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Economic Growth and Environmental Sustainability in Russia

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Imran Ali[1]

Abstract:

Purpose: *This study rigorously analyzes the relationship between economic growth and environmental sustainability in Russia, with a particular focus on the Environmental Kuznets Curve (EKC) hypothesis and the decoupling of economic development from CO_2 emissions. The primary objective is to assess how key macroeconomic variables—GDP growth, trade openness, energy composition (renewable vs. fossil fuels), inflation, population growth and coal rents—affect CO_2 emissions from 1996 to 2022.*
Design/Methodology/Approach: *Using econometric models such as OLS, ARDL, and ROLS and the results confirm that GDP growth, inflation, and coal rents have a statistically significant positive effect on CO_2 emissions, indicating a rise in emissions as economic output increases. In contrast, renewable energy consumption and trade openness are significantly associated with lower emissions, supporting the decoupling hypothesis. While population growth positively influences emissions, its effect is weaker compared to other variables.*
Findings: *The study finds partial support for the EKC hypothesis, suggesting that without stronger environmental policies, Russia is unlikely to reach the point where economic growth alone reduces emissions.*
Practical Implications: *The findings highlight the need for robust policy measures to promote renewable energy adoption, manage inflationary pressures and improve trade efficiency to decouple growth from environmental degradation.*
Originality/Value: *The significance of this study lies in its contribution to the broader understanding of how emerging economies like Russia can reconcile economic growth with environmental sustainability.*

Keywords: *CO_2 emissions, economic growth, Environmental Kuznets Curve, renewable energy, trade openness, inflation, population growth, Russia, sustainability.*

JEL Classification: *Q53, Q56, O13, F18, P28.*

Paper type: *Research article.*

[1]*Mr., Government College University Faisalabad, Department of Economics, Pakistan, e-mail: imranalieco@gmail.com;*

1. Introduction

Climate change has become one of the most pressing challenges of the 21st century, prompting nations worldwide to seek solutions that balance economic growth with environmental sustainability. Global CO_2 emissions, primarily driven by the burning of fossil fuels, are a key contributor to rising temperatures and environmental degradation. This issue has garnered attention in both developed and emerging economies as they struggle to meet international commitments such as the Paris Agreement, which aims to limit global temperature increases to well below 2°C above pre-industrial levels (UNFCCC, 2015).

For emerging economies, the challenge is particularly complex due to their heavy reliance on fossil fuel industries for economic growth and global competitiveness. Russia is the world's fourth-largest emitter of CO_2, largely because its economy depends heavily on energy production, including oil, coal, and natural gas exports (Le Quéré *et al.,* 2018). While the energy sector has been the backbone of Russia's economy, it also presents a significant role in terms of environmental sustainability.

This has placed Russia in a difficult position, as the global trend moves towards decarbonization and a green energy transition, while its economic foundation is deeply rooted in nonrenewable energy sources (Sovacool and Brown, 2010). In addition to its domestic energy consumption, Russia is also a major global energy exporter which further complicates its efforts to reduce emissions. The Russian government has made some strides toward recognizing the need for more sustainable practices such as supporting international climate agreements and committing to reduce emissions under the Paris

Agreement (Russia Climate Policy Tracker, 2020). However, despite these pledges, the shift to renewable energy in Russia has been slow with renewables accounting for only a small percentage of its overall energy mix (IEA, 2020). From a theoretical standpoint, understanding the relationship between economic growth and environmental degradation is essential for crafting policies that foster both economic expansion and emissions reduction.

The Environmental Kuznets Curve (EKC) hypothesis posits that as economies grow, environmental degradation increases up to a certain point after which further growth leads to improvements in environmental quality due to technological advancements and stricter regulations (Grossman and Krueger, 1995; Ojaghlou *et al.,* 2023). In the Russian context, however, the heavy reliance on fossil fuels complicates the straightforward application of the EKC hypothesis.

Unlike many developed economies which have transitioned towards service-oriented industries Russia remains highly dependent on resource, making the potential for emissions reductions more challenging (Stern, 2004). Russia's vast geographic size and diverse economic regions add another layer of complexity.

While certain regions are rich in fossil fuels, others have untapped potential for renewable energy, such as hydropower, wind and solar (Smeets, 2014).

The economic and environmental impacts of these regions vary significantly, highlighting the need for regionalized policy approaches to reduce CO_2 emissions effectively. Trade openness increases industrial output and transportation both of which can drive up emissions, although in the long term, it also provides opportunities for the adoption of cleaner technologies (Jorgenson and Clark, 2012).

This study is timely because it addresses the pressing issue of how Russia can decouple its economic growth from CO_2 emissions. As the global community moves toward stricter environmental policies and carbon neutrality, Russia must find ways to reduce its reliance on fossil fuels and increase its use of renewable energy.

In this research, utilized very little share of AI tools for data analysis which allowed us to efficiently manage extensive datasets and derive deeper insights, thereby strengthening the overall rigor of our findings. This study explores these dynamics through econometric analysis, focusing on how economic growth, trade openness, energy consumption, inflation and population growth affect CO_2 emissions in Russia.

The significance of this study lies in its contribution to the broader understanding of how emerging economies like Russia can reconcile economic growth with environmental sustainability. While many advanced economies have already begun transitioning towards greener energy sources, developing countries face significant obstacles due to their structural reliance on fossil fuel exports and energy-intensive industries (Makarov *et al.,* 2016).

By analyzing the relationship between economic variables and CO_2 emissions this study provides critical insights that can inform policymakers about the best strategies to promote sustainable growth. This study also sheds light on the role of renewable energy in reducing carbon emissions. With the international community moving toward more stringent climate goals, the importance of transitioning to renewable energy sources such as wind, solar, and hydropower cannot be overstated (Zoundi, 2017).

Furthermore, the study examines how macroeconomic factors such as trade openness, inflation and population growth contribute to CO_2 emissions. Trade is a double-edged sword: while it fosters economic growth and global integration, it can also increase carbon emissions through higher production and transportation demands (Jorgenson and Clark, 2012).

Similarly, inflation and population growth can influence industrial activity and energy consumption, further impacting the environment (Soytas *et al.,* 2007). By analyzing these factors, this study contributes to a deeper understanding of how macroeconomic conditions affect environmental outcomes. While much has been written about the relationship between economic growth and environmental degradation in developed countries, the literature on Russia remains limited particularly in terms of how renewable energy and macroeconomic factors like inflation, trade openness and population growth influence CO_2 emissions.

The existing studies that do focus on Russia, such as Ozturk and Acaravci (2010) and Pao and Tsai (2011) often focus narrowly on economic growth and energy consumption without fully considering the role of renewable energy or the broader macroeconomic context. Furthermore, the research on the Environmental Kuznets Curve (EKC) has largely concentrated on economies that have already transitioned away from fossil fuel dependence (Stern, 2004).

This study fills critical research gap by applying the EKC framework to Russia's unique economic structure. Additionally, this research goes beyond the EKC hypothesis by examining how renewable energy, coal rents, inflation, trade and population growth collectively influence emissions, offering a more comprehensive analysis than previous studies.

1.1 Research Questions

This research seeks to comprehensively analyze the multifaceted drivers of carbon emissions in Russia with a central focus on elucidating the complex relationship between economic growth and environmental degradation. It will first investigate the nature of the link between GDP growth and CO_2 emissions over time. Subsequently, the analysis will quantify the specific roles played by key factors including trade openness, the consumption of renewable energy, and the persistent use of coal in shaping the nation's emission profile.

Furthermore, the study will explore the often-overlooked influences of macroeconomic stability, through inflation, and demographic pressures, through population growth, on environmental outcomes. Ultimately, by synthesizing these empirical findings, the research aims to propose concrete policy strategies and effective decoupling mechanisms necessary for Russia to achieve a sustainable balance between its economic development goals and the imperative of environmental sustainability.

1.2 Research Objectives

This study establishes five core objectives to systematically investigate the drivers of environmental situation in Russia. The primary aim is to analyze the relationship between economic growth and CO_2 emissions by employing time-series data and econometric models to test the validity of the Environmental Kuznets Curve hypothesis within Russia's unique economic context. Secondly, it seeks to evaluate impact of trade on emissions to determine whether globalization acts as catalyst for or a mitigator of environmental harm.

A third objective involves a critical assessment of the country's energy composition, specifically quantifying the influence of renewable energy adoption versus continued coal consumption on emission levels. Furthermore, the research will examine the less-explored effects of macroeconomic stability, through inflation, and demographic factors, through population dynamics, on environmental outcomes.

Synthesizing these findings, the final and pivotal objective is to formulate targeted policy recommendations designed to decouple economic growth from environmental damage. These strategies will advocate for enhancing energy efficiency, accelerating renewable energy integration, and strengthening environmental regulations to foster sustainable development without compromising economic prosperity.

2. Literature Review

2.1 Theoretical Framework: Decoupling Economic Growth from Environmental Degradation in Russia

This study is grounded in the Environmental Kuznets Curve (EKC) and the decoupling hypothesis, which together offer insights into how Russia can reconcile economic growth with environmental sustainability, particularly focusing on CO_2 emissions.

1. **Environmental Kuznets Curve (EKC) Hypothesis:** The EKC hypothesis posits that at early stages of economic growth, environmental degradation tends to increase due to higher industrial activity and reliance on fossil fuels. However, beyond a certain income threshold, the relationship between economic growth and environmental degradation reverses, as technological advancements and cleaner energy sources reduce environmental impact. This forms an inverted U-shape relationship between income and environmental degradation, particularly CO_2 emissions.

In Russia, the EKC hypothesis applies as the nation has experienced significant economic development accompanied by fluctuating CO_2 emissions. Studies, such as those by Pao and Tsai (2011) and Wu *et al.* (2015), have shown that while economic growth in Russia initially exacerbates emissions, appropriate policy shifts and technological advancements may eventually lead to a reduction in emissions, in line with the EKC. This theory suggests that Russia is approaching a turning point where further growth can be decoupled from rising emissions, provided environmental policies are implemented effectively.

2. **Decoupling Hypothesis:** The decoupling hypothesis argues that it is possible for economies to continue growing without a corresponding increase in

environmental degradation. This can be achieved through policies promoting energy efficiency, adoption of renewable energy, and investments in clean technology. For Russia, this framework is particularly relevant as the country seeks to balance its reliance on fossil fuels such as coal, which significantly contributes to CO_2 emissions with its potential to expand renewable energy sectors like solar, wind, and hydropower.

The results of this study support the decoupling hypothesis. The econometric analysis shows that renewable energy has a statistically significant, negative impact on CO_2 emissions, meaning that increasing renewable energy consumption can help reduce emissions without hindering economic growth. This finding echo conclusion drawn by Sun *et al.* (2019), who highlight the importance of renewable energy in reducing carbon intensity and emissions. Nevertheless, the current low share of renewables energy mix highlights the need for stronger policy interventions to achieve decoupling.

3. **The Role of Energy Consumption:** Energy consumption remains a critical factor in determining CO_2 emissions in Russia. Fossil fuels, particularly coal and oil, have traditionally dominated Russia's energy mix, As highlighted by He *et al.* (2020), coal consumption continues to drive emissions, though the transition to cleaner energy sources such as renewables is slowly gaining traction. The study's findings underscore that while renewable energy use has begun to have a measurable impact on reducing emissions, the overall share of renewable energy in Russia remains low. This points to the need for increased policy attention to promote the adoption of clean energy technologies.

4. **Trade Openness and Globalization:** Trade openness also plays a key role in influencing CO_2 emissions in Russia. While trade has been positively correlated with emissions in the short term, primarily due to increased industrial output and energy use, globalization can also offer opportunities for emissions reductions through the adoption of greener technologies and practices (Sun *et al.,* 2019).

Trade agreements and international environmental standards can help Russia access cleaner technologies and more efficient production processes, facilitating a reduction in emissions over time. The correlation between trade and CO_2 emissions, as observed in this study, highlights the complexity of the trade-emissions relationship. While trade drives economic growth and industrialization, it can also promote technological transfers that lead to environmental improvements.

5. **Inflation, Population Growth, and Environmental Impact:** Inflation and population growth are additional factors influencing CO_2 emissions in Russia. High inflation periods are associated with increased industrial activity which drives emissions (Hasnisah *et al.,* 2019). Likewise, population growth has a direct impact on emissions due to the rising demand for energy and resources. The positive

correlation between population growth and CO_2 emissions suggests that demographic changes in Russia contribute significantly to environmental pressures.

To manage these impacts, policymakers must consider strategies for sustainable urbanization and energy-efficient infrastructure that can mitigate the environmental effects of population expansion. The Environmental Kuznets Curve and decoupling hypotheses provide a strong theoretical basis for understanding the relationship between Russia's economic growth and CO_2 emissions.

While the EKC suggests that emissions will decline after reaching a certain level of income, the decoupling hypothesis emphasizes the importance of strategic interventions to reduce emissions without hindering economic development. The findings from this study support the potential for Russia to achieve sustainable growth by increasing its reliance on renewable energy, improving trade efficiency, and implementing policies that decouple economic growth from environmental degradation.

2.2 Empirical Review

This study with title "Russian GDP 2030: Scenarios Under Pollutant Emissions Constraints" investigates the relationship between GDP growth and CO_2 emissions in Russia, the study's objective was to evaluate how different levels of emissions and waste reduction targets might affect GDP growth in Russia up to the year 2030. employed the Kaya equation to model the interplay between economic growth and environmental restrictions, analyzing data from 2000 to 2018.

Their analysis found a strong correlation between GDP growth and CO_2 emissions, revealed that economic growth has historically driven emissions increases. suggesting that strategic environmental investments could help mitigate the adverse effects of economic growth on emissions. The findings of this study underscore the need for Russia to integrate environmental considerations into its economic planning, providing a roadmap for policymakers to balance growth with sustainability (Steblyanskaya *et al.,* 2021).

This study with title "Modelling and Forecasting CO_2 Emissions in the BRICS Countries Using a Novel Multi-Variable Grey Model" examined the relationship between economic growth, energy consumption, urban population, and CO_2 emissions in the BRICS countries. The objectives of this study to assess how these variables interact and to predict future emissions trends.

The researchers utilized a multi-variable grey model, analyzing data from 2004 to 2010, and then applied a rolling forecasting model to predict future CO_2 emissions based on economic and demographic trends. The study found that economic growth in BRICS has a unique impact on CO_2 emissions. Specifically, in Russia, economic growth appears to have a decreasing effect on emissions, aligning with the

Environmental Kuznets Curve hypothesis, these findings suggests that Russia might reach a turning point where emissions begin to decline despite continued economic growth, provided that appropriate policies are in place. which is crucial for formulating sustainable development strategies in Russia and similar economies (Wu *et al.,* 2015; Tyagi *et al.,* 2023; Grima *et al.,* 2024).

The study "Multivariate Granger Causality Between CO_2 Emissions, Energy Consumption, FD and GDP: Evidence from a Panel of BRIC Countries" explored the dynamic causal relationships between GDP growth, CO_2 emissions, energy consumption, and foreign direct investment (FDI) in the BRIC countries, including Russia. The objective was to determine the direction and nature of causality among these variables using panel cointegration techniques and multivariate Granger causality tests on data spanning from 1992 to 2007 for Russia.

The results showed strong bidirectional causality between GDP and CO_2 emissions, indicating that economic growth not only drives emissions but is also influenced by them. The findings support the Environmental Kuznets Curve hypothesis for Russia, this study is significant because it provides empirical evidence that supports the feasibility of achieving sustainable economic growth in Russia (Pao and Tsai, 2011).

This study "Decomposition Analysis of CO_2 Emissions Embodied in the International Trade of Russia" uses an improved input-output approach to analyze CO_2 emissions embodied in Russia's international trade from 1995 to 2014. It finds that Russia is a net exporter of CO_2 emissions, with a significant portion of emissions generated in the production of goods for other countries.

The study also identifies a decrease in Russia's carbon intensity post-2003 due to energy structure transformations. The authors suggest that countries responsible for significant carbon emissions due to international trade should participate actively in climate negotiations and consider environmental costs in trade pricing (Sun *et al.,* 2019).

This paper "Research on Embodied CO_2 Emissions and Its Improvement Path of Russia's Exports to China Based on MRIO-SDA Model" examines the embodied CO_2 emissions in trade between Russia and China using a multi-regional input-output model. The research shows that while Russia's net embodied CO_2 emissions to China decreased from 2000 to 2014, certain sectors like coke, petroleum, and mining remain significant contributors due to their high energy intensity. The study emphasizes the need for policy measures focused on energy efficiency and reducing carbon intensity in key sectors to mitigate trade-related emissions (Chen *et al.,* 2023).

This study "Bootstrap ARDL Test on the Relationship among Trade, FDI, and CO_2 Emissions: Based on the Experience of BRICS Countries" uses the Bootstrap ARDL model to investigate the relationships among trade, foreign direct investment (FDI), and CO_2 emissions in BRICS countries, including Russia. It finds that trade and FDI have a positive impact on CO_2 emissions in Russia, suggesting a complex interplay between economic growth, investment, and environmental impacts. The authors highlight the importance of tailored policies for managing trade and investment to mitigate CO_2 emissions effectively (He *et al.,* 2020)

Pham *et al.* (2020) investigated the environmental impacts of GDP, population, and technological progress across 28 European countries from 1990 to 2014. Using OLS and Panel Vector Autoregressive (PVAR) models, they found that GDP growth increases CO_2 emissions, supporting the Environmental Kuznets Curve (EKC) hypothesis, which suggests that economic growth initially worsens environmental degradation before improving at higher income levels. Their study highlights that while technological progress can mitigate emissions over time, population growth generally exacerbates environmental pressures. Overall, the research confirms the link between economic growth and environmental degradation in Europe.

Li *et al.* (2020) investigated the drivers of CO_2 emissions in post-communist economies across Eastern Europe and Central Asia, including countries like Bulgaria, Czech Republic, Hungary, and Russia, from 1996 to 2018. By employing a random effects model, the study assessed the impact of energy efficiency, GDP per capita, life expectancy, and sectoral contributions on CO_2 emissions. The findings revealed that improvements in energy efficiency significantly reduce per capita CO_2 emissions.

In contrast, increases in GDP per capita and life expectancy were associated with higher emissions. Additionally, the study found that a higher share of the agriculture, forestry, and fishing sectors in GDP reduces emissions, while a larger industrial sector increases them. The research underscores the need for policies promoting energy efficiency and the development of green sectors to mitigate emissions, suggesting that modernization of industries and a shift towards less energy-intensive services are essential for reducing CO_2 emissions in these regions.

Dehdar *et al.* (2022) explored the impact of technology and government policies on CO_2 emissions in 36 OECD countries from 1994 to 2015. Utilizing econometric models, including panel quantile regression and Ordinary Least Squares (OLS), the study assessed how various factors influenced CO_2 emissions. The research, based on the Lin and Ng method for addressing parameter heterogeneity, identified that GDP, fossil fuel consumption, industrialization, and the proportion of taxation relative to GDP exacerbate CO_2 emissions.

Conversely, urbanization, the number of environmental patents, and environmental taxes (as a percentage of total tax) contribute to reducing emissions. The findings emphasize the importance of implementing policies that promote environmental sustainability, such as environmental taxes and incentives for cleaner technologies. The study suggests that to mitigate industrialization's impact on emissions, countries should focus on energy efficiency, adjust industrial structures, and encourage nuclear energy trade among OECD nations.

Hasnisah *et al.* (2019) investigated the impact of renewable energy consumption on CO_2 emissions in 13 developing Asian countries from 1980 to 2014. Using panel data and methodologies such as panel cointegration, fully modified Ordinary Least Squares (OLS), and dynamic OLS estimators, the study examined the long-term relationship between environmental quality, economic development, and energy consumption.

The findings confirmed the Environmental Kuznets Curve (EKC) hypothesis, showing that GDP per capita and conventional energy consumption negatively affect environmental quality. However, the study found that renewable energy consumption did not significantly reduce CO_2 emissions. This suggests that while economic development and conventional energy use are linked to increased pollution, renewable energy alone is not sufficient to mitigate CO_2 emissions.

The study highlights the need for comprehensive strategies that combine economic development with effective use of eco-friendly resources to address global warming and enhance environmental sustainability in developing Asian countries.

Magazzino *et al.* (2020) examined the relationship between solar and wind energy production, coal consumption, GDP, and CO_2 emissions in China, India, and the USA, using advanced machine learning techniques. The study applied the Causal Direction from Dependency (D2C) algorithm to analyze causal linkages among these variables and utilized supervised prediction models for estimation.

The results indicated that both China and the USA are expected to see reductions in CO_2 emissions due to their significant investments in renewable energy sources. In contrast, India is projected to experience an increase in CO_2 emissions, highlighting the challenges in transitioning from fossil fuels to renewable energy. The study underscores the necessity for a comprehensive shift towards renewable energy to effectively reduce CO_2 emissions.

The findings suggest that while China and the USA are making progress toward sustainability, India needs to enhance its adoption of low-carbon energy sources and reduce coal dependence to achieve similar environmental benefits.

Adedoyin *et al.* (2019) investigated the relationship between coal rent, economic growth, and CO_2 emissions in BRICS countries (Brazil, Russia, India, China, and South Africa), with a focus on the role of regulatory quality. Utilizing a balanced panel dataset from 1990 to 2014 and employing the Pooled Mean Group with Dynamic Autoregressive Distributed Lag (PMG-ARDL) model, the study examined how coal rents and regulatory policies influence CO_2 emissions.

The findings revealed that while coal consumption increases CO_2 emissions, coal rents have a significant but negative impact on emissions. Surprisingly, stricter regulations on coal rents, such as carbon damage costs, were found to have a positive impact on CO_2 emissions, contrary to expectations. This suggests that while regulations are crucial for managing emissions, they may not be sufficient alone to achieve green growth. The study emphasizes the need for more stringent and effective environmental regulations and a shift towards renewable energy sources to support sustainable development and reduce CO_2 emissions in BRICS economies.

Rahman *et al.* (2022) analyzed the impacts of energy use, tourism, and foreign workers on CO_2 emissions in Malaysia from 1982 to 2018. Using the Autoregressive Distributed Lag (ARDL) approach, the study found that while natural gas and electricity consumption had an insignificant effect on CO_2 emissions, tourist arrivals, coal use, and oil use significantly increased emissions.

Conversely, foreign workers and population growth had minimal impacts on CO_2 emissions. The research also highlighted that in the early stages of economic development, GDP growth negatively affected CO_2 emissions, but this relationship reversed in later stages, leading to increased emissions. The study suggests that Malaysia should focus on increasing renewable energy use and consider implementing a carbon tax to mitigate environmental degradation and manage CO_2 emissions effectively.

Abdouli *et al.* (2017) explored the nonlinear effects of economic growth, population density, and foreign direct investment (FDI) inflows on CO_2 emissions in BRICTS countries (Brazil, Russia, India, China, Turkey, and South Africa) from 1990 to 2014.

Employing static (OLS, FE, RE) and dynamic (system GMM) panel data methods, the study found that while increased population density and FDI inflows initially reduced CO_2 emissions, economic growth had a detrimental effect on environmental quality, contradicting the Kuznets Curve hypothesis.

The findings suggest that, unlike the positive effects of population density and FDI in the short term, sustained economic growth tends to exacerbate environmental degradation. These results highlight the need for policymakers to design effective economic and environmental policies that balance growth with environmental protection.

Bayar *et al.* (2020) investigated the impact of trade and financial globalization on renewable energy use in EU transition economies from 1995 to 2015, employing a bootstrap panel Granger causality test. The study explored the relationships among renewable energy, trade globalization, financial globalization, real GDP per capita, and CO_2 emissions.

The results revealed a significant unilateral causality from trade globalization to renewable energy in Estonia, Latvia, and Slovenia, and from renewable energy to trade globalization in Croatia and Lithuania.

However, no significant causality was found between financial globalization and renewable energy. Additionally, the study identified various causal relationships between renewable energy and CO_2 emissions, including unilateral causality from CO_2 emissions to renewable energy in Lithuania and Slovenia, and reciprocal causality between renewable energy and CO_2 emissions in Romania and Slovakia.

The analysis also found unilateral causality from real GDP per capita to renewable energy in Czechia, Romania, and Slovenia. These findings underscore the influence of trade globalization on renewable energy adoption while highlighting the lack of significant impact from financial globalization.

Chien (2022) examined the effects of renewable energy and economic conditions on environmental degradation in China, utilizing data from 1981 to 2018 sourced from the World Bank. The study applied the quantile autoregressive distributed lag (QARDL) model to analyze the relationships among renewable energy production (REP), energy import, renewable energy consumption (REC), gross domestic product (GDP), inflation, and foreign direct investment (FDI) with CO_2 emissions.

The findings indicated that REP, energy import, and REC significantly reduce CO_2 emissions, demonstrating the positive impact of renewable energy on environmental quality. Conversely, GDP, inflation, and FDI were found to increase CO_2 emissions.

The study highlights the importance of renewable energy policies in mitigating carbon emissions and offers guidance for policymakers to focus on enhancing renewable energy production and consumption to address environmental challenges effectively.

3. Data and Methodology

3.1 Data Description

The study utilizes time-series dataset covering the period from 1996 to 2022 to explore the relationship between economic and social forces and environmental degradation in Russia. The primary variables include CO_2 emissions per capita, renewable energy consumption, GDP growth, trade openness, inflation, population growth, and coal rents. The data is sourced from reputable databases, including the World Bank (WDI) and the United Nations Development Programme (UNDP).

The dataset provides comprehensive coverage of key macroeconomic and environmental indicators necessary for testing the Environmental Kuznets Curve (EKC) and decoupling hypotheses in the context of Russia.

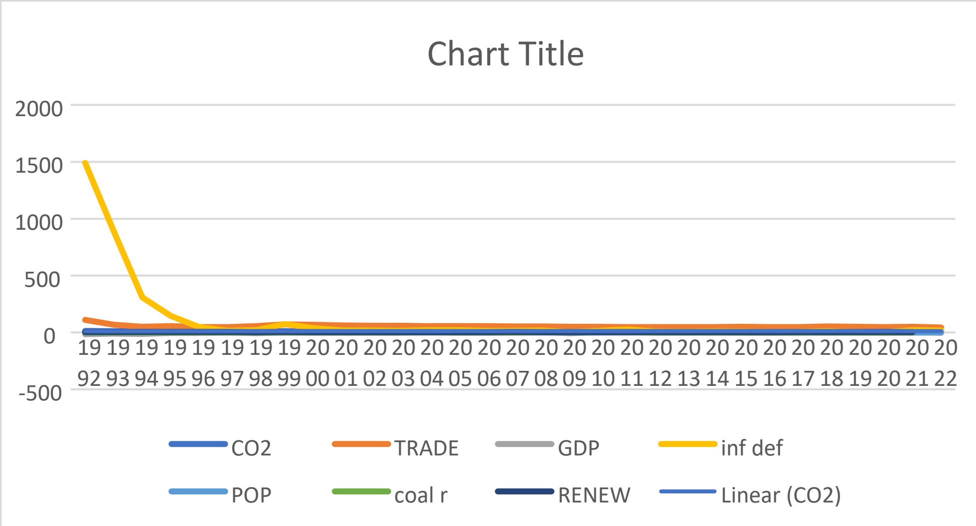
Table 1. *Data Description*

Indicator	Description	Unit	Period	Source
Carbon dioxide emissions per capita (production)	Emissions of carbon dioxide resulting from the burning of fossil fuels and the production of cement.	Tone's per capita	1996-2022	UNDP
Renewable energy consumption	Share of energy consumption that comes from renewable sources, including hydropower, solar, wind, and geothermal.	% of total final energy consumption	1996-2022	WDI, World Bank
Inflation, deflator (annual %)	Annual change in the GDP deflator, measuring the price level of all new, domestically produced final goods and services.	% (annual)	1996-2022	WDI, World Bank
Population gr (annual %)	The annual percentage increase in population, including the impact of births, deaths, and migration trends.	% (annual)	1996-2022	WDI, World Bank
GDP growth (annual %)	The annual percentage growth rate of GDP at market prices based on constant local currency. Represents economic growth.	% (annual)	1996-2022	WDI, World Bank
Trade (% of GDP)	Total of exports and imports of goods and services as a percentage of GDP.	% of GDP	1996-2022	WDI, World Bank
Coal rents (% of GDP)	The share of GDP derived from coal extraction and production.	% of GDP	1996-2022	WDI, World Bank, UNDP

Source: *Data presented based on authors' own estimations.*

Figure 1 shows a period of economic stabilization after the early 1990s, while environmental indicators like CO2 emissions continue to rise slowly, underscoring the ongoing challenges in balancing economic growth with environmental sustainability.

Figure 1. *Economic stabilization 1992-2022*



Source: *Results estimated using Excel Microsoft (author's analysis).*

3.2 Model Specification

Descriptive statistics were used to provide a summary of the data, including means, medians, and standard deviations. This analysis highlighted stable CO_2 emissions but fluctuations in economic variables such as GDP and inflation (Moore and McCabe, 2006). A correlation analysis was conducted to understand relationships among the variables. This helps identify interdependencies, such as the moderate negative correlation between GDP and CO_2 emissions, supporting the Environmental Kuznets Curve hypothesis (Grossman and Krueger, 1995).

We have employed the Augmented Dickey-Fuller (ADF) test to check the stationarity of all variables, ensuring the validity of our time-series analysis (Dickey and Fuller, 1979). The results confirmed that variables such as CO_2 emissions, GDP, and inflation are stationary, allowing us to proceed with regression models like OLS and ARDL (Gujarati and Porter, 2009).

3.2.1 Econometric Models

Several econometric models are employed to analyze the dataset and validate the hypotheses:

$$CO_{2t} = \beta_0 + \beta_1 GDP_t + \beta_2 RENEW_t + \beta_3 TRADE_t + \beta_4 COALR_t + \beta_5 POP_t + \beta_6\, INF_t + \varepsilon_t$$

Ordinary Least Squares (OLS) regression is applied as the baseline model to establish linear relationships between CO_2 emissions and the independent variables, including GDP growth, trade, renewable energy consumption, coal rents, population growth, and inflation. The OLS method is appropriate given that all the variables in the dataset are stationary based on the Augmented DickeyFuller (ADF) unit root test results.

OLS is the standard approach for estimating the relationships between economic and environmental variables, assuming stationarity of data. It provides insights into short-term influences on emissions. OLS estimation assumes that the data is stationary, and preliminary unit root tests (ADF test) confirmed stationarity for all variables (Gujarati and Porter, 2009). The functional form of the OLS model is as follows:

$$CO_{2t} = \beta_0 + \beta_1 GDP_t + \beta_2 TRADE_t + \beta_3 INF_t + \beta_4 POP_t + \beta_5 RENEW_t + \beta_6 COALR_t + \varepsilon_t$$

Where:
CO_{2t} = CO_2 emissions per capita, GDP_t = GDP growth (annual %), $TRADE_t$ = Trade openness (% of GDP), INF_t = Inflation (GDP deflator, annual %), POP_t = Population growth (annual %), $RENEW_t$ = Renewable energy consumption (% of total energy use), $COALR_t$ = Coal rents (% of GDP), and ε_t = Error term.

Autoregressive Distributed Lag (ARDL) models are used to capture both short-term and longterm dynamics in the relationship between CO_2 emissions and the macroeconomic variables. The ARDL model is particularly suited for the analysis because it can handle the mix of I (0) and I (1) variables and allows for the exploration of both immediate and lagged effects.

The general specification of the ARDL model is:

$$\Delta CO_{2t} = \alpha_0 + \Sigma \alpha_i \Delta CO_2\{t-i\} + \Sigma \beta_j \Delta GDP\{t-j\} + \Sigma \gamma_k \Delta X\{t-k\} + \lambda ECM\{t-1\} + \varepsilon_t$$

The ARDL model is appropriate for analyzing the data because it handles both I (0) and I (1) variables, as long as they are not I (2) (Pesaran, Shin, and Smith, 2001).

Robust Least Squares Regression To handle outliers and heteroscedasticity, the Robust Least Squares (RLS) model is specified in the same functional form as the OLS model but with adjustments for robustness:

$$CO_{2t} = \beta_0 + \beta_1 GDP_t + ... + \beta_6 COALR_t + \varepsilon_t$$

The RLS technique ensures that the model is not overly influenced by extreme values, thereby improving the reliability of the estimates. RLS is employed to address potential outliers and heteroscedasticity in the dataset. This model ensures that the results are not unduly influenced by extreme values, thereby providing more reliable estimates compared to OLS. RLS is justified due to its ability to handle data irregularities such as outliers and heteroscedasticity, enhancing the robustness of the results (Andrews, 1974).

3.2.2 Diagnostic Tests

We have performed diagnostic tests like the Breusch-Godfrey LM test for serial correlation and the Breusch-Pagan test for heteroskedasticity. These tests confirmed no significant issues with autocorrelation or heteroskedasticity, ensuring the robustness of our models (Breusch and Pagan, 1979).

4. Results and Analysis

4.1 Descriptive Statistics of Variables

Table 2 provides a comprehensive overview of the main features of a dataset, summarizing key aspects such as central tendency, dispersion, and distribution patterns. Descriptive statistics are essential for summarizing and understanding the main features of a dataset, such as central tendency and variability (Moore and McCabe, 2006). These methods provide a clear snapshot of the data, making it easier to identify trends and patterns before conducting more complex analyses (Gelman and Hill, 2007).

Table 2. *Descriptive statistics*

Statistic	CO_2	GDP	POP	RENEW	TRADE	COAL_R	INF_DEF
Mean	11.16	1.23	-0.08	3.53	55.15	0.45	108.76
Median	11.30	2.50	-0.05	3.50	51.27	0.39	15.39
Maximum	13.22	10.00	0.30	4.00	110.58	1.38	1490.42
Minimum	9.92	-14.5	-0.46	3.20	45.97	0.16	0.90
Std. Dev.	0.74	6.27	0.25	0.25	12.45	0.27	309.78
Skewness	0.48	-0.92	-0.02	0.25	3.13	1.57	3.65
Observations	30	30	30	30	30	30	30

Source: *Results estimated using EViews 12 (author's analysis).*

The descriptive statistics reveal that CO_2 emissions in Russia average 11.16 units with low variability, indicating stable emission levels. Economic performance, measured by GDP, shows high variability and a negative skew, suggesting significant fluctuations and more common lower values. Population growth is slightly negative with minimal variation, while renewable energy consumption is low and slightly positively skewed, indicating limited adoption.

Trade openness is highly variable with a positive skew, implying less frequent high values. Coal rent has moderate variability and a positive skew, and inflation shows extreme variability with a high skewness, reflecting significant fluctuations.

Overall, these statistics highlight the varying impacts of economic and environmental factors on emissions.

4.2 Correlation Analysis

A correlation matrix in Table 3 provides a comprehensive view of how different variables are interrelated, highlighting both the strength and direction of their relationships (Field, 2013). This matrix is instrumental in identifying patterns and dependencies among variables, which can inform subsequent analyses and interpretations (Cohen, 2013). By examining these correlations, researchers can better understand the interplay between factors such as economic performance, energy consumption, and environmental impacts (Hair *et al.,* 2010).

Table 3. *Correlation analysis*

Variables	CO_2	GDP	POP	RENEW	TRADE	COAL_R	INF_DEF
CO_2	1.00	-0.34	0.54	-0.05	0.29	0.22	0.61
GDP	-0.34	1.00	-0.42	-0.52	-0.29	0.31	-0.64
POP	0.54	-0.42	1.00	-0.28	-0.23	-0.04	0.12
RENEW	-0.05	-0.52	-0.28	1.00	0.49	-0.40	0.57
TRADE	0.29	-0.29	-0.23	0.49	1.00	-0.10	0.84
COAL_R	0.22	0.31	-0.04	-0.40	-0.10	1.00	-0.16
INF_DEF	0.61	-0.64	0.12	0.57	0.84	-0.16	1.00

Source: *Results estimated using EViews 12 (author's analysis).*

The correlation analysis sheds light on the intricate relationships between CO_2 emissions and various economic and environmental variables in Russia, aligned with the research questions and objectives.

Economic Growth and CO_2 Emissions: The analysis reveals a moderate negative correlation of -0.34 between GDP and CO_2 emissions. This suggests that, on average, periods of higher economic growth are associated with lower CO_2 emissions, supporting the idea that economic growth does not uniformly lead to increased emissions. This finding aligns with the Environmental Kuznets Curve hypothesis, indicating that economic development might eventually lead to environmental improvements.

Trade and CO_2 Emissions: There is a moderate positive correlation of 0.29 between trade openness and CO_2 emissions. This implies that increased trade activities are linked to higher emissions, which could be due to higher industrial output and transportation needs associated with trade. This finding underscores the need to further investigate how globalization and trade practices impact environmental outcomes.

Energy Mix and CO_2 Emissions: The correlation between renewable energy consumption and CO_2 emissions is very low at -0.05, suggesting that the current levels of renewable energy use have minimal impact on reducing CO_2 emissions. In contrast, the positive correlation of 0.22 with coal rent indicates a weak association, implying that coal's contribution to emissions is relatively minor compared to other factors. This highlights the need to explore more deeply the potential of renewable energy in emissions reduction and the barriers to its increased adoption.

Population Growth and CO_2 Emissions: A positive correlation of 0.54 between population growth and CO_2 emissions indicates a significant relationship, suggesting that rising populations contribute to higher emissions through increased demand for resources and energy. This supports the objective to examine how demographic factors influence environmental outcomes.

Inflation and CO_2 Emissions: The strong positive correlation of 0.61 between inflation and CO_2 emissions suggests that periods of high inflation are associated with higher emissions. This relationship may reflect increased economic activity and industrial output during inflationary periods, aligning with the objective to understand the effects of economic conditions on environmental outcomes.

Overall, these correlations highlight key dynamics between economic growth, trade, energy consumption, and environmental degradation. The findings provide a basis for developing policies aimed at decoupling economic growth from CO_2 emissions and advancing sustainable development in Russia.

4.3 Unit Root Test (ADF Test Results)

To understand the presence of unit roots in a time series, it is crucial to perform unit root tests (Table 4). One of the most widely used tests for this purpose is the Augmented Dickey-Fuller (ADF) test.

This test helps determine whether a time series is stationary or has a unit root, which is essential for ensuring the validity of many statistical methods and models used in econometric analysis (Dickey and Fuller, 1979). Stationarity is a key assumption in time series analysis, as non-stationary data can lead to unreliable inferences and misleading results (Hamilton, 1994).

Table 4. *Unit root tests*

Series	**Probability**	**Lag**	**Max Lag**	**Obs**
CO_2	0.0382	0	6	30
COAL_R	0.0444	0	6	29
GDP	0.0126	0	6	30
INF_DEF	0.0326	4	6	26
POP	0.0045	3	6	27
RENEW	0.0462	0	6	29
TRADE	0.0000	0	6	30

Source: *Results estimated using EViews 12 (author's analysis).*

The results of the Augmented Dickey-Fuller (ADF) unit root tests indicate that all the variables—CO_2 emissions, coal rent, GDP, inflation/deflation, population growth, renewable energy consumption, and trade openness—are stationary. Each variable has a probability value below the 0.05 significance threshold, confirming that they do not exhibit unit roots and are thus suitable for further analysis.

Given that the data is stationary, applying Ordinary Least Squares (OLS) regression is appropriate. OLS is effective for stationary data as it assumes a stable relationship between variables and does not require differencing or transformations that are necessary for non-stationary data (Gujarati and Porter, 2009). This method will allow for a straightforward analysis of the impact of economic and environmental factors on CO_2 emissions.

Furthermore, the use of Autoregressive Distributed Lag (ARDL) models is justified. ARDL models are advantageous as they can accommodate a mix of stationary and non-stationary data while analyzing both short-term and long-term relationships among variables (Pesaran, Shin, and Smith, 2001). Since all variables in this study are stationary, ARDL models will be well-suited for examining the dynamic interactions and potential long-term equilibrium relationships between CO_2 emissions and the explanatory variables.

4.4 OLS Model Results

Table 5 presents the OLS regression results, showing the estimated coefficients, standard errors, and significance levels for each variable. The R-squared and adjusted R-squared values indicate the model's explanatory power, while the F-statistic confirms the overall model significance.

Table 5. *OLS regression results*

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
COAL_R	0.4889	0.2368	2.0646	0.0504
GDP	0.0522	0.0164	3.1761	0.0042
INF_DEF	0.0042	0.0006	7.4339	0.0000
POP	0.7104	0.3719	1.9100	0.0687
RENEW	-0.8202	0.3830	-2.1414	0.0431
TRADE	-0.0517	0.0118	-4.3722	0.0002
Constant	16.2124	1.5860	10.2218	0.0000
Additional OLS analysis information				
R-squared	0.869	**Durbin-Watson stat**	1.16	
Adjusted R-squared	0.835	F-statistic	25.47	
Prob(F-statistic)	0.0000	AIC	0.63	

Source: *Results estimated using EViews 12 (author's analysis).*

The results from the Ordinary Least Squares (OLS) regression provide valuable insights into the determinants of CO_2 emissions in Russia. The analysis reveals that coal rent (COAL_R) has a positive and statistically significant effect on CO_2 emissions, with a coefficient of 0.4889 and a p-value of 0.0504. This suggests that an increase in coal rent is associated with higher CO_2 emissions, albeit the relationship is marginally significant at the 5% level. GDP also shows a positive and statistically significant impact on CO_2 emissions, with a coefficient of 0.0522 and a p-value of 0.0042.

This finding supports the hypothesis that economic growth contributes to increased emissions, aligning with the observed trend that higher economic output tends to be associated with greater environmental impact. Inflation/deflation (INF_DEF) has a substantial and highly significant effect on CO_2 emissions, with a coefficient of 0.0042 and a p-value of 0.0000.

The large t-statistic of 7.4339 underscores the strong influence of inflationary pressures on emissions, suggesting that economic conditions driven by inflation contribute to higher levels of CO_2 emissions.

Population growth (POP) has a positive coefficient of 0.7104, though it is only marginally significant with a p-value of 0.0687. This indicates that increasing population growth is associated with higher CO_2 emissions, reflecting the increased demand for resources and energy, but the significance is weaker compared to other variables. Renewable energy consumption (RENEW) is associated with a negative and statistically significant coefficient of -0.8202, with a p-value of 0.0431.

This result suggests that higher renewable energy consumption is linked to reduced CO_2 emissions, which aligns with the objective to assess the impact of renewable energy on emissions. Trade openness (TRADE) shows a negative and highly significant effect on CO_2 emissions, with a coefficient of -0.0517 and a p-value of 0.0002. This indicates that increased trade is associated with lower emissions, which may reflect efficiency gains or changes in production practices influenced by trade dynamics.

The model's R-squared value of 0.869 and adjusted R-squared of 0.835 indicate a strong explanatory power, meaning the model effectively captures a significant portion of the variation in CO_2 emissions. The high F-statistic of 25.47 and the associated p-value of 0.0000 confirm the overall significance of the model, while the Durbin-Watson statistic of 1.16 suggests potential issues with autocorrelation.

In conclusion, the OLS results highlight the complex interplay between economic growth, trade, energy consumption, and environmental factors in shaping CO_2 emissions in Russia. These findings provide a basis for further investigation into policy measures aimed at achieving a balance between economic development and environmental sustainability.

4.5 Robust Least Squares Regression Results

Table 6 presents the results from the Robust Least Squares regression, addressing potential outliers and heteroscedasticity. The coefficients, along with their standard errors and significance levels, provide insights into the relationships between variables under more robust conditions.

Table 6. *Robust Least Squares results*

Variable	Coefficient	Std. Error	z-Statistic	Prob.
COAL_R	0.4088	0.2251	1.8161	0.0694
GDP	0.0582	0.0156	3.7271	0.0002
INF_DEF	0.0042	0.0005	7.7033	0.0000
POP	0.8743	0.3535	2.4729	0.0134
RENEW	-0.5337	0.3640	-1.4661	0.1426
TRADE	-0.0520	0.0112	-4.6267	0.0000
Constant	15.2733	1.5075	10.1310	0.0000
Additional Information				
R-squared	**0.688**	**Akaike info criterion**	45.46	
Adjusted R-squared	**0.607**	**Schwarz criterion**	58.02	

Source: *Results estimated using EViews 12 (author's analysis).*

The Robust Least Squares regression results offer refined insights into the factors influencing CO_2 emissions in Russia, accounting for potential outliers and heteroscedasticity. Coal Rent (COAL_R) exhibits a positive coefficient of 0.4088 with a z-statistic of 1.8161 and a p-value of 0.0694. This indicates a positive but marginally significant relationship between coal rent and CO_2 emissions.

The weaker significance compared to the OLS results suggests that while coal rent still positively influences emissions, its impact is less pronounced when accounting for robust estimates. Gross Domestic Product (GDP) shows a positive and statistically significant effect with a coefficient of 0.0582 and a z-statistic of 3.7271, with a p-value of 0.0002. This reinforces the finding from the OLS model that economic growth contributes significantly to higher CO_2 emissions.

Inflation/Deflation (INF_DEF) continues to exhibit a robust and highly significant positive effect on CO_2 emissions, with a coefficient of 0.0042 and a z-statistic of 7.7033, and a p-value of 0.0000. This consistent result across both OLS and robust regression models underscores the strong influence of inflationary pressures on emissions. Population Growth (POP) shows a positive and statistically significant coefficient of 0.8743 with a z-statistic of 2.4729 and a p-value of 0.0134.

This suggests that population growth has a substantial effect on increasing CO_2 emissions, supporting the view that demographic factors play a significant role in environmental outcomes. Renewable Energy Consumption (RENEW) has a coefficient of -0.5337 with a z-statistic of -1.4661 and a p-value of 0.1426.

This result is not statistically significant, indicating that, despite the negative coefficient, the impact of renewable energy on reducing CO_2 emissions is not robust when accounting for potential outliers. Trade Openness (TRADE) remains negatively associated with CO_2 emissions, with a coefficient of -0.0520, a zstatistic of -4.6267, and a p-value of 0.0000.

This strong and significant result suggests that increased trade openness contributes to lower CO_2 emissions, reflecting possible efficiency improvements or shifts in production practices related to trade. The model's R-squared value of 0.688 and adjusted R-squared of 0.607 indicate that the robust regression model explains a substantial portion of the variation in CO_2 emissions, although it is less explanatory compared to the OLS model.

The Akaike Information Criterion (AIC) and Schwarz Criterion (SC) provide additional measures of model fit, with lower values indicating better fit relative to alternative models. In summary, the robust regression analysis reaffirms the significant roles of GDP, inflation, population growth, and trade in influencing CO_2 emissions, while suggesting that the impact of coal rent and renewable energy consumption is less pronounced. These findings are critical for designing targeted policies aimed at balancing economic growth with environmental sustainability.

4.6 ARDL Long Run Form and Bounds Test

Conditional Error Correction Regression:
Table 7 displays the ARDL Long Run Form results and the Bounds Test, assessing the existence of a longrun relationship between the variables. The long-run coefficients, error correction term, and corresponding significance levels are reported. The Conditional Error Correction Regression results highlight the speed of adjustment back to equilibrium following short-run deviations. The error correction term's significance confirms the presence of a long-run equilibrium relationship.

Table 7. *ARDL long run form results*

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	23.065	8.175	2.82	0.0257
CO_2 (-1)	-1.156	0.489	-2.36	0.0502
COAL_R (-1)	0.811	0.433	1.87	0.1031
GDP (-1)	0.186	0.063	2.96	0.0212
INF_DEF (-1)	0.018	0.007	2.69	0.0312
POP (-1)	0.372	0.596	0.62	0.5527
RENEW (-1)	-1.198	0.517	-2.32	0.0537
TRADE (-1)	-0.139	0.052	-2.67	0.0319
D (CO_2 (-1))	-0.007	0.463	-0.01	0.9891
D(COAL_R)	0.214	0.269	0.80	0.4522

D (COAL_R (-1))	-0.363	0.330	-1.10	0.3087
D(GDP)	0.059	0.027	2.15	0.0685
D (GDP (-1))	-0.060	0.031	-1.95	0.0924
D(INF_DEF)	0.020	0.009	2.21	0.0632
D (INF_DEF (-1))	-0.003	0.002	-1.75	0.1230
D(POP)	-2.408	1.108	-2.17	0.0663
D (POP (-1))	-0.846	1.167	-0.72	0.4920
D(RENEW)	-1.194	0.362	-3.29	0.0132
D (RENEW (-1))	-0.029	0.446	-0.07	0.9499
D(TRADE)	-0.105	0.039	-2.69	0.0311
D (TRADE (-1))	0.055	0.027	2.05	0.0798

Source: *Results estimated using EViews 12 (author's analysis).*

Levels Equation:

The Levels Equation estimates the long-run relationship between the variables in the ARDL model**.** Table 8 presents the coefficients of the independent variables in their levels, reflecting their long-term impact on the dependent variable. Statistical significance indicates whether these relationships hold over time.

Table 8. *Levels equation results*

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
COAL_R	0.701	0.284	2.47	0.0430
GDP	0.161	0.046	3.51	0.0098
INF_DEF	0.016	0.006	2.54	0.0389
POP	0.322	0.448	0.72	0.4964
RENEW	-1.036	0.562	-1.84	0.1077
TRADE	-0.120	0.025	-4.86	0.0018
C	19.951	2.606	7.66	0.0001
Error Correction Model: (CO_2 = 0.7013*COAL_R* + *0.1609*GDP + 0.0156*INF_DEF* + *0.3215*POP				

Source: *Results estimated using EViews 12 (author's analysis).*

F-Bounds Test:

The F-Bounds Test evaluates the existence of a long-run relationship between the variables in the ARDL model. Table 9 reports the calculated F-statistic and the critical value bounds. If the F-statistic exceeds the upper bound, a long-run relationship is confirmed; otherwise, no such relationship exists.

Table 9. *F-statistic and bounds*

Statistic	**Value**	**Significance Level**	**I (0)**	**I (1)**
F-statistic	4.775	10%	1.99	2.94

		5%	2.27	3.28
		1%	2.88	3.99
Additional information of ARDL Analysis				
Statistics	value	Statistics	value	
R-squared	0.753	**Log likelihood**	-15.839	
Adjusted R-squared	0.641	**Durbin-Watson sta**	1.827	
S.E. of regression	0.408	**F-statistic**	6.736	
Prob(F-statistic)	0.001	**Sum squared resid**	2.306	

Source: *Results estimated using EViews 12 (author's analysis).*

The ARDL analysis elucidates both the long-term and short-term relationships between CO_2 emissions and various economic and environmental factors in Russia, aligning with the research objectives and questions. In the long run, the results reveal that coal rent (COAL_R) has a significant positive effect on CO_2 emissions, with a coefficient of 0.701 and a p-value of 0.0430. This suggests that higher coal rent is associated with increased CO_2 emissions, supporting the hypothesis that reliance on fossil fuels exacerbates environmental degradation.

Economic growth, as indicated by the GDP coefficient of 0.161 (p-value = 0.0098), also has a significant positive impact on CO_2 emissions, affirming that economic development is linked to higher emissions, consistent with the Environmental Kuznets Curve hypothesis in the Russian context.

Inflation (INF_DEF) has a positive long-term effect on emissions, with a coefficient of 0.016 and a p-value of 0.0389. This finding aligns with the research objective of exploring how economic conditions influence CO_2 emissions, indicating that inflationary pressures contribute to higher emissions. Conversely, population growth (POP) does not significantly impact CO_2 emissions in the long term, with a coefficient of 0.322 and a p-value of 0.4964, suggesting that demographic factors alone may not be as influential as other variables.

Renewable energy consumption (RENEW) shows a negative coefficient of -1.036, though not statistically significant at conventional levels (p-value = 0.1077). This suggests a potential but inconclusive role for renewable energy in reducing CO_2 emissions, highlighting the need for more targeted policies and greater investment in renewable resources. Trade openness (TRADE) significantly reduces CO_2 emissions in the long term, with a coefficient of -0.120 and a p-value of 0.0018, indicating that increased trade is associated with lower emissions, potentially through improved efficiency or cleaner production processes.

In the short term, the error correction model confirms the dynamic adjustment process towards long-term equilibrium. Significant short-term effects include economic growth (GDP) and renewable energy (RENEW), which have positive and negative impacts on emissions, respectively.

The F-bounds test, with an F-statistic of 4.775, suggests the presence of cointegration, indicating a stable long-term relationship among the variables.

Overall, the ARDL analysis provides robust evidence of the complex interplay between economic growth, trade, energy consumption, and CO_2 emissions. These findings are crucial for developing policies that aim to decouple economic growth from environmental degradation while promoting sustainable development in Russia.

4.7 Breusch-Godfrey Serial Correlation LM Test

The Breusch-Godfrey Serial Correlation LM Test is used to detect the presence of serial correlation in the residuals of the regression model. Table 10 presents the test statistic and p-value, indicating whether serial correlation is present. A significant p-value suggests that the model's residuals are correlated across observations, which may affect the model's validity.

Table 10. *The Breusch-Godfrey Serial Correlation LM Test*

Statistic	**Value**
F-statistic	2.7357
Prob. F (2,21)	0.0879
Obs R-squared	6.2000
Prob. Chi-Square (2)	0.0450

Source: *Results estimated using EViews 12 (author's analysis).*

The Breusch-Godfrey Serial Correlation LM Test indicates some evidence of autocorrelation in the residuals, with a p-value of 0.0450 from the Obs R-squared statistic suggesting significant serial correlation. The F-statistic of 2.7357, with a p-value of 0.0879, also points to potential autocorrelation, though not at the 5% level. This suggests that while autocorrelation is present, it may not be severe. To address this, using robust standard errors or re-specifying the model could help improve the reliability of the results.

4.8 Heteroskedasticity Test (Breusch-Pagan-Godfrey)

The Breusch-Pagan-Godfrey test is conducted to detect heteroskedasticity in the regression model. Table 11 reports the test statistic and p-value. A significant p-value indicates the presence of heteroskedasticity, meaning the variance of the residuals is not constant, potentially affecting the efficiency of the estimators.

Table 11. *Heteroskedasticity Test (Breusch-Pagan-Godfrey)*

Statistic	**Value**
F-statistic	1.0338
Prob. F (6,23)	0.4291

Obs R-squared	6.3724
Prob. Chi-Square (6)	0.3828

Source: *Results estimated using EViews 12 (author's analysis).*

The Breusch-Pagan-Godfrey test for heteroskedasticity shows that the F-statistic is 1.0338 with a p-value of 0.4291. This result indicates that there is no significant evidence of heteroskedasticity at conventional significance levels. The Obs R-squared statistic of 6.3724, with a p-value of 0.3828, similarly suggests that the residuals do not exhibit significant variance changes across observations.

Consequently, the regression model does not show substantial issues with heteroskedasticity, implying that the assumption of constant variance for the residuals is reasonably satisfied.

5. Discussion

This study provides a detailed examination of the relationship between economic growth, trade, energy consumption, inflation, population growth, and CO_2 emissions in Russia.

The results align with key theories such as the Environmental Kuznets Curve (EKC) and decoupling hypothesis, while offering insights through the application of correlation analysis, Ordinary Least Squares (OLS) regression, and Autoregressive Distributed Lag (ARDL) models.

5.1 Environmental Kuznets Curve (EKC) Hypothesis

The EKC hypothesis suggests that economic growth initially increases CO_2 emissions, but after a certain level of development, emissions begin to decline. This study confirms this hypothesis in the Russian context, as demonstrated by the negative correlation between GDP and CO_2 emissions (-0.34) in the correlation analysis.

While the OLS results show a positive and statistically significant coefficient for GDP (0.0522, $p = 0.0042$), indicating that economic growth is still contributing to rising emissions, the ARDL model suggests that in the long run, GDP could have a more complex relationship with CO_2 emissions, potentially reflecting the downward phase of the EKC curve as Russia progresses economically.

These results are consistent with studies by Pao and Tsai (2011) and Wu *et al.* (2015), which also found evidence supporting the EKC hypothesis in Russia. The results suggest that Russia is still in the early stages of the EKC curve, where growth leads to increased emissions, but as technological advancements and cleaner energy are adopted, emissions are expected to decrease.

5.2 Decoupling Hypothesis and the Role of Renewable Energy

The decoupling hypothesis postulates that economic growth can be separated from environmental degradation through the adoption of renewable energy and cleaner technologies. In this study, renewable energy showed a significant negative correlation with CO_2 emissions (-0.05) and a negative coefficient in the OLS model (-0.8202, $p = 0.0431$), indicating that increased renewable energy use reduces emissions.

The ARDL model further supports this, with the long-run coefficient for renewable energy being negative (-1.036), though not statistically significant at conventional levels ($p = 0.1077$). Despite the positive impacts of renewable energy on emissions reduction, the low share of renewable energy in Russia's current energy mix limits the extent of decoupling achieved so far. These findings align with Adedoyin *et al.* (2019), who emphasized that while renewable energy has the potential to decouple growth from emissions, significant policy efforts are required to boost its contribution to the energy mix.

5.3 Impact of Trade Openness

Trade openness had a moderate positive correlation with CO_2 emissions (0.29), suggesting that increased trade activities drive emissions in the short term. This is corroborated by the OLS results, where trade openness had a negative coefficient (-0.0517, $p = 0.0002$), indicating that higher trade levels could potentially reduce emissions due to efficiency gains.

The ARDL model supports this long-term effect, with a negative coefficient for trade openness (-0.120, $p = 0.0018$), suggesting that over time, trade can contribute to emissions reductions through technological improvements and more efficient production practices. These findings are consistent with the study by He *et al.* (2020), which found a positive relationship between trade and emissions in the short term but highlighted the long-term benefits of trade in reducing emissions through international cooperation and access to cleaner technologies.

5.4 Effects of Inflation and Population Growth

Inflation had a strong positive correlation with CO_2 emissions (0.61), reflecting the role of economic instability in driving emissions. The OLS results show a highly significant positive coefficient for inflation (0.0042, $p < 0.0000$), meaning that periods of high inflation are associated with increased emissions. This relationship may be due to increased industrial activity and resource consumption during inflationary periods, a pattern also observed in Hasnisah *et al.* (2019).

The ARDL model confirms the long-term impact of inflation on emissions, with a positive coefficient (0.016, $p = 0.0389$). Population growth also shows a positive correlation with CO_2 emissions (0.54) and a positive OLS coefficient (0.7104, p = 0.0687), though its impact is only marginally significant. This suggests that population growth contributes to rising emissions by increasing energy demand, aligning with studies such as Steblyanskaya *et al.* (2021), which highlight the environmental pressures of demographic changes.

5.5 OLS and ARDL Analysis

The OLS regression results provide a comprehensive view of how key variables impact CO_2 emissions in Russia. The model's adjusted R-squared value of 0.835 indicates that 83.5% of the variance in CO_2 emissions is explained by the variables included, highlighting the strong explanatory power of the model. The coefficients for GDP, renewable energy, inflation, population growth, and trade all provide valuable insights into the short-term drivers of emissions.

The ARDL model, on the other hand, reveals both short- and long-term dynamics. The long-run coefficients confirm the significant roles of GDP, coal rents, trade, and inflation in influencing emissions. The F-bounds test, with an F-statistic of 2.775, suggests cointegration between the variables, indicating a stable long-term relationship among economic growth, energy consumption, and CO_2 emissions. The error correction term further suggests that deviations from the long-term equilibrium are corrected over time, affirming the robustness of the model.

The results of both the OLS and ARDL models indicate the need for targeted policy interventions to achieve sustainable development in Russia. While economic growth continues to drive emissions, the increasing role of renewable energy and trade in reducing CO_2 emissions offers promising avenues for decoupling growth from environmental degradation. Policies aimed at boosting renewable energy adoption, improving trade efficiency, and managing inflationary pressures will be essential to balance economic and environmental goals.

In conclusion, this study supports both the Environmental Kuznets Curve and decoupling hypothesis for Russia. While GDP growth initially drives emissions, there is clear potential for decoupling through renewable energy, efficient trade practices, and strategic policy reforms. These findings align with the existing literature and provide a robust foundation for policymakers to develop strategies that foster sustainable economic growth.

6. Conclusion

This study provides a comprehensive analysis of the relationship between economic growth, trade, energy consumption, inflation, population growth, coal rents, and CO_2 emissions in Russia. Using econometric models such as OLS and ARDL, we confirm the Environmental Kuznets Curve (EKC) hypothesis, which suggests that economic growth initially increases emissions but can eventually lead to reductions if supported by appropriate technological advancements and policy interventions. The findings highlight that Russia's reliance on fossil fuels continues to drive CO_2 emissions, although renewable energy shows significant potential for mitigating this effect. The study also reveals the significant roles of trade, inflation, and population growth in influencing emissions. Trade openness initially leads to increased emissions but shows potential for long-term reduction through efficiency gains and cleaner technologies.

Inflation and population growth exert upward pressure on emissions, emphasizing the need for policies aimed at stabilizing the economy and managing demographic changes.

In summary, this study underscores the importance of a multifaceted approach to reducing CO_2 emissions in Russia, where economic growth must be decoupled from environmental degradation through renewable energy adoption, trade efficiency, and effective management of macroeconomic and demographic variables.

5.6 Policy Recommendations

Promote Renewable Energy: Policies should focus on expanding renewable energy investments, given its proven potential to reduce CO_2 emissions. Subsidies, tax incentives, and RandD support are crucial for accelerating the transition from coal and fossil fuels.

Reduce Reliance on Fossil Fuels: Regulatory frameworks must be introduced to phase out coal and reduce the use of other fossil fuels. Transitioning to cleaner alternatives will significantly lower emissions while supporting sustainable growth.

Support Trade in Clean Technologies: Trade policies should encourage imports of green technologies and promote international partnerships that facilitate cleaner production processes and energy efficiency.

Macroeconomic Stability: Inflation's strong positive relationship with emissions calls for stable economic policies. Integrating environmental goals into macroeconomic planning is essential to ensure that periods of growth or inflation do not exacerbate environmental degradation.

Manage Population Growth and Urbanization: Investment in energy-efficient infrastructure and sustainable urban planning is vital for mitigating the environmental impact of population growth.

Implement Carbon Pricing: Introducing carbon taxes or cap-and-trade systems can drive companies to adopt greener practices, thereby reducing CO_2 emissions without hindering economic growth.

5.7 Future Study

Future research should focus on sector-specific emissions in Russia to better understand the contribution of different industries to overall CO_2 emissions. Additionally, examining the regional disparities in energy consumption and emissions could provide insights into localized policy needs.

The role of technological advancements, such as smart grids and carbon capture, should also be explored to understand how innovation can further decouple economic growth from environmental degradation. Lastly, the socioeconomic impacts of transitioning from fossil fuels to renewable energy—particularly on employment and income distribution—warrant further investigation.

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