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The Russian Federation's renewable energy development determinants: evidence from empirical research

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Abstract

Purpose – The Russian Federation is one of the world's largest exporters of fossil-based energy sources such as oil, natural gas and coal. Approximately 90% of the energy production in the Russian Federation consists of oil, natural gas and coal. Renewable energy (RE) in the Russian Federation mainly comprises hydroelectric energy. The purpose of this paper is to identify the factors that influenced the growth of RE resources in the Russian Federation between 1990 and 2020.

Design/methodology/approach – The unit root tests augmented Dickey and Fuller and Phillips and Perron, as well as Johansen cointegration and Granger causality approaches, were used. This study was conducted using vector error correction models for the years 1990–2020.

Findings – The cointegration method's findings demonstrate that while a rise in non-RE sources has a negative impact on RE development, an increase in income, energy consumption, trade openness and CO_2 emissions has a favorable impact on RE expansion. The vector error correction model Granger causality test also shows a unidirectional relationship between RE and non-RE sources, gross domestic product, energy consumption and CO_2 emissions. Trade openness, on the other hand, has no causal association with RE.

Practical implications – The Russian Federation must consider the practical implications of RE sources. However, there is a greater need for the Russian Federation to frame sound energy policies for RE development.

Originality/value – This paper aims to fill a gap in the literature on Russian RE development. Furthermore, the results of the methodological analysis can be used to guide policymakers in the field of RE development. This paper is also more policy-relevant and is quite useful in the context of sustainable energy development.

Keywords Renewable energy consumption, Substitute and security factors, Economic and environmental factors, VECM model

Paper type Research paper

1. Introduction

In recent decades, several countries' national planning goals have included the increase of renewable energy (RE) sources. Many countries and international organizations now regard RE as a critical component of energy security, economic development, environmental protection and greenhouse gas emission reduction (Marques and Fuinhas, 2012; Johnstone *et al.*, 2010; Carley, 2009). The majority of the research on policies and other factors that

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influence RE deployment is qualitative and theoretical (Gan *et al.*, 2007; Wang, 2006; Bird *et al.*, 2005). The majority of qualitative and theoretical studies shows a favorable association between policy variables and the increase of RE resources (Wang *et al.*, 2019; Kilinc-Ata, 2016; Shrimali and Kniefel, 2011).

The Russian Federation used to be a leader in the expansion of RE technology, but for a variety of reasons/barriers, the Russian Federation has lost interest in RE development beyond hydropower. Its most recent goals have been the development of more traditional fossil fuel and nuclear power sources (Lanshina *et al.*, 2018). However, limited fossil fuel resources are depleting day by day at a time when the world's population and demands are quickly growing. Furthermore, the impact of fossil fuels on the environment and human health is becoming better understood. As a result of this predicament, the global energy sector has begun a new structural process for acquiring energy and has turned to RE sources as a substitute. However, the Russian Federation has yet to make sufficient headway in the field of RE (Karacan *et al.*, 2021). *Which factors play a role in the RE development of the Russian Federation?* The study is being carried out to discover an answer to this question because the Russian Federation requires RE policies that will allow it to compete on an equal footing in the future in terms of maintaining its current energy advantage.

The study adds to the literature in a variety of ways. First, this paper uses a longer time range of data than previous studies, and a more recently acquired data set allows researchers to gain the most up-to-date and critical insight into the factors that influence RE development in the Russian Federation. Furthermore, to our knowledge, there has never been an attempt to use this type of method, with specific explanation variables, over a lengthy period of time for the Russian Federation.

This paper reviews the Russian Federation's RE deployment, concentrating on RE potential, hurdles and policies in place to foster RE. Section 2 of the study examines RE in the Russian Federation, including its potential, constraints and policies. Section 3 contains the literature. Section 4 examines the factors that influence the growth of RE sources using an econometric methodology. Finally, there are some closing remarks in the last part.

2. Background-renewable energy context

2.1 Potential of renewable energy sources

The Russian Federation is frequently described as a country with high-energy efficiency and RE potential. Wind and solar electricity, hydropower (in small rivers) and biomass (vast regions covered with woods) are the most potential sectors for RE sources in the Russian Federation (Chebotareva *et al.*, 2020). The Russian Federation's development of RE has been governed by decree number 449 since mid-2013. Payments are paid to enterprises that produce energy from RE sources with a capacity of 5 MW–25 MW under a fixed tariff, 15-year contract. The benefits are contingent on purchasing 65%, 70% and 45% of the equipment for wind, solar and hydro project infrastructure from within the Russian Federation in 2016. Annual bids granted significantly more than 2 GW of renewable capacity between 2013 and 2016. From 2019 to 2024, competitive bidding for new RE capacity is scheduled at slightly over 313 MW, with the majority coming from hydroelectric capacity, 78 MW from wind and 5.6 MW from solar power (Pagliaro, 2020, p. 953). On January 1, 2021, hydro, solar and wind power made up 21.47% of the country's total installed capacity of around 245.31 GW. In other words, RE accounts for 20.14% of the total power generated in 2020 (1.047 billion kWh) (Heidemann and Bogdanov, 2021).

In 2018, the effects of newly constructed wind, solar and hydro power capacity on electricity output were observed, with wind power generation increasing by 69.2% and PV generation increasing by 35.7% in the Russian Federation. In 2018, the combined output of wind and solar PV surpassed 1 TWh. In addition, in 2018, the annual number of hours that the Russian Federation wind and solar PV parks generated energy at nameplate capacities was 1,602 and 1,283 h, respectively (Ministry of Energy of the Russian Federation, 2019). The Russian Federation's RE capacity throughout time is shown in Table 1.

As seen in Table 1, hydropower constitutes the majority of the RE resource capacity. Hydro energy is followed by bioenergy, solar energy and wind energy. While wind energy capacity has expanded dramatically since 2018, solar energy capacity has increased since 2016. Figure 1 shows a graphical representation of the distribution of RE sources.

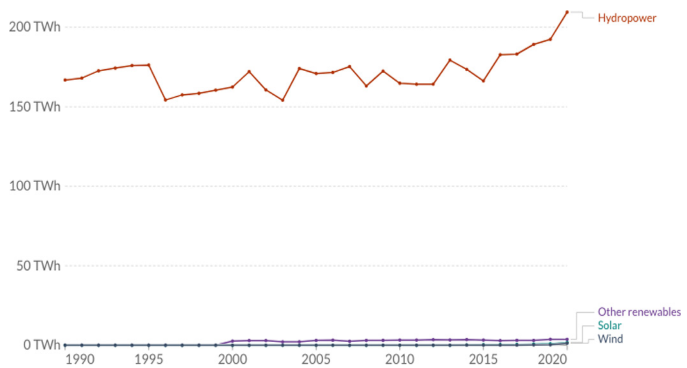
As seen in Figure 1, hydro energy is a main source of RE in the Russian Federation. The hydro energy capacity was 209.54 TW in 2020. Wind energy was initially used in 2000, and until 2013, the total capacity of wind energy was less than 0.01 TW. The amount of electricity generated by wind in 2020 was 1.34 TW. In 2011, solar energy was used for the first time, with a solar energy capacity of less than 0.01 TW. By 2020, the energy obtained from the sun increased to 1.67 TW, outpacing wind energy. Figure 2 depicts the percentage of RE sources in power generation.

As shown in Figure 2, the percentage of electricity generated from RE has fluctuated over time, but it was expected to reach around 20% in 2020. Indeed, the Russian

Year	Total	Hydro	Wind (Onshore)	Solar (PV)	Bioenergy	Geothermal
2011	47.553	47.479	10	0	1.197	81
2012	49.519	49.445	10	0	1.197	81
2013	50.177	50.104	10	1	1.197	79
2014	51.094	50.845	10	5	1.370	78
2015	51.304	50.998	11	61	1.370	78
2016	51.337	51.016	11	76	1.370	78
2017	51.709	51.241	11	225	1.373	74
2018	52.150	51.333	52	535	1.370	74
2019	53.074	51.819	102	1.064	1.370	74
2020	54.274	51.811	945	1.428	1.370	74

Source: IRENA (2021)

Table 1. Total renewable energy capacity in Russian Federation (MW)



Source: Our World in Data (2022)

Figure 1. Russian Federation renewable energy generation by sources (1990–2020)

Federation's aim of a 2.5% share of wind and solar energy in electricity generation by 2020 has not been realized, and the current ratio is 0.3%. The Russian Federation plans to reach 12 GW of RE capacity by 2035, and to do so, Russian authorities stated in June 2021 that they would grant state support to RE projects worth 360bn RUB (US$4.9bn) through 2035 (Enerdata, 2022).

2.2 Barriers to the development of renewable energy generation

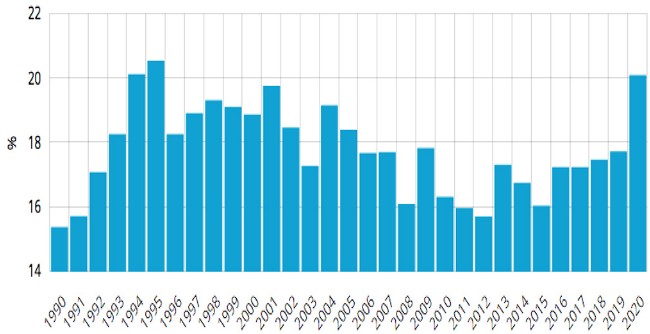
The energy industry of the Russian Federation is characterized by an abundance of fossil fuel resources. The Russian Federation is one of the world's top crude oil exporters and the world's largest natural gas exporter. The Russian Federation has long profited handsomely from the sale of oil and gas to Europe. As a result, Russian energy businesses and government agencies are hesitant to develop new sectors and technology (Lanshina *et al.*, 2018).

In addition, wind and solar energy are two of the most environmentally benign energy sources, and the Russian Federation is well suited to their utilization. However, the Russian Federation's development of wind and solar energy is constrained by the lack of sufficient and affordable electricity from nuclear and hydropower projects. There is currently no compelling reason for the Russian Federation to generate additional wind and solar energy because its current electrical supply system is based on gas, coal, hydro and nuclear energy. In particular, factors such as a lack of solar energy and high seasonal solar energy availability are effective (Chebotareva *et al.*, 2020; Panepinto *et al.*, 2017). Below list summarizes the challenges to the maturity of RE sources.

Main RE development barriers in the Russian Federation:

(1) Socio-cultural barriers:
- The development of the energy sector is in the hands of the state.
- Corporate innovation activity is low and risk aversion is high.
- There is a lack of knowledge and interest in RE from all market players.
- A negative image of hydroelectric power plants exists.

(2) Technological barriers:
- There is a huge infrastructure requirement for installing RE resources.
- The installed energy capacity is excessive.



Source: Enerdata (2022)

Figure 2. The share of renewable energy in electricity generation in Russian Federation (1990–2020, including hydro)

- The capacity of RE sources is low compared to traditional energy sources.
- There is a lack of a complete production cycle of wind generation and bioenergy in small and medium hydro production.
- There is lack of R&D on RE and lack of necessary professional skills.

(3) Economic barriers:

- The competitiveness in RE resources is low.
- Compared to typical energy generation, there are high investment expenses.
- There is a lack of price parity in the cost of RE.
- Heavy electricity debts exist.
- There are high financial and investment risks.
- Electricity generation from RE sources increases electricity prices for the customer.

(4) Institutional barriers:

- There are many legal gaps in the RE field.
- There is a lack of coherent policies on RE development.
- Government support for RE innovation is the lowest among wholesale energy market participants.
- There is a lack of effective networking institutions and forms of collaboration among the actors involved in the innovation procedure.

(5) Environmental barriers:

- The Russian Federation has different amounts of RE available in different regions.
- There is negative ecological impact of RE sources.
- There is alienation of an important region when establishing plants that generate electricity from RE sources.
- Significant damage to nature occurs from accidents that occur frequently in hydroelectric power plants (Ljovkina *et al.*, 2021, p. 107).

As indicated in the above list, the Russian Federation has a number of obstacles to the spread of RE sources, which are divided into five categories. The Russian Government, on the other hand, has committed to achieving net zero carbon by 2060. As a result, it appears that putting procedures in place to discover answers to problems in front of RE sources is critical (Sanghi and Steinbuk, 2021).

3. Literature review

The implications of policy on RE development have been extensively studied, with varying results for different nations. Empirically, it is discussed by many papers, such as Marques *et al.* (2019) for 46 countries across the world, Kilinc-Ata (2016) for EU and US states, Emodi and Ebele (2016) for Nigeria, Delmas and Montes-Sancho (2011) for US states and Lund (2009) for 20 countries, mainly Europe, who revealed that RE policies have an encouraging impact on the development of RE.

Similar to RE policies, the indicators of a country's also impact RE consumption. In terms of economic growth and CO_2 emissions, a positive effect on gross domestic product (GDP) and CO_2 to RE development was found by Salari *et al.* (2021) for the USA, Bilan *et al.* (2019) for EU membership countries, Bekhet and Othman (2018) for Malaysia and Bhattacharya *et al.* (2017) for 85 developed and developing economies across the world.

The Russian Federation's RE literature focuses mostly on potential, initiatives, policies, trends and theoretical futures. Kirsanova *et al.* (2018), for example, look into the importance of RE in the Russian Arctic's electricity generation and energy mix. Marchenko and Solomin (2017) looked at the cost-effectiveness of a hybrid electric power system that included solar modules, wind turbines, wood-fired biomass gasification plants, electric energy storage batteries and a diesel power plant in another study. Furthermore, Proskuryakova and Ermolenko (2019) expect to give scientific explanation for government and business decision-makers by foreseeing a bright future for the RE sector. Chebotareva *et al.* (2020) also provide a theoretical study of the main types of state assistance programs for RE in Russia. Furthermore, the research looks at risk dynamics across the life cycle of RE questions projects. On the other hand, some papers have examined the Russian Federation's hurdles and challenges to RE sources (Agyekum *et al.*, 2021; Ljovkina *et al.*, 2021; Morgunova *et al.*, 2020; Morgunova and Solovyev, 2017; Chernysheva, 2014; Martinot, 1998).

There are few empirical papers for the Russian Federation, as may be observed. According to the literature, oil prices and CO_2 have a negative impact on RE usage, as Karacan *et al.* (2021) evaluate the impact of oil prices, income and CO_2 on RE consumption for the Russian Federation between 1990 and 2015 using the vector error correction model (VECM) and the Canonical Co-integrating Regression technique. Burakov and Freidin (2017) used the VECM to evaluate the relationship between financial development, income and RE use for the Russian Federation between 1990 and 2014. Economic growth generates changes in RE consumption, but RE consumption does not cause economic growth or financial development, according to the research. As is evident, many studies are not available, especially when looking at the Russian Federation. By identifying the variables that affect RE capacity, this study attempts to close the literature gap and contribute to the ongoing policy discussions. Furthermore, Table 2 shows the most recent empirical literature on the factors affecting RE sources.

4. Methodology

4.1 Data

Annual data for the Russian Federation was compiled from a variety of sources, including the World Bank, the International Energy Agency and other energy websites, from 1990 to 2020. The analysis' dependent variable is RE power (wind, solar, geothermal and biomass). The research was strengthened by the assumptions and hypotheses connected to many independent variables. It is a popular literary term. Table 3 shows the explanatory variables, which are described in more depth below.

The dependent variable, *REC,* is expressed as a proportion of total power consumption. This dependent variable is more in line with the types of RE variables that have been used in previous studies (Mac Domhnaill and Ryan, 2020; Carley, 2009; Menz and Vachon, 2006). Hydropower is not included in the measurement of RE usage. Hydro energy is not included in Russia's policy on RE sources; hence, it is excluded. As a result, the inclusion of hydro energy and the factors influencing the development of RE cannot be determined.

Alternative energy sources (oil, natural gas and coal) have been identified by many studies to reduce RE demand. According to Kahia *et al.* (2016), there is a short-term negative association between RE and non-RE use, confirming the bidirectional causality that demonstrates the substitutability of the two energy types. Consumption of fossil-based

Study	Period	Country(s)	Method(s)	Results
Shahbaz *et al.* (2022)	1980–2018	China	ARDL method	Income inequality is negatively associated with RE consumption, while economic growth, urbanization and fiscal decentralization are positively associated with RE demand
Camacho Ballesta *et al.* (2022)	2001–2015	176 countries	OLS, FGLS and PCSE	The results show that economic factors have a negative effect on RE, while social factors such as education have a positive effect on RE
Chen *et al.* (2021)	1995–2015	97 countries	Panel threshold model	Democratic institutions heavily influence RE use
Yu *et al.* (2021)	2001–2017	EU countries	LMDI method	While the investment effect makes the biggest contribution to the spread of RE electricity, the production effect is the biggest hindrance
Dogan *et al.* (2021)	1980–2016	72 countries	Panel Pooled OLS	Increases in income and energy prices have a positive effect on RE
Bayale *et al.* (2021)	1990–2017	WAEMU countries	FMOLS and DOLS	While GDP, energy investments, urbanization and unemployment encourage RE, CO_2 emissions and energy imports hinder RE production
Gershon and Emekalam (2021)	1990–2014	Nigeria	ARDL method	Environmental considerations are less critical than income for RE development in Nigeria
Khezri *et al.* (2021)	2000–2018	31 Asia Pacific countries	Durbin model	While R&D reduces the hydroelectric market, it positively affects solar, wind, bioenergy and geothermal energy resources
Bednarczyk *et al.* (2021)	2010–2019	Poland	Dynamic Panel model	The development of RE is unaffected by R&D
Belaïd *et al.* (2021)	1984–2014	MENA region	Panel quantile regression	Financial development and political stability promote RE production in the MENA region
Gyamfi *et al.* (2021)	1990–2016	E7 Economies	Panel quantile regression	RE was found as a negative and significant impact on CO_2 emissions in E7 countries, as a 1% increase in RE consumption improves environmental quality by 0.588%

(continued)

Table 2. Recent empirical research: an overview

Study	Period	Country(s)	Method(s)	Results
Melnyk *et al.* (2020)	2001–2015	OECD countries	Random effect GLS regression	GDP per capita growth has a negative impact on RE diffusion but has a positive impact on non-RE sources
Bourcet (2020)	2009–2017	72 countries	GMM	The results show that there is little consensus on the impact of economic, environmental and energy-related determinants on RE
Zhao *et al.* (2020)	1980–2016	China	FMOLS	Financial development and per capita income are important factors in RE development in China
Przychodzen and Przychodzen (2020)	1990–2014	27 countries	Panel analysis	GDP growth results in RE production Unemployment level positively affects RE distribution
Akintande *et al.* (2020)	1996–2016	Five African countries	Bayesian Model	The findings show that the increase in population growth, urban population, energy demand/use and electrical power demand/consumption causes an increase in RE consumption
Ergun *et al.* (2019)	1990–2013	21 African countries	Panel analysis	The level of democracy does not directly affect RE sources But there is a negative relationship between GDP and the share of RE
Lin and Zhu (2019)	2000–2015	China	Panel analysis	Intense CO_2 emissions and R&D investments support the RE technological innovation level Energy price, on the contrary, has an insignificant effect on RE technologies

Table 2.

sources has been identified as a key component in the transition from non-renewable to RE sources (Yuksel and Ubay, 2020). Another study by Dong *et al.* (2017) claims that there is a bidirectional relationship between natural gas use and RE utilization in the long term. Variables that are not renewable are expressed as a percentage of total electricity. Nuclear energy is essentially another form of alternative energy, but the Russian Federation has proclaimed that it has a "National Outline for the Development of the Nuclear Industry Complex" to maintain its leadership position in the global nuclear technology and services market (Zhan *et al.*, 2021). As a result, the Russian Federation policymakers advocate for nuclear energy to be strengthened (Romanova, 2021; Zavalny, 2019). In September 2021, the Russian Federation approved nuclear energy as a green energy source. France and Hungary, for example, endorse the Russian Federation's classification of nuclear energy as a clean energy source, emphasizing the importance of encouraging investments in low-

Table 3. Variables in the model and their descriptions

	Variables	Units	Sources	Expectation
REC	Electricity production from RE consumption without hydro energy (Dependent variable)	Percentage of Total Electricity	World Bank	–
NREC	Electricity production from oil, gas, coal and nuclear sources as *substitute variable*	Percentage of Total Electricity	World Bank	Negative
GDP	Economic growth, energy consumption and	PPP, constant 2017 international $	World Bank	Positive
EC	trade openness as *economic variables*	Kg of oil equivalent per capita (ktoe)	Enerdata	Positive
TO		BoP, current US$	World Bank	Positive
CO_2	*Environmental variable*	Metric tons per capita	International Energy Agency	Positive

Note: NREC = Non-renewable energy consumption

carbon energy resources to combat climate change. Austria and Luxembourg, on the contrary, are adamant about nuclear energy not being included in the clean energy category (Rosatom, 2021). Nuclear energy is considered a substitution variable in the study, despite the Russian Federation's acceptance of it as clean nuclear energy.

In the literature, *economic variables* such as income and GDP, measured per capita as an indicator of economic development, have been extensively studied. Many studies have discovered that economic growth has a favorable impact on the expansion of RE (Chen *et al.*, 2021; Keek *et al.*, 2019; Singh *et al.*, 2019; Blazejczak *et al.*, 2014). For instance, according to Dogan *et al.* (2021), a 1% rise in GDP or per capita GDP results in an increase in RE of between 0.05 and 1.01%.

Energy consumption is another economic variable, as it has a favorable impact on the use of RE in energy exporting countries (AlZgool *et al.*, 2020). As a result, it tries to show how energy use impacts the Russian Federation, which imports energy. The amount of energy used per person is measured in kilograms of oil equivalent per person.

Energy and power export statistics are commonly used as a security variable in the literature, and numerous studies have demonstrated that safety data has a favorable impact on RE development (Carfora *et al.*, 2021; Sachs *et al.*, 2019; Cole and Banks, 2017; Lucas *et al.*, 2016; Kilinc-Ata, 2016). However, as the Russian Federation is a net importer of energy and power, trade openness is factored into the research. Trade openness measures total exports and imports as a proportion of GDP, and it is projected that increased trade openness will increase energy demand and support the construction of RE capacity (Ibrahiem and Hanafy, 2021). In contrast, Chen *et al.* (2021) find that increased trade openness is associated with lower RE deployment rates in less democratic countries. The balance of payment in current US dollars is used to measure trade openness.

The environmental variable of CO_2 emission per capita is involved because CO_2 emission creates pressure on political leaders for environmental issues. The paper hypothesizes that CO_2 emissions have a positive effect on RE development. Because CO_2 emissions are emitted by fossil fuel-based sources and rising CO_2 levels endanger ecological balance and a global rise in temperature, all countries must limit CO_2 emissions (Banday and Aneja, 2020; Hanif *et al.*, 2019; Sadorsky, 2009; Raghuvanshi *et al.*, 2006). The amount of CO_2 emitted per person is measured in metric tons.

4.2 Methods

This research uses the VECMs to undertake individual time-series analysis for the Russian Federation, focusing on the impact of substitution, economic and environmental factors on RE usage. This paper's regressions can be represented as follows:

$$RE_t = a_o + a_1 Substitute_t + a_2 Economic_t + a_3 Environmental_t + \varepsilon_t \tag{1}$$

$$InRE_t = a_o + a_1 InNREC_t + a_2 InGDP_t + a_3 InEC_t + a_4 InTO_t + a_5 InCO2_t + \varepsilon_t \tag{2}$$

All variables are transformed to logarithmic form, and unit root tests [Augmented Dickey and Fuller (ADF) and Philips and Perron (PP)] are performed to determine whether the variables are non-stationary. For ADF and PP tests, the null hypothesis is that the series has a unit root. If the series is not stationary, then the first difference must be taken to make it stationary. Stationary series at level is signified by I (0); unit root is indicated as I (1) (Gokmenoglu *et al.*, 2015; Enders, 2008). Then, the Johansen cointegration test is used to evaluate if variables are cointegrated and if the variable orders of integration are the same. It is well known that using the cointegration method provides two distinct advantages. First, it allows for the distinction between short- and long-term impacts (Bernard and Durlauf, 1995). The second involves calculating the rate of adjustment to long-term values (Johansen and Juselius, 1994; Johansen, 1992). Finally, if there are cointegration linkages between variables, then the current paper uses the VECM to look into the long-term relationship between them. The VECM approach would be the first best option if the variables had only one cointegration relationship (Masih and Masih, 1997). According to Granger (1988a), if a cointegration relationship between the variables is found, then at least one causation link between the variables is expected. In this scenario, the VECM method should be used to determine causation because the different operation used to render the variables stationary may result in the loss of the variables' long-term information. In this aspect, the VECM has an advantage over other approaches because it prevents losses (Sajid and Sarfraz, 2008). However, there is discussion over how lag lengths should be calculated (Abduvaliev and Bustillo, 2020). The VECM residuals are also used in the paper for diagnostic tests. The model for operating the VECM mechanism, according to Engle and Granger (1987), is as follows:

$$\Delta Y_t = \beta_o + \beta_1 X_t + u_t$$

$$\Delta Y_t = a_o + a_1 \Delta X_t + a_2 u_{t-1} + \varepsilon_t$$

The ADF unit root test (Dickey and Fuller, 1979) and the PP unit root test (Phillips and Perron, 1988) were used in the first stage of the analysis to see if the variables were stationary. The Johansen cointegration test (Johansen, 1992) is used to determine whether the variables are cointegrated if the integration orders of the variables are the same. The long-term relationship between the variables was investigated using the VECM after proving the presence of a cointegration connection between the variables. The Granger causality test (Granger, 1988b) was used as the final step in assessing the relationship and direction between the independent factors and the dependent variable.

Many studies have used the methods provided in this paper, so detailed information about ADF and PP unit root tests, Johansen cointegration and Granger causality tests are not given.

4.3 Empirical findings

The stationarity features of the variables were tested using ADF and PP unit root tests during the analysis. The results of the unit root test are summarized in Table 4.

The unit root tests demonstrate that all variables are non-stationary at their level. However, in both the ADF and PP unit root tests, they are stationary at the initial discrepancies, allowing us to do the cointegration test. Because all series should not be level stationary and should instead become level stationary when the difference is obtained at the same level, and the Johansen cointegration approach, one of the cointegration tests, was applied (Johansen and Juselius, 1990). The optimal lag number is first calculated, with the results of the analysis shown in Table 5. In this work, all of the lag selection criteria indicate that a lag of order two is best.

A stable vector autoregressive (VAR) model has some characteristics, such as residuals that are normally distributed and do not indicate a series correlation or changing variance problem (Karacan *et al.*, 2021). Table 6 shows the results of the LM, normality, heteroscedasticity, trace and maximum eigenvalue tests.

Based on the results of the trace and maximum eigenvalue tests, Table 6 demonstrates that the variables exhibit a cointegration relationship. In other words, there is a long-term relationship between RE capacity and independent factors in the Russian Federation. Table 7 shows the coefficient of the long-term relationship in the Russian Federation between RE capacity, non-RE capacity, GDP, energy consumption, trade openness and CO_2 emissions.

The estimated cointegration model in equation (2) is expressed as:

$$REC_t = -0.79NREC_t + 0.12GDP_t + 0.05EC_t + 0.25TO_t + 0.68CO_{2t} + 0.01$$

Table 7 illustrates that all factors are significant at a 1% significance level. An increase in GDP of 1% translates to a 0.12% increase in RE development. The positive impact of GDP on RE deployment in this result supports the findings of Dogan *et al.* (2021) for a global

	The ADF test		The PP test	
Variables	I (0) Level	I (1) Level	I (0) Level	I (1) Level
REC	2.3797 (*0.9944*)	−2.5686 (*0.0121*) **	3.1067 *(0.9991)*	−2.3935 *(0.0185)* **
NREC	−0.7124 (*0.3996*)	−5.8352 (*0.0000*) ***	−0.7124 (*0.3996*)	−5.8352 (*0.0000*) ***
GDP	0.5731 *(0.8345)*	−2.5497 (*0.0127*) **	0.3168 *(0.7707)*	−2.4254 *(0.0172)* **
EC	−0.7461 (*0.3847*)	−3.6941 (*0.0006*) ***	−0.5646 (*0.4642*)	−3.6313 (*0.0007*)***
TO	−0.0930 (*0.6434*)	−4.5411 *(0.0001)* ***	−0.0930 (*0.6434*)	−4.9891 (*0.0000*) ***
CO_2	−1.7968 (*0.0692*)	−3.6034 (*0.0008*) ***	−1.3452 (*0.1616*)	−3.4394 *(0.0012)* ***

Notes: (*) significant at the 10%; (**) significant at the 5%; (***) significant at the 1%; Probability values are indicated via parenthesis

Table 4.
Unit root test' results

Lag	LogL	LR	FPE	AIC	SC	HQ
0	393.9765	NA	9.66e-20	−26.75700	−26.47411	−26.66840
1	539.4929	220.7835	5.37e-23	−34.30986	−32.32964*	−33.68968
2	596.2716	62.65229*	1.82e-23*	−35.74287*	−32.06531	−34.59110*

Note: * Indicates lag order selected by the criterion

Table 5.
VAR lag selection criteria

LM test[a]				
Lags		LM statistics		*p*-value
1		40.30650		0.2855
2		37.86907		0.3840
Normality test[b]				
Jarque-Bera	χ^2		df	*p*-value
	5.26787		6	0.4459
Heteroscedasticity test[c]				
White Statistics	χ^2		df	*p*-value
	520.6486		504	0.2947
Johansen cointegration rank trace test[d]				
Null hypothesis	Eigenvalue	Trace statistics	0.05 critical value	*p*-value
None*	0.928000	169.0243	103.8473	0.0000
At most 1*	0.768265	97.98487	76.97277	0.0005
At most 2	0.618325	58.50649	30.07904	0.0691
At most 3	0.536150	32.50049	25.19275	0.0949
Johansen cointegration rank maximum eigenvalue test[e]				
Null hypothesis	Eigenvalue	Trace statistics	0.05 critical value	*p*-value
None*	0.928000	71.03947	40.95680	0.0000
At most 1*	0.768265	39.47838	34.80587	0.0129

Notes: [a]*The null hypothesis of the LM test shows no serial correlation in residuals at lag 2;* [b]*The normality test shows the normal distribution of residuals;* [c]*The white heteroscedasticity test shows that the residuals have varying variance problems;* [d]**indicates that the hypothesis is rejected at the 0.05 level, and the trace test shows 3 cointegrating at the 0.05 level;* [e]**denotes a 0.05-level rejection of the hypothesis and trace test displays 2 cointegrating at the 0.05 level*

Table 6. Results of VAR and Johansen cointegration tests

REC	non-REC	GDP	EC	TO	CO_2	Constant
Coefficient	6.142852	−0.887943	−1.319592	−0.208329	−1.762600	−1.02367
Standard error	0.62996	0.17419	0.47470	0.02447	0.60772	–
t-value *	−9.75	5.24	2.81	8.75	2.90	–
p-value**	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	–
Log of coefficient	−0.79	0.12	0.05	0.25	0.68	0.01

Notes: **t-value is calculated as coefficient/standard error;* ***p-value of all variables is less than 0.01 and there is a statistically significant relationship between RE and all explanatory variables (%1 significance level)*

Table 7. Normalized cointegration coefficient

sample of developed countries and developing countries; Papież *et al.* (2018) for EU countries; and Narbel (2013) for 107 middle- and high-income economies.

In addition, a 1% increase in CO_2 emissions, energy consumption and trade openness, respectively, contributes 0.68, 0.05 and 0.12% to RE development. CO_2 emissions have been shown in numerous studies to have a positive impact on RE; for example, Aguirre and Ibikunle (2014) found that CO_2 emissions have a positive impact on RE.

Ibrahiem and Hanafy (2021) reveal that trade openness drives RE for North African countries, and Lin *et al.* (2016) show that trade openness affects RE development for China. Similarly, Sebri and Ben-Salha (2014) discover that BRICS nations' RE usage and trade openness are linked. Yazdi and Mastorakis (2014) revealed a link between trade openness and the adoption of RE for Iran.

However, Non-Renewable Energy Consumption (NREC) (substitute variables) has a negative impact on RE expansion, with a 1% rise in non-RE sources resulting in a 0.79% reduction in RE deployment in the Russian Federation. This result confirms a study by Saibu and Omoju (2016), which indicated that non-RE sources have a detrimental influence on RE deployment. Substitute RE sources, according to Sovacool (2009), have a detrimental impact on RE because of lobbying effects. The VECM results are shown in Table 8.

The long-run coefficients of the variables are statistically significant, as shown in Table 8, and the findings are remarkably similar in terms of both significance and sign to normalize cointegration analysis results. In other words, the VECM residuals exhibit no serial correlation, instability or heteroscedasticity issues, as demonstrated in Table 8. As a result,

Variable (REC_t)	Coefficient	Standard error	z	*p*-values
NREC	−6.142852	0.62996	9.75117	< 0.01
GDP	0.887943	0.17419	5.09746	< 0.01
EC	1.319592	0.47470	2.77986	< 0.01
TO	0.208329	0.02447	8.51484	< 0.01
CO_2	1.762600	0.60772	2.90035	< 0.01
Residuals diagnostic test results of VECM				
LM_{SC}		40.30 (36), $p = 0.28$		
$\mathbf{X}^2_{\mathbf{HETR}}$		520.65 (504), $p = 0.29$		
JB_N		0.53 ($p = 0.77$)		
Vector error correction estimates				
Variable REC (−1)	Coefficient	Standard error	z	*p*-values
NREC (−1)	−5.578118	1.83048	3.04736	< 0.01
GDP(−1)	0.327908	0.21157	−1.54988	< 0.01
EC (−1)	−0.885546	0.82147	1.07801	< 0.01
TO (−1)	−0.119410	0.05945	2.00864	< 0.01
CO_2 (−1)	3.411272	0.88625	−3.84913	< 0.01

Error correction model

$$D(REC) = C(1)*(REC(-1) + 0.119409789136*TO(-1) + 5.57811759086*NREC(-1) - 0.32790812306*GDP(-1) + 0.885546051826*EC(-1) - 3.41127201122*CO2(-1) - 9.57417451096) + C(2)*D(REC(-1)) + C(3)*D(REC(-2)) + C(4)*D(TO(-1)) + C(5)*D(TO(-2)) + C(6)*D(NREC(-1)) + C(7)*D(NREC(-2)) + C(8)*D(GDP(-1)) + C(9)*D(GDP(-2)) + C(10)*D(EC(-1)) + C(11)*D(EC(-2)) + C(12)*D(CO2(-1)) + C(13)*D(CO2(-2))$$

ECM	Coefficient	Standard error	z	*p*-values
C(1)	−0.338221	0.039774	10.960950	0.0018*
C(2)	0.702404	0.242602	2.895294	0.0111*
C(3)	−0.470410	0.217137	−2.425879	0.0386*
C(4)	−0.023507	0.008910	−2.393591	0.0324*
C(5)	−0.022201	0.008835	−2.380922	0.0375*
C(6)	−0.199496	0.333707	−0.597819	0.5589
C(7)	−0.720151	0.306114	−2.352554	0.0327*
C(8)	0.246128	0.106962	2.301069	0.0361*
C(9)	0.001047	0.095511	0.010961	0.9914
C(10)	0.426951	0.205322	2.218299	0.0357*
C(11)	0.448138	0.200941	2.034878	0.0459*
C(12)	−0.313654	0.159877	−2.036366	0.0413*
C(13)	−0.317217	0.164425	−1.992889	0.0469*

Notes: (*) denotes statistical significance. LM_{SC} is Lagrange multiplier statistic for serial correlation test; $\mathbf{X}^2_{\mathbf{HETR}}$ is Chi-squared statistic of heteroscedasticity test; and JB_N Jarque-Bera statistic for normality test

Table 8. Summary results of the vector error correction model

the examined specifications' residuals satisfy the criteria for residuals diagnostic tests, demonstrating the reliability of the estimation results. According to the VECM findings, non-REC has a statistically significant and negative impact on RE sources, while other explanatory variables have a statistically significant and positive influence on RE development over time. As can be seen from the table, the value of the error correction term C (1) has a negative sign and is statistically significant. This indicates the existence of a long-term relationship between the variables of the sample. C(1) indicates the speed of the long-term adjustment. In other words, this coefficient represents how quickly the system of associated variables will reach equilibrium or be long-term rectified. The system of variables corrects prior period imbalance at a rate of 33.82% in one year, given statistical significance at the 5% level (*p*-value less than 5%) and negative significance (meaning an optimal one-year lag for ECM). It suggests that for this model to reach the long-term steady-state equilibrium, the substantial adjustment rate with 33.82% of imbalance correction takes place over the course of a year.

According to these findings, the growth in revenue in the Russian Federation could indicate that it was used in the shift to RE sources, and the outcome is as expected. Similarly, because of the 2060 net zero CO_2 emission objectives, an increase in CO_2 emissions supports a shift to RE sources. According to the findings of the VECM, trade openness has a beneficial impact on RE use in the Russian Federation. This indicates that the Russian Federation gains from technological transfer as a result of international trade to promote the RE sector (Sebri and Ben-Salha, 2014). The last step of the analysis is the test results for causality in Granger's causality in the VEC environment. Table 9 shows the results of the Granger causality test.

The Granger test results reveal a one-way relationship between RE usage and non-RE consumption, income, energy consumption and CO_2 emissions. There is a causal relationship between RE consumption and non-RE consumption, GDP and energy consumption, as well as a link between CO_2 emissions and RE consumption. Some studies in the literature back up this finding of causality. For example, Nathaniel and Iheonu (2019) discover a bidirectional association between RE and non-RE sources for 19 African countries, and Khoshnevis Yazdi and Shakouri (2017) identify a unidirectional causality between economic growth and RE consumption in Iran. Furthermore, Menyah and Wolde-Rufael (2010) find one-way causality between CO_2 emissions and RE usage, similar to our findings.

On the contrary, there is no link between RE and trade openness. The findings are in line with those of Dogan and Seker (2016), who found that there is a cointegration relationship between RE and trade openness in the EU but no causality. In contrast, Tiba *et al.* (2016) establish bidirectional causality between trade openness and RE in China, Sweden and the UK.

5. Conclusion

Using operating data from 1990 to 2020, as well as the Johansen Cointegration and VECM techniques, this research empirically evaluated the factors impacting the development of RE in the Russian Federation. This is the first attempt to use this approach for the Russian Federation over such a long period of time and using specific explanatory variables.

The study's findings suggest that there is a long-term relationship between RE and non-RE consumption, GDP, total energy consumption, trade openness and CO_2 emissions for the Russian Federation. Non-RE consumption has a negative impact on RE sources in this long-term connection although other factors such as GDP, energy consumption, trade openness and CO_2 emissions have a favorable impact. Because trade openness promotes RE usage, RE

Equation	Excluded	Chi^2	*p*-value
REC	NREC	7.470165	*0.023871*
	GDP	6.957946	*0.030839*
	EC	6.456665	*0.039624*
	TO	1.237595	0.538592
	CO_2	0.150689	0.927424
NREC	REC	0.454042	0.796904
	GDP	0.672122	0.71458
	EC	6.465217	*0.039454*
	TO	2.186867	0.335064
	CO_2	6.066717	*0.048154*
GDP	REC	0.268810	0.874236
	NREC	1.340819	0.511499
	EC	6.575515	*0.037337*
	TO	3.140025	0.208043
	CO_2	8.835601	*0.012061*
EC	REC	0.623626	0.732118
	NREC	4.336423	0.114382
	GDP	0.320891	0.851764
	TO	5.635242	*0.059748*
	CO_2	6.979941	*0.030502*
TO	REC	0.021316	0.989399
	NREC	2.488373	0.288175
	GDP	0.831956	0.659695
	EC	2.421562	0.297964
	CO_2	7.449254	*0.024122*
CO_2	REC	6.947500	*0.031001*
	NREC	6.313080	*0.042573*
	GDP	0.505525	0.776652
	EC	4.981882	*0.082832*
	TO	0.430906	0.806176

Table 9.
Results of Granger causality test

innovations can spread and be exchanged. The findings also indicate that the increase in CO_2 emissions has a positive effect on RE consumption.

According to the Granger causality test, there is a unidirectional relationship between RE consumption and non-RE sources, GDP, total energy consumption and CO_2 emissions. Trade openness, on the contrary, has no causal association with RE. The same findings were obtained by Ben Mbarek *et al.* (2018) find that there is a unidirectional correlation between GDP per capita and RE in the short and long term. Likewise, Nathaniel and Iheonu (2019) discover that there is a unidirectional causality between renewable and non-RE and CO_2 emissions. Contrary to the finding of Ndlovu and Inglesi-Lotz (2020), it was observed that there is a bidirectional relationship between RE and non-RE, while Bekhet *et al.* (2017) find that there is bidirectional causality running from economic growth to energy consumption and CO_2 emissions in the short run.

In light of the current study's findings, policymakers should introduce appropriate incentive mechanisms for the development and market accessibility of RE because existing RE policies are not sufficient. Tax credits and/or subsidies for both RE production and consumption may be used as incentives. To put it another way, officials should urge a multifaceted fight to promote RE in all countries, not only the Russian Federation. For the growth of RE markets, information sharing on active projects and technologies, as well as finance and investment strategies between countries, regional collaboration between public and private sector shareholders may be possible. The existence of public–private partnerships/consultations will also aid in the technology transfer process for the introduction of RE projects to the market.

In addition to the policy recommendations, governments should continue to boost RE use and decrease non-RE use to minimize CO_2 emissions. Considering non-RE is less expensive to produce than RE, universities and academics should be encouraged to conduct more research and develop more projects to make RE production more cost-effective. As a result, increasing the use of RE in the energy mix in any country may be economically viable over time. Furthermore, increased public awareness of RE and environmental protection should be a priority for policymakers. It should keep concentrating on low-energy and low-environmental products.

The findings highlight the need of addressing climate change, which comes as a result of the widespread problem of fossil fuel use around the world. Reduced use of fossil fuels and increased use of clean energy resources are the most crucial initiatives to take in the battle against climate change. In this context, the Russian Federation's adoption of climate policies, which is the world's leading emitter of CO_2, will benefit the entire world.

Some caution is urged when interpreting these findings. The purpose of this study was not to examine all possible explanatory variables. RE policies and grid transmission variables, for example, were not included in the study, despite the fact that a more in-depth investigation in the future may indicate that these are important predictors of RE development. Furthermore, RE projects can work in conjunction with economic growth and RE policies. However, RE policies are not included in this study because only substitution, economic and environmental variables that are useful in the development of RE are considered in this research.

Another study limitation is that, while the purpose of the study is to offer a comprehensive picture of the overall effectiveness of the factors influencing RE development, it is difficult to relate the findings to a specific place or country. Because countries or states have distinct political, economic, social and environmental factors, several elements may be effective in the growth of RE. Likewise, the dependent variable selected may have limitations. The percentage of electricity capacity generated from RE sources (wind, solar, geothermal and biomass) is integrated into a single measurement in this research. For example, in one region of Russia, solely wind energy is used, whereas in another region of the country, solar energy is used. These variances cannot be totally managed because of the vast disparities between Russian regions.

A final recommendation for future work is the need to comprehensively consider how the sanctions imposed on Russia in the aftermath of the Ukraine–Russia conflict will affect RE development and the 2060 net-zero carbon objective in depth.

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