Validation of The Environmental Kuznets Curve Hypothesis And Role of Carbon Emission Policies In The Case of Russian Federation

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Abstract

Climate change currently observed and expected in the future is associated with risks to security and sustainable development as well as natural and irreversible consequences. To minimize these risks, it is necessary to adapt the public administration, economic sectors, and regional infrastructure to the changing climate conditions. This paper discovers the links between CO₂ emission and their key determinants such as economic growth, energy consumption, population, trade openness, and financial development for the Russian Federation using data from 1990 through 2020. Findings reveal that energy consumption, and population have a positive impact on CO₂ emissions, while economic growth, financial development, and trade openness has been found to decrease CO₂ emissions in the long term. The results of the paper show that there is a "U" shaped relationship between CO₂ emissions and economic growth in the Russian Federation. This shows that EKC is valid up to a certain income level in the Russian Federation and when this income level is exceeded, a positive relationship will begin between economic growth and environmental degradation.

Keywords: *Environmental Kuznets Curve, carbon emission, economic growth, energy consumption, population, trade openness, financial development.*

1. Introduction

With the start of the industrial revolution, technological developments accelerated and investments increased and a growth in the income levels of the countries was observed. However, as a result of increasing energy use -especially the consumption of fossil fuels- environmental changes and degradations has started. Since the primary goal of the countries is economic growth and development, the negativities that have arisen have been ignored. Conversely, rising worldwide warming and ecological pollution in the 1960s expose the significance of this topic and principal to the questioning of the relationship between economy and ecological pollution (Balado-Naves, et al. 2018: 266). Furthermore, energy is a strong input for enabling economic growth but it also exerts adverse environmental consequences.

However, the use of renewable and clean energy resources is often linked with environmental improvement while fossil fuel consumption is usually alleged to hamper environmental well-being (Kanat, 2021: 2).

Russian Federation is the fourth country to contribute to carbon dioxide (CO₂) emissions the entire world, after China, the United States (US), and India, respectively, although Russian Federation has signed the Kyoto Protocol and adopted the Paris Agreement (Ketenci, 2018: 250). In 2020, CO₂ emissions in Russian Federation amounted to approximately 1.48 billion metric tons of CO₂, making a decrease relative to the previous year but emissions of the Russian Federation are expected to continue rising until 2030 due to the geographical location and the characteristics of the climate and fossil fuels still make up 90% of Russian Federation energy mix (e.g. power, heat, transport, etc.). Russian Federation's emissions dropped by 41% between 1990 and 1998 but increased by 15% between 1998 and 2017 (Climate Transparency, 2020). The carbon zero target of the Russian Federation is 2060.

CO₂ emissions have been extensively studied at national and regional scales, and most research emphasizes on the link between CO₂ emissions and possible impact factors, including economic growth, population, energy consumption, energy intensity, and industrial structures. While some researchers have studied national groups such as Gulf Cooperation Council (GCC) countries (Ansari et al. 2020; Alsamara et al. 2018; Beck and Joshi, 2015; Salahuddin and Gow, 2014), Organization for Economic Cooperation and Development (OECD) countries (Isik et al. 2021; Leal and Marques, 2020; Iwata et al. 2012) and the Middle East and North Africa (MENA) countries (Cheikh et al. 2021; Gorus and Aslan, 2019; Abdallh and Abugamos, 2017; Al-Rawashdeh et al. 2014) and so on. Some researchers also have investigated a specific country. Conversely, the link between economic growth and greenhouse gas emissions in Russian Federation has rarely been studied. Russian Federation is rich in natural resources, which has made Russian Federation a typical resource-based economy country. In addition, there is a conflict between the Russian Federation's economic development and greenhouse gas emission reduction (Yang, et al. 2017: 163). Therefore, examining the relationship between greenhouse gas emissions related to the economy and Gross Domestic Product (GDP) in Russian Federation has important implications both in theory and in practice.

The presented study aims to investigate empirically factors (population, GDP per capita, energy consumption, trade openness, and financial development) affecting CO₂ emissions per capita in the Russian Federation during the period of 1990-2020. Furthermore, this paper scrutinizes validation of the Environmental Kuznets Curve (EKC) hypothesis for the Russian Federation that contributes to CO₂ emission policies.

The contribution of the present paper to the previous literature is manifold. Firstly, this study is the first attempt, to the best of our knowledge, that analyse the validity of the EKC hypothesis for a selected long-term dataset time interval (covering the period 1990-2020) and various data Russian Federation. Second, existing studies on Russian Federation largely look at the CO₂ emission impact of economic growth and energy consumption, the current paper also includes trade openness and financial development variables which are important in developing countries. Third, the current paper includes more recent and up-to-date observations compared to previous studies in the literature.

The rest of the present study is as follows: The following section assessments empirical papers in the literature. The third section presents the methods applied in the paper and empirical results are outlined as well. The discussion and conclusion on policy implications are performed in the following part.

2. Literature Review

The reduction in emissions is explained by several of factors, such as changes in household consumption, the effectiveness of environmental policies, and important changes in the economy resulting from technological modernization (Gavrilyeva et al. 2020). Therefore, the relationship between a nation's economic development and its CO₂ emissions is regarded as empirically significant. There are several methods to scrutinize the link between economic growth and CO₂. The EKC model, which is one of these methods, is well developed and widely used in investigating the economy-emissions relationship (Youssef et al. 2020; Brown and McDonough, 2016; Yang et al. 2015). In this study, unlike other studies, the EKC hypothesis was verified with more specific and extensive data, and the findings were compared with the EKC studies in the literature.

Generally, research shows that the inverse U-shaped link between economic growth and CO₂ is valid. From recent studies, Salari et al. (2021) assess the link

between CO₂ emissions, energy consumption, and economic growth GDP at the state level in the US between 1997 and 2016. The findings show an inverted U-shaped link between CO₂ emissions and GDP, providing sufficient evidence to confirm the EKC hypothesis across states. Similarly, AlZgool et al. (2020) display that the EKC hypothesis is effective for Bahrain as there is an encouraging link between economic growth and CO₂ emissions and the square of economic growth has an adverse impact on CO₂ emissions.

The EKC test for various countries and regions shows that this hypothesis is not always valid. To a large extent, this is determined by the length of time intervals analyzed and by national and regional characteristics (Friedl and Getzner, 2003). For example, Lantz and Feng (2006) calculations over 30 years (1970–2000) revealed no correlation between emissions and GDP for the five Canadian regions. Similarly, Baek (2015) discovered that the EKC hypothesis was not acceptable for Arctic countries between 1960 and 2010. Economic growth only has a beneficial effect on the environment in some Arctic countries. Finally, energy consumption has been discovered to have a negative impact on CO₂ emissions in most countries.

In Russian Federation, where the link between economic growth and greenhouse gas emissions is rarely examined, some studies found the EKC hypothesis valid, while others found it invalid. Of the studies that specifically investigated Russian Federation, Yang, et al. (2017) tested the inverted U-shaped link between GDP per capita and greenhouse gas emissions linked to the economy per capita. The findings encouraged the EKC hypothesis for Russian Federation. This result is also supported by Burakov (2019); Bass et al. (2019); Ketenci (2018); Rudenko and Skripnuk (2016), their results are coherent with the EKC hypothesis and valid for Russian Federation. Differently, Pao et al. (2011) analysed the inverse U-shaped relationship between CO₂ emissions, energy consumption, and economic growth in Russian Federation from 1990 to 2007 and found that CO₂ emissions decrease as GDP increases when energy consumption is adjusted, and the EKC hypothesis is not acceptable for Russian Federation. This idea is supported by Rustemoglu and Andrés (2016) in their study by investigating Russian Federation and Brazil, they indicated that changes in CO₂ emissions from 1992 to 2011 in Russian Federation were affected by economic activities, but a decoupling also emerged between GDP and CO₂ emissions.

3. Data and Method

3.1. Data

In this paper, the acceptability of the EKC hypothesis in the Russian Federation was investigated for the years 1990-2020 by tested with the time series analysis method within the scope of the EKC hypothesis. At this point, we would like to emphasize that with the disintegration of the Union of Soviet Socialist Republics (USSR) in 1991, the Russian Federation economy began a radical transformation. For the Russian Federation economy, which experienced an acute financial crisis in 1998, serious economic reforms have been made since the 2000s (Shumkov, 2010).

The variables used for analysis, as well as their definition, unit of measurement and sources are presented in Table 1 and all variables are stated in natural logs.

Table 1: Description of the Variables Used for Analysis

Variables	Definition	Unit of measurement	Sources
CO ₂	Carbon Dioxide Emission per capita	Tons CO ₂ per capita	IEA
GDP	Gross Domestic Product per capita	PPP current international US\$	World Bank
EC	Energy consumption	Kilowatt-hours	World Bank
TO	Trade openness	BoP, current US\$	World Bank
FD	Financial development index	Percentage (index)	IMF
POP	Population	Million	Statista

CO₂ is the log of total CO₂ emission from the consumption of fossil-based sources such as oil, natural gas, and coal gas measured tons per capita. GDP is the log of the GDP measured in per capita as an indicator of economic development. Similarly, GDP² is the log of the square of the GDP measured in PPP (Purchase Power Parity) current international dollar.

EC is the log of total energy consumption measured in per capita kilowatt-hours. EC variable includes oil, coal, gas, renewable energy, and nuclear power generation. When the literature is reviewed, many studies certainly prefer the data of energy consumption to strengthen the EKC model (Amri, 2018; Shahbaz et al. 2013a), since a large proportion of total energy consumption is composed of fossil fuels, and its inclusion is not surprising given the obvious harmful effects of fossil

fuels on the environment. Furthermore, some obstacles are effective in the high CO₂ emission due to the presence and excess of energy consumption, especially fossil-based energy sources. For instance, the fact that weather conditions in Russian Federation are incomparable to many countries (e.g. many USA states and EU countries, Turkey) and the low air temperature is increases the energy consumption (Cruz Rios et al. 2017). In addition, Russian Federation ranks first in the world's natural gas reserves (Marshintsev and Gadiyatov, 2021) and therefore natural gas use in the country is cheap. This is another important obstacle to the transition to zero CO₂ emission renewable energy sources.

TO is the log of the sum of export and imports of total goods and services as an indicator of the trade openness, which measures the balance of payment (BoP) in the current US dollar. Grossman and Krueger (1991) discuss that trade openness is linked to three main thoughts. These are scale effect, composition effect, and technical effect. The first two effects would be anticipated to have adverse impact on the environment in a developing country. The technical impact is assumed to contribute to the protection of the environment. The comparison of trade openness with the countries (China, Netherlands, and United Kingdom (UK)) to which the Russian Federation exports the most in 2020 is as in Figure 1 below.

Figure 1: Trade Openness: Export Plus Imports as Percent of GDP

Source: World Bank, (2021), <https://www.theglobaleconomy.com/compare-countries/>, Access Date: 15.12.2021.

As seen in Figure 1, the trade openness of China, the Russian Federation, and the UK is very similar and close, while the trade openness of the Netherlands is different from these countries. The reason for including trade openness in our variables is to reveal that trade openness increases or decreases environmental pollution for the Russian Federation. For example, Aydın and Turan (2020) find in their study that trade openness reduces environmental pollution in China and India, and increases it in South Africa. Conversely, Jalil and Feridun (2011) discover that trade openness has an increasing effect on CO₂ emissions for China. Similarly, Farhani and Ozturk, (2015) obtain that a 1% increase in trade openness raises CO₂ emissions by 0.418% in the long term for Tunisia.

FD is financial development measure and analyses the factors enabling the development of the financial system. To represent which financial development, the financial development index created by Svirydzenka (2016) within the International Monetary Fund was used. Financial development can have various effects on CO₂ emissions. Primary, there is evidence in the literature that financial development promotes to economic growth by increasing foreign direct investment (FDI) (Nasir et al. 2019) and improving the equity and credit market (Hsu et al. 2014), which means easier access to credit for stockholders and customers (Zhang 2011). Higher economic growth needs more energy consumption and can contribute to CO₂ emissions (Pao and Tsai, 2011). Also, financial development can support companies' access the more funds to invest in ecologically friendly technologies and projects that reduce CO₂ emissions (Shahbaz et al. 2013b). For Russian Federation, Haseeb et al. (2018) find that financial development plays a significant role in decreasing the level of CO₂ emissions in Russian Federation. Similarly, Bass (2019) finds that the financial sector is an essential factor of CO₂ emissions in the Russian Federation. Therefore, including the financial development data in the model is essential to increase the validity of the EKC hypothesis for the Russian Federation. Furthermore, we would also like to emphasize that Russian Federation has never been a popular Financial Direct Investment (FDI) destination by western countries. The latest data show that FDI flows into Russian Federation decreased from \$32 billion in 2019 to \$10 billion in 2020 with down 70%, and this has had an influence on the Covid-19 pandemic as well (UNCTAD World Investment Report, 2021).

POP is the log of the population measured in millions. Studies on population growth and EKC emphasize that population growth shifts the EKC curve upward,

causing deforestation, and that the negative environmental impact is greater with population growth (Wang et al. 2015; Culas, 2007).

Largely, previous studies testing the EKC hypothesis have used only pollutant emissions, economic development, and energy consumption (Jun et al. 2021; Yusuf et al. 2020; Zhang et al. 2019; Alege et al. 2016; Ozcan, 2013; Pao and Tsai, 2010), while some studies have considered new variables such as electricity consumption (Saint Akadiri et al. 2020; Cowan et al. 2014; Akpan and Akpan, 2012), trade openness (Koc and Bulus, 2020; Mahmood et al. 2019; Ozatac et al. 2017), financial development (Amri, 2018; Jamel and Maktouf, 2017; Shahbaz et al. 2013a), renewable/non-renewable energy/electricity production (Chen et al. 2019; Bento and Moutinho, 2016), oil prices (Erdogan et al. 2020; Balaguer and Cantavella, 2016), population (Liu et al. 2015; Begum et al. 2015), urbanization (Salim et al. 2019; Hanif, 2018; Pata, 2018), and corruption (Balsalobre-Lorente, 2019; Sekrafi and Sghaier, 2018).

3.2. Method

The EKC hypothesis suggests that ecological pollution growth in the initial periods of economic development. According to the EKC hypothesis, it assumes that as the welfare level of a country increases, environmental pollution will increase and after a certain income, income increase will contribute positively to environmental quality (Karaca, 2012: 143). The current study scrutinizes the link between ecological pollution and economic development in Russian Federation including the period from 1990-2020 and the basic EKC hypothesis is formulated as follows Equation (1):

$$CO_{2t} = f(GDP_t, GDP_t^2, EC_t, TO_t, FD_t, POP_t) \quad (1)$$

In Equation (1), CO_{2t} states the CO₂ emission per capita, GDP_t , and GDP_t^2 states GDP per capita and its square, respectively. EC_t states energy consumption, TO_t states trade openness, FD_t states financial development and POP_t indicates population. All data used in the study are at the annual frequency and all are included in the analysis in logarithmic form. Thus, the log linear-quadratic model formulated is shows in Equation (2).

$$\ln CO_{2t} = \beta_0 + \beta_1 \ln GDP_t + \beta_2 \ln(GDP_t^2) + \beta_3 \ln EC_t + \beta_4 \ln TO_t + \beta_5 \ln FD_t + \beta_6 \ln POP_t + \varepsilon_t \quad (2)$$

According to Equation (2), t denotes time and means that the natural logarithm of the relevant variable is taken. The possible results of the model expressed in Equation 2 within the scope of EKC are as follows (Dinda, 2004: 431).

- I.** $\beta_1 = \beta_2 = 0$, There is no link between CO₂ and income.
- II.** $\beta_1 > 0$ and $\beta_2 = 0$, The link between CO₂ and income is linear.
- III.** $\beta_1 < 0$ and $\beta_2 = 0$, The link between CO₂ and income is negative.
- IV.** $\beta_1 > 0$ and $\beta_2 < 0$, The link between CO₂ and income is “inverted U” and the EKC is acceptable.

For the EKC to be valid, there must be an "inverted U" link between CO₂ and economic growth (Allard et al. 2018: 5848). When the EKC hypothesis is approved, the turning point in which environmental pollution decreases, the level of GDP per capita, $GDP^* = -\beta_1/2\beta_2$ and the turning point is the monetary value representing that point. However, Iwata et al. (2012) argued that the turning points of developing countries can be outside the sample period and that environmental pollution continues to increase with economic growth in developing countries.

Cointegration tests are performed to examine the long-term relationship between the variables. For cointegration, the Engle and Granger (1987), Johansen and Juselius (1990) tests are pioneering and frequently used. However, an important limitation of these tests is that the variables must be equally stationary. Therefore, this paper was conducted by Pesaran et al. (2001) ARDL bounds test approach has been applied and this approach allows to determine the cointegration relationship between variables with different levels of stationarity. The ARDL bounds test was performed using Equation (3), which shows the unbounded error correction model (UECM) by applying the Wald test.

$$\begin{aligned} \Delta \ln CO_{2t} = & \beta_0 + \sum_{i=1}^a \beta_{1i} \Delta \ln CO_{2t-i} + \sum_{i=0}^b \beta_{2i} \Delta \ln GDP_{t-i} + \\ & \sum_{i=0}^c \beta_{3i} \Delta \ln (GDP_{t-1})^2 + \sum_{i=0}^d \beta_{4i} \Delta \ln EC_{t-i} + \sum_{i=0}^e \beta_{5i} \Delta \ln TO_{t-i} + \\ & \sum_{i=0}^f \beta_{6i} \Delta \ln FD_{t-i} + \sum_{i=0}^g \beta_{7i} \Delta \ln POP_{t-i} + \delta_1 \ln CO_{2t-1} + \delta_2 \ln GDP_{t-1} + \\ & \delta_3 \ln (GDP_{t-1})^2 + \delta_4 \ln EC_{t-1} + \delta_5 \ln TO_{t-1} + \delta_6 \ln FD_{t-1} + \delta_7 \ln POP_{t-1} + u_t \end{aligned} \quad (3)$$

In Equation (3), β_0 denotes the constant term; Δ denotes the difference operator, u_t denotes the error term, $\beta_1 \dots \beta_7$ denote the short-term coefficient, $\delta_1 \dots \delta_7$ denote long-term coefficient. The letters a, b,.....g denote the optimal lag

lengths. The model allows the determination of separate lag lengths for each variable, and the null hypothesis ($H_0: \beta_0 = \delta_1 = \dots = \delta_7 = 0$) stating that there is no cointegration link between the variables and the alternative ($H_0: \beta_0 \neq \delta_1 \neq \dots \neq \delta_7 \neq 0$) is being created.

The ARDL method gives better results with small sample sizes when compared to other traditional cointegration tests (Nkoro and Uko, 2016: 63). The state of the cointegration link between the variables is interpreted by comparing the F test statistic with the critical values. The F statistic above the upper critical value is considered as the presence of cointegration, and the F statistic less than the lower critical value is considered as an indication of the absence of cointegration. The short-term dynamics are determined by Equation (4), which is established after the determination of the cointegration relationship:

$$\begin{aligned} \Delta \ln CO_{2t} = & \lambda_0 + \sum_{i=1}^h \lambda_{1i} \Delta \ln CO_{2t-i} + \sum_{i=0}^j \lambda_{2i} \Delta \ln GDP_{t-i} + \\ & \sum_{i=0}^k \lambda_{3i} \Delta \ln (GDP_{t-1})^2 + \sum_{i=0}^l \lambda_{4i} \Delta \ln EC_{t-i} + \sum_{i=0}^m \lambda_{5i} \Delta \ln TO_{t-i} + \\ & \sum_{i=0}^n \lambda_{6i} \Delta \ln FD_{t-i} + \sum_{i=0}^o \lambda_{7i} \Delta \ln POP_{t-i} + \tau ECT_{t-1} + u_t \end{aligned} \quad (4)$$

In Equation (4), λ_0 represents the constant term, $\lambda_1 \dots \lambda_7$ represents the short-term coefficient; τ shows the coefficient of the error correction term (ECT). If the ECM coefficient is between 0 and -1, there is a direct convergence to the long-term equilibrium value. If the ECM coefficient is between -1 and -2, it is interpreted that the error correction process proceeds in the form of decreasing fluctuations around the long-term balance. If the coefficient is positive or greater than -2, it indicates that the equilibrium has been moved away (Alam and Quazi, 2003: 97; Narayan and Smyth, 2006: 335). Lastly, the stability of the model was checked operating the CUSUM and CUSUMSQ tests suggested by Brown et al. (1975). The CUSUM and CUSUMSQ tests are suitable for time series data and can be used when it is uncertain when a structural break has occurred (Yoo, 2005: 1630).

3.4. Empirical Findings

Firstly, the augmented Dickey-Fuller (ADF) test developed by Dickey and Fuller (1979) and Philips Perron (PP) test is used to check the stationarity of the variables. In addition, the unit root test developed by Zivot and Andrews (2002) was

used to determine the stationarity of the variables more reliably, which stated that the ADF test would give more reliable results with a single internal structural break. Unit root tests were applied to the level and first difference values of each variable, respectively. The findings are presented in Table 2 and Table 3.

Table 2: ADF and PP Unit Root Test Results

Variables	ADF				PP			
	I(0)		I(1)		I(0)		I(1)	
	Constant	Constant + Trend	Constant	Constant + Trend	Constant	Constant + Trend	Constant	Constant + Trend
GDP	0.4107	-3.9186**	-2.7030**	-2.5984***	-0.1417	-2.4388	-2.7030*	-2.5984**
GDP ²	0.4466	-3.8688**	-2.7598*	-2.6567	-0.0961	-2.4365	2.7598*	-2.6567
EC	-2.9282*	-2.8560	-2.6426**	-2.6180**	-2.7430*	-2.8560	-2.6043**	-2.6180**
TO	-1.8565	-0.7233	-4.7548***	-5.2334***	-2.0015	-0.9470	-4.4149***	-9.6007***
FD	-1.6406	-2.0084	-6.0588***	-5.8867***	-1.6690	-2.1201	-6.0265***	-5.8644***
POP	-0.2562	-3.3983*	-2.9821**	-2.1362**	-1.1787	-0.9557	-4.0016***	-3.2565***
CO ₂	-5.0405***	-4.5341***	-3.7833***	-4.5330***	-4.6747***	-5.6063***	-3.7316***	-4.6709***

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels, correspondingly.

According to the ADF and PP unit root test findings in Table 2, it is seen that the variables are stationary at different degrees. It was confirmed by both unit root tests that the CO₂ and energy consumption variables were stationary at the level, while the other variables were stationary at the first difference. Since the variables are stationary at different levels, it is appropriate to use the ARDL bounds test to find long-run relationships.

Table 3: ZA Unit Root Test Results

Variables	I(0)		I(1)		Critical Value		
	Model A	Model C	Model A	Model C	1%	5%	10%
GDP	-5.230483 (2006)*	-6.072760 (2008)**	-	-	-5.34	-4.93	-4.58
GDP²	-5.230483 (2006)*	-3.688048 (2014)**	-	-	-5.34	-4.93	-4.58
EC	-6.289674 (2010)	-7.155943 (2012)	-5.942081 (2010)***	-6.866678 (2012)***	-5.57	-5.08	-4.82
TO	-8.061211 (1999)***	-7.863766 (1999)***	-	-	-5.57	-5.08	-4.82
FD	-3.642614 (1999)***	-4.181533 (1999)**	-	-	-5.34	-4.93	-4.58
POP	-7.967528 (1999)***	-7.776862 (1999)**	-	-	-5.34	-4.93	-4.58
CO₂	-3.455754 (2004)	-3.146150 (2006)	-5.323842 (2003)***	-4.604411 (2015)*	-5.34	-4.93	-4.58

*Notes: ***, ** and * indicate 1%, 5% and 10% significance levels, correspondingly. Zivot-Andrews' (1992) critical values were used for the ZA test.*

As seen in the ZA test results, it was concluded that while the CO₂ and energy consumption (EC) variables were stationary I(1), the GDP, GDP², trade openness, financial development, and population variables were stationary I(0) at the level. It has been determined that Model C is suitable for CO₂ and GDP variables and Model A is suitable for GDP², TO, FD, POP, and EC variables. The fact that the test statistic is greater than the critical values means that the H₀ hypothesis, which argues that the series contains a unit root without a structural break, is rejected. Therefore, the break dates do not have a permanent effect on the relevant variables.

In the study, a randomly selected lag interval containing the selected variables to determine the lag delay interval, and a Vector Auto-Regressive (VAR) model to scrutinise the lag interval were determined. The lag interval test results obtained are shown in Table 4.

Table 4: VAR Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	324.7306	NA	7.48e-21	-26.47755	-26.13396*	-26.38640
1	394.5348	93.07217*	1.59e-21	-28.21123	-25.46244	-27.48198
2	477.1100	61.93141	3.66e-22*	-31.00917*	-25.85518	-29.64181*

* Specifies lag order selected by the criterion

LR: sequential modified LR test statistic (each test at 5% level)

FPE: Final prediction error

AIC: Akaike information criterion

SC: Schwarz information criterion

HQ: Hannan-Quinn information criterion

As seen in Table 4, the appropriate lag length to be used to test the cointegration was chosen as VAR=2, because the appropriate lag length was decided as 2 since three different criteria point in this direction. In addition, AIC (Akaike Information Criteria), SC (Schwarz's Criterion) and HQC (Hannan-Quinn information criterion) information criteria were used to find the optimal lag lengths for the ARDL bounds test used for the cointegration connection between the 6 variables included in the study. AIC helps in selecting the maximum possible delay length, while SBC assists in selecting the minimum possible delay length. Table 5 shows the model summaries in the lag order selection criteria.

Table 5: Model Selection Summary

Model	AIC	SC	HQC
2, 2, 2, 2, 2, 2, 2	-5.467975	-4.437178	-5.194504
1, 1, 0, 0, 2, 0, 0	-5.065364	-4.533092	-4.912089
2, 2, 2, 0, 1, 0, 0	-5.315414	-4.637978	-5.120337

* Denotes lag order selected by the criterion.

As shown in Table 5 the lag length was selected as Model 2, 2, 2, 2, 2, 2, 2 because it had the lowest AIC and HQC values. The Bounds Test results for the long-term relationship are presented in Table 6.

Table 6: Bounds Test and Long-term Coefficients for the ARDL Model

k=6	Case II		Case III	
F-statistic	11.642600***		6.642600***	
Narayan Level	I(0)	I(1)	I(0)	I(1)
10%	1.99	2.94	1.99	2.94
5%	2.27	3.28	2.27	3.28
1%	2.88	3.99	2.88	3.99
Pesaran et al. (2001) Level	I(0)	I(1)	I(0)	I(1)
10%	2.25	3.38	-2.57	-3.86
5%	2.68	3.96	-2.86	-4.19
1%	3.71	5.32	-3.43	-4.79

*** shows significant at 1% level.

According to Table 6, the estimated F statistics for the selected model are significant at the 1% significance level for Case II and III. Since the F statistic is larger than the low critical values, the null hypothesis is rejected and the existence of cointegration is confirmed. The estimated long-term coefficients are displayed in Table 7.

Table 7: Long-term Coefficients for the ARDL Model

Variables	Coefficient	t- statistics	Diagnostic Test	F-statistics	P value
InGDP	-1.7596**	-3.1083	BG-LM Test	0.9349	0.4531
InGDP²	0.2879**	-3.1342	Ramsey Reset Test	0.0852	0.7743
InEC	1.0657***	6.5665	F Statistics	4.9112	0.003
InTO	-0.7163**	-2.2967	Jarque-Bera	0.3208	0.851
InFD	-0.0220***	-3.4218	White Test	1.344051	0.3616
InPOP	4.2365**	2.0389	Model Standard Deviation	0.0284	
C	0.0024	0.6024	Durbin Watson Value	1.9597	

			R²	0.7660
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*Notes: ***, ** and * indicate 1%, 5% and 10% significance levels, correspondingly.*

In the long-term ARDL model estimated in Table 7, energy consumption, and population raise CO₂ emissions while GDP, financial development and trade openness decreases CO₂ emissions in the long run. Additionally, the GDP coefficient was found to be -1.7596 in the model and $\beta_1 > 0$. The GDP² coefficient was 0.2879, and according to the EKC hypothesis, $\beta_1 < 0$. This indicates that the EKC is valid up to a certain income level in the Russian Federation, and when this income level is exceeded, a positive relationship will begin between economic growth and environmental degradation. It has been determined that there is a positive relationship between energy consumption and population and environmental pollution. 1% increase in energy consumption and population increases environmental pollution by 1.06% and 4.23%, respectively. In addition, there is a negative relationship between financial development and trade openness on environmental pollution. A 1% increase in financial development and trade openness reduces environmental pollution by 0.02% and 0.71%, respectively.

Two lag lengths are used in the estimated ARDL model. The autocorrelation problem was determined by the Breusch-Godfrey Serial Correlation LM Test and by the Ramsey-Reset test that the model had an appropriate functional form. The Jarque-Bera test showed that the error terms are normally distributed. Another step related to the ARDL cointegration test is the short-term analysis of the established model and the values related to the created model are reported in Table 8.

Table 8: Short-term ARDL Error Correction Model

Variables	Coefficient	t- statistics	Variables	Coefficient	t- statistics
$\Delta \ln GDP$	-5.2290**	-4.1147	$\Delta \ln FD$	0.0323	0.7586
$\Delta \ln GDP_{t-1}$	2.7458**	3.5028	$\Delta \ln FD_{t-1}$	0.1315**	3.0008
$\Delta \ln GDP^2$	0.2751**	4.1839	$\Delta \ln TO$	-0.0505**	-4.1040
$\Delta \ln GDP^2_{t-1}$	-0.1398**	-3.4958	$\Delta \ln TO_{t-1}$	0.02839*	3.2787
$\Delta \ln EC$	0.8514***	6.9870	$\Delta \ln POP$	-15.1608	-2.2284
$\Delta \ln EC_{t-1}$	-1.1929**	-3.6214	$\Delta \ln POP_{t-1}$	23.0065**	3.0630
ECT_{t-1}	-0.7682***	-6.6183	R²	0.97	

Notes: ***, **, * denote 1%, 5% and 10% significance levels, correspondingly.

$$ECT_{t-1} = \ln CO_2 - 1.7596 \ln GDP + 0.0879 \ln GDP^2 - 1.0657 \ln EC - 0.0221 \ln FD \\ - 0.7163 \ln TO + 4.2365 \ln POP + 0.0025$$

As seen in Table 7, it is seen that the test statistics for the model are appropriate. An important issue in short-term analysis is the error correction term. The error correction term should generally have a statistical value between “0” and “-1”. The error correction term of the established model is statistically significant and was found to be -0.7682. In other words, 97% of short-term deviations are corrected in the next period.

Finally, CUSUM and CUSUMQ tests were conducted to test the stability of the ARDL model and its long-run coefficients, in other words, to provide information about the incidence of structural breaks in the data set in general. CUSUM test indicates whether there is a structural break or not and CUSUMQ indicates the period of the break (Doguwa et al., 2014: 20). The interpretation of the related tests is that the curves obtained with the error terms test statistics are within the critical limits and if they are, the estimated parameters are stable. Figure 2 shows the CUSUM and CUSUMQ test charts.

Figure 2: CUSUM and CUSUMQ Plots for the ARDL Model

As seen in the CUSUM and CUSUMQ graphs, the fact that the curves are within the critical value band at the 5% significance level indicates that there are no structural breaks in the determined long-term relationship, and it can be interpreted that the parameters are significant. Furthermore, the outcomes of the CUSUM and CUSUMSQ tests show that the coefficients in the two ARDL models are stable.

4. Conclusion and Policy Implications

In this study, the acceptability of the EKC for the economy of the Russian Federation was tested with the 1990-2020 period data. In this framework, the ARDL cointegration test was applied within the framework of a quadric model. It was determined that the coefficients of the GDP, GDP² variables, which were taken into account to test the EKC hypothesis, were statistically significant.

According to findings, energy consumption, financial development, trade openness, population, GDP and its square are the most significant indicators of CO₂ emissions in the long term. A 1% raises energy consumption and population increases CO₂ emissions by 1.0657% and 4.2365%, correspondingly. A 1% increases in GDP, financial development and trade openness decreases CO₂ emissions by 1.7596%, 0.0220% and 0.7163%, correspondingly.

The analysis findings of the study showed the existence of a U-shaped link between economic development and CO₂ emissions, which does not approve the acceptability of the EKC hypothesis in the long term for the Russian Federation. It was determined that the coefficients of the GDP, GDP², variables, which were taken into account to test the EKC hypothesis, were statistically significant. However, it is seen that the relevant variables are marked (-), (+) respectively. This situation is not in line with the EKC and expresses a "U" link between the environment and economic growth. The same findings were obtained by Gavrielyeva et al. (2020) indicates that EKC hypothesis is not acceptable for Russian Federation. Furthermore, Rudenko and Skripnuk (2016) ensure little evidence to support the existence of EKC for the Russian Arctic areas. The contrary of a finding of Sohag et al. (2021), Burakov (2019), Bass et al. (2019), Ketenci (2018), Yang et al. (2017) find that EKC is valid for the Russian Federation. Among the studies conducted for BRICS countries, Aydin and Turan (2020) found that the EKC hypothesis is not valid for Russian Federation, but Ummalla and Goyari (2021), Ferreira et al. (2021), Erataş and Uysal (2014) find that EKC is acceptable for BRICS countries, as well Russian Federation.

The EKC hypothesis is valid up to a certain income level in the Russian Federation, and when this income level is exceeded, a positive relationship between economic growth and environmental degradation is predicted. While this is a positive result for the first stages of economic growth, it is an unacceptable result for the

advanced stages of economic growth within the framework of the EKC hypothesis. In the short-term relationship of the model established for the analysis, it is seen that the error correction mechanism works and its coefficient is statistically and significant. Most of the short-term deviations are corrected in the next period.

The other independent variable used in the study, energy consumption, has a significant effect on the findings. There is a positive and strong relationship between CO₂ emissions and energy consumption. The increase in energy consumption increases CO₂ emissions. While fossil-based energy sources are mostly used in energy consumption for the Russian Federation, the use of renewable energy is very limited.

In the scope of the obtained findings, some policy recommendations can be made for the Russian Federation. The Russian Federation should prefer the use of clean energy (renewable, nuclear, etc.) instead of fossil energy resources to decrease CO₂ emissions. In addition, various energy sources should be used in order to expansion the share of energy sources that do not emit carbon in total energy consumption and to increase energy use efficiency through advanced technologies. There is strong evidence that energy use has a devastating impact on CO₂ emissions, and financial development encouragingly influences ecological quality in the long term. Thus, policymakers should apply appropriate strategies concerning financial development.

The current study is important both in terms of national economy and environmental quality. Therefore, in future studies, it is essential to evaluate the issue from different dimensions with additional variables or to compare the current situation with other countries in order to reveal the effects of the policy applied and the changes made for the geography.

Furthermore, EKC hypothesis concentrated on the rise in the production level due to the economies of scale, together with the economic development, causes fast ecological pollution. When the income reaches a certain point, the process enters the recovery process (Dinda, 2004). However, this study found the relationship between CO₂ and income in a “U” shape. Therefore, future studies will focus on the question of *"What needs to be done for the CKE hypothesis to be valid for the Russian Federation?"*

507 **Ethics approval and consent to participate**

508 Not Applicable.

509

510 **Consent for publication**

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512

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522

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524 The datasets used and/or analyzed during the current study are available from the

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526

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