1988). Testing for a unit root in time series regression. Biometrika, 75(2), 335-346.

Raihan, A., Begum, R. A., Said, M. N. M., & Abdullah, S. M. S. (2018). Climate change mitigation options in the forestry sector of Malaysia. J. Kejuruter, 1, 89-98. http://dx.doi.org/10.17576/jkukm-2018-si1(6)-11

Raihan, A., Begum, R. A., Mohd Said, M. N., & Abdullah, S. M. S. (2019). A review of emission reduction potential and cost savings through forest carbon sequestration. Asian Journal of Water, Environment and Pollution, 16(3), 1-7. https://doi.org/10.3233/AJW190027

Raihan, A., Begum, R. A., & Said, M. N. M. (2021a). A meta-analysis of the economic value of forest carbon stock. Geografia–Malaysian Journal of Society and Space, 17(4), 321-338. https://doi.org/10.17576/geo-2021-1704-22

Raihan, A., Begum, R. A., Mohd Said, M. N., & Pereira, J. J. (2021b). Assessment of carbon stock in forest biomass and emission reduction potential in Malaysia. Forests, 12(10), 1294. https://doi.org/10.3390/f12101294

Raihan, A., Begum, R. A., Nizam, M., Said, M., & Pereira, J. J. (2022a). Dynamic impacts of energy use, agricultural land expansion, and deforestation on CO2 emissions in Malaysia. Environmental and Ecological Statistics, 29, 477-507. https://doi.org/10.1007/s10651-022-00532-9

Raihan, A., Begum, R. A., Said, M. N. M., & Pereira, J. J. (2022b). Relationship between economic growth, renewable energy use, technological innovation, and carbon emission toward achieving Malaysia's Paris agreement. Environment Systems and Decisions. https://doi.org/10.1007/s10669-022-09848-0

Raihan, A., Muhtasim, D. A., Pavel, M. I., Faruk, O., & Rahman, M. (2022c). Dynamic Impacts of Economic Growth, Renewable Energy Use, Urbanization, and Tourism on Carbon Dioxide Emissions in Argentina. Environmental Processes, 9, 38. https://doi.org/10.1007/s40710-022-00590-y

Raihan, A., Muhtasim, D. A., Pavel, M. I., Faruk, O., & Rahman, M. (2022d). An econometric analysis of the potential emission reduction components in Indonesia. Cleaner Production Letters, 3, 100008. https://doi.org/10.1016/j.clpl.2022.100008

Raihan, A., Muhtasim, D. A., Farhana, S., Pavel, M. I., Faruk, O., Rahman, M., & Mahmood, A. (2022e). Nexus between carbon emissions, economic growth, renewable energy use, urbanization, industrialization, technological innovation, and forest area towards achieving environmental sustainability in Bangladesh. Energy and Climate Change, 3, 100080. https://doi.org/10.1016/j.egycc.2022.100080

Raihan, A., & Said, M. N. M. (2022). Cost–benefit analysis of climate change mitigation measures in the forestry sector of Peninsular Malaysia. Earth Systems and Environment, 6(2), 405-419. https://doi.org/10.1007/s41748-021-00241-6

Raihan, A., & Tuspekova, A. (2022a). The nexus between economic growth, renewable energy use, agricultural land expansion, and carbon emissions: New insights from Peru. Energy Nexus, 6, 100067. https://doi.org/10.1016/j.nexus.2022.100067

Raihan, A., & Tuspekova, A. (2022b). Role of economic growth, renewable energy, and technological innovation to achieve environmental sustainability in Kazakhstan. Current Research in Environmental Sustainability, 4, 100165. https://doi.org/10.1016/j.crsust.2022.100165

Raihan, A., & Tuspekova, A. (2022c). Toward a sustainable environment: nexus between economic growth, renewable energy use, forested area, and carbon emissions in Malaysia. Resources, Conservation & Recycling Advances, 15, 200096. https://doi.org/10.1016/j.rcradv.2022.200096

Raihan, A., & Tuspekova, A. (2022d). Dynamic impacts of economic growth, energy use, urbanization, agricultural productivity, and forested area on carbon emissions: New insights from Kazakhstan. World Development Sustainability, 1, 100019. https://doi.org/10.1016/j.wds.2022.100019

Raihan, A., & Tuspekova, A. (2022e). Nexus between economic growth, energy use, agricultural productivity, and carbon dioxide emissions: new evidence from Nepal. Energy Nexus, 7, 100113. https://doi.org/10.1016/j.nexus.2022.100113

Raihan, A., & Tuspekova, A. (2022f). Nexus between emission reduction factors and anthropogenic carbon emissions in India. Anthropocene Science, 1(2), 295-310. https://doi.org/10.1007/s44177-022-00028-y

Raihan, A., & Tuspekova, A. (2022g). Dynamic impacts of economic growth, energy use, urbanization, tourism, agricultural value-added, and forested area on carbon dioxide emissions in Brazil. Journal of Environmental Studies and Sciences, 12, 1-21. https://doi.org/10.1007/s13412-022-00782-w

Stock, J. H., & Watson, M. W. (1993). A simple estimator of cointegrating vectors in higher order integrated systems. Econometrica: journal of the Econometric Society, 61(4), 783-820.

World Bank. (2022). World Development Indicators (WDI); Data series by The World Bank Group; The World Bank: Washington, DC, USA. Retrieved from https://databank.worldbank.org/source/world-development-indicators