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Article

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The Causal Nexus between Renewable Energy, CO_2 Emissions, and Economic Growth: New Evidence from CIS Countries

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ABSTRACT

This study examines the long-run and short-run of causal nexus between renewable energy generation, CO_2 emissions, and economic growth in selected Commonwealth of Independent States (CIS), namely Azerbaijan, Russian Federation, Belarus, Kazakhstan, and Uzbekistan over the period from 2002M01 to 2020M12. The study uses the nonlinear autoregressive distributed lag (NARDL) model to examine the long-run and short-run asymmetric effects between selected variables under concern. The results of empirical model estimation suggested that renewable energy generation has a significant long-run positive effect on CO_2 emissions and economic growth in the economies under study, except Kazakhstan. Indeed, renewable energy has an insignificant negative long-run effect on the economic growth in Kazakhstan. Our empirical results summarized that the short-run coefficients of renewable energy generation have a significant steadily positive effect on carbon emission and economic growth in all selected countries under study. Finally, results of the GIRF analysis provided that the innovation shocks of renewable energy generation have a positive steady-state impact on CO_2 emissions in the economies of CIS countries. For the policy implication, energy policy must be designed with the development of the economy, the development of the environment, and the use of renewable energy sources in the countries in mind. The promotion of renewable energy sources benefits not only the environment but also the economic conditions of the countries. Thus, economic growth is essential to generate the necessary resources for the research and development of renewable energy technologies and related infrastructure.

Keywords: Renewable Energy, Carbon Emissions, Economic Growth, Asymmetric Analysis, Nonlinear ARDL
JEL Classifications: F47, G15, G17, Q20, Q40

1. INTRODUCTION

The reliance on conventional energy sources has resulted in a slew of worldwide concerns. Renewable energy sources are a critical component of economic growth in the world. Since the world's population is increasing at an alarming rate, the demand for energy generated from nonrenewable conventional resources has surged dramatically in the last decades. Thus, environmental concerns and rising energy prices endanger the long-term viability of the expanding economy. On the other hand, renewable energy is created via the replenishment of natural resources in order to provide energy security while also addressing the challenges of global warming and climate change (Li et al. 2021).

It should be noted that renewable energy capacity is expected to grow at a faster rate over the next 5 years, accounting for approximately 95% of the increase in global electricity capacity through 2026. Renewable power capacity is expected to grow by more than 60% between 2020 and 2026, reaching more than 4 800 gigawatts (GW) globally. In terms of global power capacity, this is similar to the existing combined capacity of fossil fuels and nuclear power energy (Renewables 2021. Analysis and forecast to 2026, International Energy Agency). The post-pandemic has the potential to change the priority of government policies and budgets, developers' investment decisions, and the availability of financing through 2025. This casts a great deal of uncertainty on a market that had been expanding at a rapid pace over the last 5 years. At the same time, several countries are introducing extensive incentive programs to respond to the current economic meltdown and support the economies of the countries. Some of these stimulus measures may be relevant for renewables. There is little doubt that significant cost reductions over the past decade are one of the main reasons behind renewables rapidly transforming the global electricity mix. The cost of electricity from onshore wind and solar PV is getting cheaper and cheaper than from new and some existing fossil fuel plants. In some emerging economies, renewables are the cheapest way of meeting growing demand (Renewable Energy Market update. Outlook for 2020 and 2021, International Energy Agency).

Today, renewable energy resources have become increasingly more important because they have fewer negative impacts on the environment than other sources of energy and the growing limitations of fossil fuels. Its consumption contributed to about 22% of the World's final energy consumption by 2015 (Balsalobre-Lorente et al., 2018). Due to the comprehensive benefits of using renewable energy, the global demand for renewable energy is predicted to rise to 31% by 2035 (Sieminski, 2016).

There has been a substantial increase in the number of empirical studies that have investigated the causal relationship between the consumption of renewable energy and economic growth in emerging economies. Despite this, there is still a significant gap in the available research. There is a relatively limited number of empirical data to support the hypothesis that renewable energy generation has different impacts on CO_2 emissions and economic growth in the Commonwealth of Independent States (CIS). Recently, some scholars focused on the investigation of the relationship between renewable energy consumption, economic growth, and sustainable development. For instance, Azam et al. (2021) discovered the positive and significant impact of renewable electricity generation on economic growth. They showed that renewable electricity generation sources stimulate economic growth in the long run uzing second-generation cross-sectional dependence test Im, K.S., Pesaran and Augmented Dickey Fuller panel unit root test, panel cointegration, autoregressive distributed lag with respect to the pooled mean group estimation and panel heterogeneous Dumitrescu and Hurlin (2012) causality methods.

By employing the nonlinear ARDL approach (NARDL) approach Avazkhodjayev et al. (2022) have examined the asymmetric impact of renewable energy generation and clean energy prices on green economy stock prices in Asia, Europe, and US. The authors' empirical results indicated that renewable energy generation significant negative impact on green economy stock prices. The clean energy prices have a positive and negative significant impact on green economy stock prices in selected markets. The short-run coefficients of clean energy stock prices have a significant positive effect on green economy stock prices. Indeed, clean energy prices respond quickly to the changes (both positive and negative) on green economy prices in all selected markets. Finally, the negative shocks dominate positive shocks in renewable energy generation and clean energy, and results indicate that a positive and negative relationship was noted between these covariates and green economy stock prices. But authors' have had a gap in the study regarding how long short-run and long-run (positive and negative) effects continue in selected economies.

Moreover, using the dynamic ordinary least squares and heterogeneous non-causality approaches Shahbaz et al., (2020) have investigated the effect of renewable energy consumption on economic growth across 38 renewable-energy-consuming countries. They found that, the presence of a long-run relationship between renewable energy consumption and economic growth. Authors suggest that governments, energy organizations and companies, and also associated bodies must act together in increasing renewable energy investment for low carbon growth in economies under concern. Likewise, Wang and Wang (2020) found that the effect of renewable energy consumption on economic growth is positive, which indicates that increased renewable energy consumption contributes to economic growth in OECD countries. In addition, this positive relationship changes as the threshold value changes, which means that the role of increasing renewable energy consumption to promote economic development is nonlinear.

Moreover, Salari et al. (2021) have investigated the causal nexus between economic growth and energy consumption in the US. The authors applied four known hypotheses: growth conservative, feedback, and neutral, differentiating between renewable and non-renewable energy consumption. Results for renewable energy, industrial energy, and residential energy consumption showed more support for the growth hypothesis. Their results have policy implications in terms of optimizing decisions and investments to efficiently improve economic growth while reducing energy consumption. More recently, Li and Leung (2021) evaluated the renewable energy-economic growth nexus in seven European countries from 1985 through 2018. In the study, long-run causality is found to flow from all explanatory variables to renewable energy consumption. Short-run causality is also detected from the two fossil fuel prices to renewable energy consumption. Authors provide empirical support for the important role of economic growth and non-renewable energy prices in the renewable energy transition. Their findings showed that there is no evidence of Granger causality from renewable energy consumption to economic growth.

In addition, other empirical studies investigated the nexus between returns of energy and commodity market prices (Sadorsky,1999; Choi and Hammoudeh, 2010; Salisu and Oloko, 2015), while other researchers examined the influence of investor sentiment on energy and commodity markets (Wang et al., 2013; Aloui et al., 2018; Bekiros et al., 2016; Perez-Liston et al., 2016; Dash and Maitra, 2017; Hasanov and Avazkhodjaev, 2022; Shakhabiddinovich et al., 2022; Avazkhodjaev et al., 2022).

This paper differs from other empirical research on this issue as most papers in this field study renewable energy generation on

CO_2 emissions and economic growth in selected CIS countries. For our research objective, we make three key contributions. First, energy market, especially renewable energy generation, can help develop green energy industries raise and circulate capital within the broader economic system. While, as mentioned above, some empirical studies have examined the relationship between energy consumption and economic growth with nonrenewable and renewable energies, there is a gap in research about the relationship between renewable energy, CO_2 emissions and economic growth, especially in CIS countries. The study covers this gap by focusing on the renewable energy industry that has largely been ignored in prior research.

Secondly, we argue that analyses of the relationship between the variables in a nonlinear setting have at least two important reasons: (1) a time series can have hidden cointegration if positive and negative components of a series are cointegrated (Granger and Yoon, 2002) and (2) asymmetry is types of nonlinearities that affect the market dynamics, especially when the sample period is marked with the pre-and post-pandemic. To achieve these purposes, we employ the Nonlinear Autoregressive Distributed Lag (NARDL) approach proposed by Shin et al. (2014) which allows testing the long-run and short-run asymmetries. Moreover, unlike the standard cointegration techniques, this method permits time series to have different orders of integration (Shin et al., 2014).

Thirdly, we examine the time mode of the effects of renewable energy generation shocks on future behavior of CO_2 emissions and economic growth, we employ the Generalized impulses response function analysis (GIRF) proposed by Koop et al. (1996). This type of analysis has the potential to support future policy recommendations. We will discussed below recent renewable energy developments and policy implications of the selected countries under study.

1.1. Azerbaijan

In a fact, Azerbaijan's hydrocarbon sector is well-established and well-resourced. Since the country's regaining of independence in 1991, oil and gas have played a critical role in the economic development of the country. With a series of laws noting how important it is to move to carbon-free energy production in the 1990s, the legal groundwork was set for the transition. The government has a large-scale strategy to address the situation, but an action plan with a targeted percentage of renewables in production and consumption is still being created. The legal framework in Azerbaijan needs changesdeveloped to include more specific details on the market liberalization, support mechanisms and the role of private entities, or simple rules for contract renewals big projects should be established. In Azerbaijan, with a limited number of companies involved in energy policy realization, the energy market should be liberalized and supported with easy access to relevant information for all participants (Mustafayev et al., 2022). There are several problems with technologies, Azerbaijan has little paid attention to getting foreign financial and technical assistance in renewable energy technologies that cause no harm to the environment while respecting sustainable supplies of energy sources (Vidadilia et al., 2016).

1.2. Belarus

Energy cooperation is a critical component of the "One Belt, One Road" strategy, serving as a foundation and source of support. As part of its long-term strategy for sustainable social and economic development, Belarus has prioritized improving energy efficiency, conserving energy and reducing emissions, as well as developing renewable energy sources, in recent years. Policy support, active development and use of clean energy technology and the development of renewable energies are all part of the plan to make the energy structure more efficient. Although Belarus's natural resources may not be as goods as those of many countries, electricity generation that uses renewable resources requires more invention, is well prepared for renewable energy development of renewable energy and shows regional diversity (Niu et al., 2021). The Republic of Belarus has great potential for the economic development of the renewable energy industry. On the other hand, Belarus is uniquely positioned to develop a hybrid supply of renewable energy and electricity. Belarus' oil and gas reserves, on the other hand, have been weakened by the country's high reliance on natural gas imports. A lack of renewable energy development is a result of the widespread availability of fossil fuels (Niu et al., 2021). Belarus also has far cheaper energy costs and taxes than most other nations, with gasoline costing only 0.5% of what it would in the rest of the globe. It's around $0.68/l (August 2017). Renewable energy is expensive in Belarus, making the fiscal policy more challenging. These drawbacks have resulted in a scarcity of renewable energy development skills. Second, the shift in global energy patterns has a significant influence on Belarus's energy policy, especially in light of the hostility between Belarus and Western nations.

1.3. Russia Federation

The Russian economy relies heavily on the electric power industry and renewable energy. When it comes to developing Russia's renewable energy resources, it is important to remember the role that the energy industry plays in both economic growth and national security. In truth, Russia's mineral and land resources are surprisingly rich in energy resources. In federal territories of the Russian Federation that rely on imported fuel, this is a very typical and significant trend to watch (Tarkhanova et al., 2021). The development of Russian renewable energy is determined, firstly, by the importance of the energy sector in economic development and ensuring the national security of the country. Despite it, the development of alternative energy sources is hopeful and highly promising. This trend is very characteristic and significant for the Russian Federation territories that use imported fuel. Secondly, there is an increasing trend of depletion of the most affordable and profitable reserves of classical energy resources. Thirdly, there is global climate change and the need to reduce greenhouse gas emissions. Their growth is caused by man-made emissions from energy sector facilities. Russian renewable energy development issues are mostly due to the country's inability to create renewable energy all the time. There may not be enough solar or wind power in some places. Then there's the polar opposite. Natural resources abound, yet energy is in short supply in certain areas. In addition, the low level of funding for contemporary renewable energy sources is a major obstacle to their growth in Russia (Tarkhanova et al., 2021).

1.4. Kazakhstan

Kazakhstan has a potential for renewable energy generation, which has a big land area but a relatively small population is enormous. There is a big quantity of land that is suitable for harvesting solar energy, as well as a large amount of windy land that can create substantial wind energy. Renewable energy production in the country has several compelling factors. Kazakhstan's government is considering ways to shift the country's economy away from one based on natural resources (the country contains more than 2% of the world's oil reserves, among other things) and toward one based on cutting-edge technology. Kazakhstan, which has signed up to the Kyoto Protocol and the Paris Agreement, is another source of inspiration. In this way, Kazakhstan aims to cut greenhouse gas emissions and shift to renewable energy production (Vakhguelt, 2017). Despite the great renewable energy potential in Kazakhstan, to implement that potential it is necessary to overcome many barriers which are still pulling back renewable energy generation. These barriers are low electricity tariffs; transmission losses and inefficient technologies; weak regulatory and legal frameworks to stimulate the use of renewable energy in the electricity sector; persistent governmental body reforms; inadequate levels and quality of scientific support; awareness and information barriers; and a high-risk business environment. The development of alternative energy in Kazakhstan is constrained also because the implementation of such projects requires bigger initial capital investments and the recoupment period is going to be longer (Vakhguelt, 2017).

1.5. Uzbekistan

Today, many countries renewable energy goals include reducing GHG emissions, increasing the share of renewable energy in final energy consumption, and meeting the growing energy demand. Uzbekistan is also developing objectives to promote renewable energy and increase its share in the overall energy balance. It particularly aims to increase the share of renewable energy in total electricity production from 10% to 12% in 2018 to 20% by 2025, including raising the HPP portion from 10 to 12% to 15.8%, solar energy from 1.95% to 2.3% and wind energy from 1.36% to 1.6%. Uzbekistan's total electricity generation capacity is 14.1 GW, with TPPs accounting for 85.8%. With GDP and population growth, the country's electricity demand is bound to increase. Production is therefore forecast to rise to 84.9 billion kWh by 2025–40% above the 2018 level. Electricity generation capacity is expected to expand 2.5 times to double annual production by 2030 (International Energy Agency. Uzbekistan Energy Profile 2021). In 2018, Uzbekistan ratified the Paris Agreement and adopted a national commitment to reduce GHG emissions per unit of GDP by 10% of the 2010 level by 2030. According to the Strategy on the Transition of the Republic of Uzbekistan to the "Green" Economy for the Period 2019–2030, Uzbekistan aims to increase the share of RESs in total electricity generation to more than 25% by 2030. It also plans to double its energy efficiency indicator, reduce the carbon intensity of GDP, and provide the entire population and all economic sectors with access to modern, inexpensive and reliable energy. However, there are no large-scale wind farms since wind potential has not been well-structured. As the percentage of solar, wind, and biomass energy generation is limited, statistics agencies do not presently include these (International Energy Agency. Uzbekistan Energy Profile 2021).

The remainder of this paper is structured as follows. Section 2 presents a literature review on the causal nexus between renewable energy, CO_2 emissions and economic growth. Section 3 describes the data and the descriptive statistics. Section 4 introduces the empirical methodology, including model specifications. In section 5, we report and analyze the empirical results and discussion. Finally, section 6 provides conclusions and policy implications.

2. LITERATURE REVIEW

In the existing empirical literature, the causal nexus between renewable energy, CO_2 emissions and economic growth has significantly attracted energy scholars and policymakers worldwide. Indeed, many studies have explored this relationship by using three different types of data horizons: panel, time-series, and cross-country analyses. In a fact, there is still a significant gap in the recent empirical research. There is a relatively limited number of empirical data to support the hypothesis that renewable energy generation has different impacts on CO_2 emissions and economic growth in the Commonwealth of Independent States (CIS).

Boguslaw Slusarczyk et al. (2022) have examined the relationship between renewable energy and economic development in Poland, a low-income EU member, and Sweden, a high-income member. A significant link (statistical significance) was found between Sweden's GDP (84.6%) and Poland's GDP (83.7%), both of which impact the usage of renewable energy sources, according to the findings of the analysis. Likewise, Rafal Kasperowicz et al. (2020) studied the long-term nexus between renewable energy consumption and economic growth in 29 European countries between 1995 and 2016. They achieved a long-run positive relationship between economic growth and renewable energy consumption nexus.

The South Asian Association for Regional Cooperation (SAARC) countries' economic growth and renewable energy sources were examined by Li et al. (2021). The research relies on geothermal, hydroelectric, and wind power as the three primary sources of renewable energy for its operations. The study's overall findings reveal that the SAARC countries' economies benefit greatly from the use of all three types of renewable energy. In addition, hydropower has a significant impact on economic development than the other two renewable energy sources. Moreover, Egypt's economic growth (EEC) has been studied by Salman et al. (2021). The authors used an autoregressive distributed lag (ARDL) model for the period 1990–2019. The findings indicated that government assistance is a crucial driver for the positive and considerable benefits on Egypt's economic development of power produced from renewable energy sources, CO_2 emissions, and exchange rates.

Chen et al. (2020) have examined the relationship between renewable energy and economic growth by employing a threshold model. The result demonstrated that the effect of renewable energy consumption on economic growth is positive and significant if and only if developing countries or non-OECD countries surpass a certain threshold of renewable energy consumption. In the paper, the authors suggested that for developing countries to realize positive economic growth from their investment in renewable energy, they need to surpass a certain threshold of renewable energy consumption.

Likewise, Karimi et al. (2021) investigated the relationship between economic growth, renewable energy consumption, and carbon emissions in Iran during 1975–2017. The authors followed the testing of the limits technique to cointegration and the asymmetric methods in the paper. The findings showed that the long-term increase in renewable energy consumption and CO_2 emissions generates an increase in real GDP per capita. Meanwhile, the reduction in renewable energy has the same impact, although GDP per capita responds more significant to the growth in renewable energy than the loss. Besides, in the long-term, a decrease in CO_2 emissions has a relatively small effect on GDP per capita. The findings from asymmetric testing imply that reducing CO_2 emissions and using renewable energy do not have a significant impact on slowing growth in the near future. However, a rise in renewable energy consumption and CO_2 emissions does support enhancing economic growth. These main findings on the impact of renewable and renewable energy, as well as CO_2 emissions on Iranian economic development, have some limitations. The key issue was a lack of access to various forms of renewable energy throughout the time of the research. As a result, some studies into the impact of hydropower, solar, wind, bioenergy, and geothermal energy on economic development would be an intriguing prospect.

Syzdykova et al. (2020) examined the relationship between energy consumption and economic growth in the Commonwealth of Independent States (CIS) for the period of 1992–2018. According to the findings of the study, there is a two-way causality between energy consumption and economic growth in CIS countries. This shows that the feedback hypothesis is valid in these countries. Azam et al. (2021) studied the short- and long-run of causal correlation between economic growth and renewable electricity generation sources for a panel of 25 developing nations over the period 1990–2017. They concluded that renewable energy sources had a long-term favourable influence on economic development in these chosen nations. Furthermore, both short-term and long-term economic development may be linked to the use of renewable energy sources. The feedback theory holds true in developing countries, according to research.

Using panel data for the periods 2011–2020, Guan et al. (2021) analyzed the short-term and long-term effects of China's rapid economic expansion on the country's consumption of renewable energy sources. Although economic and financial growth has a positive impact on renewable energy consumption in China as a whole, long-run impacts showed that financial development has a negative impact on the consumption of renewable energy in China's western regions. The results of the paper should be treated with caution due to the limited sample size and probable sensitivity of the numerical results to major fluctuations in the variables used.

Furthermore, Saidi and Omri (2020) studied both growth and environmental functions, authors looked at 15 major renewable energy-consuming nations and used both FMOLS and VECM approaches to illustrate the benefits of renewable energy in supporting economic development and decreasing carbon emissions. The findings of the FMOLS approach suggested that renewable energy has a significant impact on both economic growth and carbon emissions. There is (i) bidirectional causality between economic growth and renewable energy in the short-run and long-run for both estimated functions; (ii) no causal relationship between CO_2 emissions and renewable energy in the long run, but a bidirectional causality between these variables are found in the short run; (iii) a bidirectional relationship between economic growth and CO_2 emission in the short run; and (iv) a bidirectional relationship between economic growth and CO_2 emission in the long run.

3. DATA AND DESCRIPTIVE STATISTICS

To accurately represent the amount of renewable energy that is generated by hydropower, we depend on the three indices that are the most extensively used in the macroeconomic, carbon emission, and renewable energy sector from five selected countries within the Commonwealth of Independent States (CIS), namely Azerbaijan, Russian Federation, Belarus, Kazakhstan, and Uzbekistan. First, we use electricity generation (hydropower), as a proxy for renewable energy (REG) which comes from the International Renewable Energy Agency (IRENA) database. Secondly, to determine whether or not economies under study are contributing to climate change, we chose their carbon emission emissions (CO_2). Lastly, we have chosen the gross domestic product (GDP) as a crucial macroeconomic indicator in selected countries under concern, and GDP will be used as a proxy for economic growth. The CO_2 and GDP data from the World Development Indicators database. The monthly sample periods for all three variables from 2002M01 to 2020M12.

The descriptive statistics for renewable energy, including the amount of electricity generated by hydropower, as well as carbon emissions and economic growth are shown in Table 1. The entries in the table indicate that in every circumstance, the averages of the monthly series are less than the standard deviations that have been computed for them. We compare the maximum and minimum values of GDP and find that the minimum and maximum values are comparable. However, the maximum value of GDP (Russian Federation) is higher than that of other countries under study, which indicates that the Russian Federation attaches great importance to the growth of renewable energy generation and the reduction of carbon emissions.

Furthermore, we found that the standard deviation of CO_2 is much lower than the standard deviation of the other selected series. Both the skewness and the kurtosis of the selected series are statistically significant. In sum, it seems as if the selected variables that were investigated exhibit conditional heteroskedasticity when considering the sample size that was taken into account for this paper.

Since the meaningful nonlinear framework requires the stationarity of all series under consideration, we first test for a unit root by employing the conventional augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests for the series that are being investigated. These tests are carried out to determine whether or not there is a unit root. The findings are described in Table 2, and they imply that none of the variables under consideration is stationary in levels. However, when their first difference form is employed, which includes the intercept and trend, the variables do become stationary. It is important to note that when the variables are integrated in order one or more, denoted by the symbol I(I), the NARDL approach produces results that are comparable to those produced by the other cointegration procedures (Fousekis et al., 2016). As a result, we are free to go on with the testing of cointegration inside a framework that is nonlinear.

The existence of a long-run asymmetric relationship between stock prices of renewable energy generation, CO_2 and economic growth is ascertained using the bound testing procedure in Eq. (5). The empirical estimates of nonlinear specifications are summarized in Table 3. F_{PSS} denotes the F-statistic proposed by Pesaran et al. (2001) for testing the null hypothesis of no cointegration, while t_{BDM} is the *t-statistic* proposed by Banerjee et al. (1998) for testing the null of no long-run relationship. The results of both tests show the presence of a nonlinear long-run relationship between selected variables under study.

4. EMPIRICAL METHODOLOGY

We employ the nonlinear autoregressive distributed lag (NARDL) model to examine the long-run and short-run asymmetric effects of renewable energy on CO_2 emissions and economic growth. The nonlinear ARDL (hereafter, NARDL) approach proposed by Shin et al. (2014) allows testing the long-run and short-run asymmetries. NARDL approach provides robust empirical results even for the small sample sizes (Chatak and Siddiki, 2001; Narayan and Narayan, 2007; Pesaran et al., 2001) and can be applied regardless of the order of integration with the exception that the series is integrated with the maximum order of one. The order of integration can be verified using unit root tests. Indeed, when the time series are noted to have cointegration using their positive and negative components (Granger and Yoon, 2002), the case of nonlinear cointegration is implied. Finally, we used generalized impulse response function analysis among variables, and vice versa.

Table 1: Descriptive statistics for selected variables

Variable	Mean	Max.	Min.	SD	Skewness	Kurtosis	J-B
Azerbaijan							
REG	7.6284	8.1461	7.1738	0.2581	–0.0014	1.8507	12.546
CO_2	10.373	10.596	10.094	0.1232	–0.4003	2.7057	6.9136
GDP	10.249	11.228	8.5748	0.9023	–0.7439	1.9741	31.025
Belarus							
REG	4.1741	6.0149	3.3002	0.8502	0.8794	2.3990	32.819
CO_2	10.948	11.026	10.853	0.0488	–0.6851	2.2495	23.188
GDP	10.616	11.278	9.4268	0.5734	–0.9520	2.4795	37.015
Kazakhstan							
REG	9.0429	9.3590	8.8256	0.1346	1.0110	2.9374	38.881
CO_2	12.152	12.454	11.627	0.2497	–0.9085	2.4537	34.202
GDP	11.495	12.375	9.8184	0.7932	–0.8289	2.2429	31.555
Russian Federation							
REG	12.078	12.192	11.973	0.0477	0.4658	2.9807	8.2489
CO_2	14.264	14.326	14.214	0.0321	0.1067	2.0849	8.3863
GDP	13.902	14.648	12.470	0.6469	–0.9012	2.4839	33.397
Uzbekistan							
REG	8.9660	9.3408	8.6819	0.1512	–0.3336	2.7856	4.6662
CO_2	11.661	11.739	11.528	0.0563	–0.6427	2.3369	19.874
GDP	10.396	11.366	9.1842	0.7870	–0.2761	1.4585	25.469

Here, REG, CO_2 and GDP represent log changes in renewable energy generation, carbon emission and gross domestic product, respectively

Table 2: Results of unit root tests

Variable	Azerbaijan	Belarus	Kazakhstan	Russian Federation	Uzbekistan
ADF					
REG	–2.8392***	–3.6633***	–2.8048***	–3.4123***	–3.1395***
CO_2	–2.9066***	–2.8271***	–2.7398***	–8.4569***	–2.8527***
GDP	–15.824***	–3.1753***	–2.8072***	–2.9862***	–18.445***
PP					
REG	–3.1196***	–3.8522***	–2.9232***	–4.0620***	–4.2025***
CO_2	–3.0364***	–4.0777***	–3.6842***	–9.1260***	–4.1258***
GDP	–15.824***	–3.1820***	–2.8294***	–2.9879***	–18.411***
KPSS					
REG	0.5073***	1.3599***	0.9219***	1.0660***	0.3175***
CO_2	0.6881***	0.8666***	1.5662***	0.8333***	1.3159***
GDP	1.3906***	1.5448***	1.6640***	1.4213***	1.7258***

***, **, *indicate 1%, 5% and 10% significance level, respectively. ADF, PP and KPSS are the empirical statistics of the Augmented Dickey–Fuller (1979), the Phillips–Perron (1988) unit root tests, and the Kwiatkowski et al. (1992) stationarity test, respectively. The critical values of the KPSS unit root tests for 5% significance level are 0.463 and 0.146, respectively

Table 3: Bounds tests for nonlinear specification

Dependent variable	FPSSNonlinear	tBDM
Azerbaijan		
REG	3.5550***	–3.7163***
Belarus		
REG	4.7661***	–4.3045***
Kazakhstan		
REG	4.7285***	–4.5765***
Russian federation		
REG	3.7667***	–3.0621***
Uzbekistan		
REG	4.0802***	–4.3595***

Here, REG, CO and GDP represent log changes in renewable generation, carbon emission and green economic growth, respectively. 99% upper (lower) bound with k=4 is 5.06 (3.74). 95% upper (lower) bound with k=6 is 4.43 (3.15). ** Indicates significance at 5% level. *** Indicates significance of bound test at 1% level

4.1. Nonlinear Autoregressive Distributed Lag (NARDL) Model

The NARDL approach allows modelling asymmetric cointegration using positive and negative partial sum decompositions and detecting the asymmetric effects both in the short- and long-run. It also allows the joint analysis of the issues of non-stationarity and nonlinearity in the context of an unrestricted error correction model. The nonlinear cointegration regression (Shin et al., 2014) is specified as follows:

$$y_t = \beta^+ x_t^+ + \beta^- x_t^- + \mu_t \tag{1}$$

Were β^+ and β^- are long-term parameters of k ×1 vector of regressors x_t, decomposed as:

$$x_t = x_0 + x_t^+ + x_t^- \tag{2}$$

where x_t^+ and x_t^- are the partial sums of positive or negative changes in x_t as follows:

$$x_t^+ = \sum_{j=1}^{t} \Delta x_j^+ = \sum_{j=1}^{t} \max(\Delta x_j, 0) \tag{3}$$

$$x_t^- = \sum_{j=1}^{t} \Delta x_j^- = \sum_{j=1}^{t} \min(\Delta x_j, 0) \tag{4}$$

4.2. Nonlinear ARDL–ECM Model

The NARDL (p,q) from Eq.(2), in the form of an asymmetric error correction model (ECM) (Raza et al., 2016) can be presented as follows:

$$\Delta y_t = \rho y_{t-1} + \theta^+ x_{t-1}^+ + \theta^- x_{t-1}^- + \sum_{j=1}^{p-1} \varphi_j \Delta y_{t-j} + \sum_{j=0}^{p} (\pi_j^+ \Delta x_{t-j}^+ + \pi_j^- \Delta x_{j-t}^-) + \varepsilon_t \tag{5}$$

where $\theta^+ = -\rho\beta^+$ and $\theta^- = -\rho\beta^-$. In a nonlinear framework, the first two steps to ascertain cointegration between the variables are the same as in linear ARDL bound testing procedure i.e. estimation Eq. (5) using OLS and conduction of the joint null ($\rho = \theta^+ = \theta^- = 0$) hypothesis test of no asymmetric relationship. However, in NARDL, the Wald test is used to examine the long-run ($\theta^+ = \theta^-$) and short-run ($\pi^+ = \pi^-$) asymmetries in the relationship.

Finally, the asymmetric cumulative dynamic multiplier effects of a unit change in on can be calculated as follows:

$$v_h^+ = \sum_{j=0}^{h} \frac{\partial y_{t+j}}{\partial x_t^+}, v_h^- = \sum_{j=0}^{h} \frac{\partial y_{t+j}}{\partial x_t^-}, h = 0,1,2,\ldots. \tag{6}$$

whereas h=∞, the $v_h^+ \to \beta^+$ and $v_h^- \to \beta^-$. A mentioned above β^+ and β^- are the asymmetric long-run coefficients and here can be examined as $\beta^+ = -\theta^+/\rho$ and $\beta^- = -\theta^-/\rho$, respectively.

4.3. Generalized Impulses Response Function Analysis (GIRF)

To examine the time mode of the effects of renewable energy generation (production) on future behavior of CO_2 emission and economic growth, we employ the GIRF proposed by Koop et al. (1996). We created an analytical framework of impulse responses of renewable energy generation to one unit of CO_2 emissions and economic growth under the VAR process. As given in Grier et al. (2004) the GIRF of the paper is detailed as follows:

$$GIRF_K(n, \varrho_t, \omega_{t-1}) = E[K_{t+n} | \varrho_t, \omega_{t-1}] - E[K_{t+n} | \omega_{t-1}] \tag{7}$$

where n = 0,1,2,3., thus the GIRF is conditional on ϱ_t and ω_{t-1} and constructed the responses by average future shocks given in the previous and present. Giving it, a natural reference point for GIRF is the conditional expectation of K_{t+n} given only the history ω_{t-1}, and in this shock response, the current shock is also averaged out.

5. EMPIRICAL RESULTS AND DISCUSSION

Throughout this section, the empirical results from model estimation will be exhaustively discussed. As mentioned in our introduction, our primary objective is to investigate the asymmetric effects of renewable energy generation on carbon emission and economic growth. More specifically, we will be looked at the cases of the hydropower generation sector from five selected countries within the Commonwealth of Independent States (CIS), namely Azerbaijan, Russian Federation, Belarus, Kazakhstan, and Uzbekistan. We employ the NARDL model to examine the long-run and short-run asymmetric effects of renewable energy generation on carbon emissions and economic growth. Finally, we conducted the generalized impulse response function analysis for renewable energy generation to a one unit of carbon emissions and economic growth of the respective five selected countries within the Commonwealth of Independent States (CIS) under the VAR process.

After confirmation of cointegration between the variables, we proceed with the estimation results of the long-run and short-run asymmetric impact of renewable energy generation on carbon emission and economic growth. In Table 4, the estimation results illustrated that renewable energy generation has a significant positive effect on CO_2 emissions and economic growth in the

Table 4: Long-run coefficient estimates of the NARDL Model

Market	Variable	Coefficient	Probability
Azerbaijan	LCO_POS	–3.6296	0.0000
	LCO_NEG	–1.5351	0.8692
	LGDP_POS	0.0483	0.0292
	LGDP_NEG	–0.7071	0.9395
	C	21.590	0.0000
Belarus	LCO_POS	0.1158	0.0000
	LCO_NEG	–0.4551	0.9045
	LGDP_POS	0.4063	0.0683
	LGDP_NEG	0.7160	0.2270
	C	6.8904	0.2031
Kazakhstan	LCO_POS	0.7799	0.0000
	LCO_NEG	–0.6100	0.7740
	LGDP_POS	–0.0311	0.0000
	LGDP_NEG	0.9788	0.0000
	C	7.0029	0.4759
Russian federation	LCO_POS	–0.1782	0.0000
Russian federation	LCO_NEG	–0.3612	0.6341
	LGDP_POS	0.8544	0.0005
	LGDP_NEG	0.9271	0.8599
	C	6.9659	0.0000
Uzbekistan	LCO_POS	0.1158	0.0001
	LCO_NEG	–0.4551	0.8855
	LGDP_POS	0.4063	0.0000
	LGDP_NEG	0.7160	0.5842
	C	6.8904	0.3617

Here, LCO and LGDP represent carbon emission and economic growth, respectively

economies under study (except Kazakhstan). From a different point of view, it can be estimated that the generation of renewable energy has an insignificant negative effect on the economic growth of Kazakhstan. The renewable energy generation have a positive and negative insignificant impact on carbon emission in Azerbaijan.

The short-run dynamics are provided in the following Table 5. Empirical estimation results summarized that the short-run coefficients of renewable energy production have a significant positive effect on carbon emission in all selected countries under concern. Changes in the production of renewable energy have a positive but insignificant effect on economic growth in Azerbaijan, Belarus, and Kazakhstan. On other hand, short-run coefficients of renewable energy generation have a positive significant impact on carbon emissions for all selected economies under investigation and a positive significant effect on economic growth for Russian Federation and Uzbekistan.

In addition, we applied the Wald test to verify the suitability of a nonlinear model (Table 6). The Wald tests reject the null hypothesis of long-run and short-run symmetry of positive and negative components of all examined variables. Findings demonstrated that the adjustment to the production of renewable energy is moving in the direction of a constant increase both in the long-and short-run, with respect to a considerably positive and insignificantly negative influence on carbon emissions and economic development. These show the unequal influence that long-term and short-term factors have on economic growth throughout a range of time periods. According to what we know, the effects of the generation of renewable energy on carbon emissions in the economies of Azerbaijan, Belarus, Kazakhstan, Russia, and Uzbekistan are

Table 5: Short-run coefficient estimates of the NARDL Model

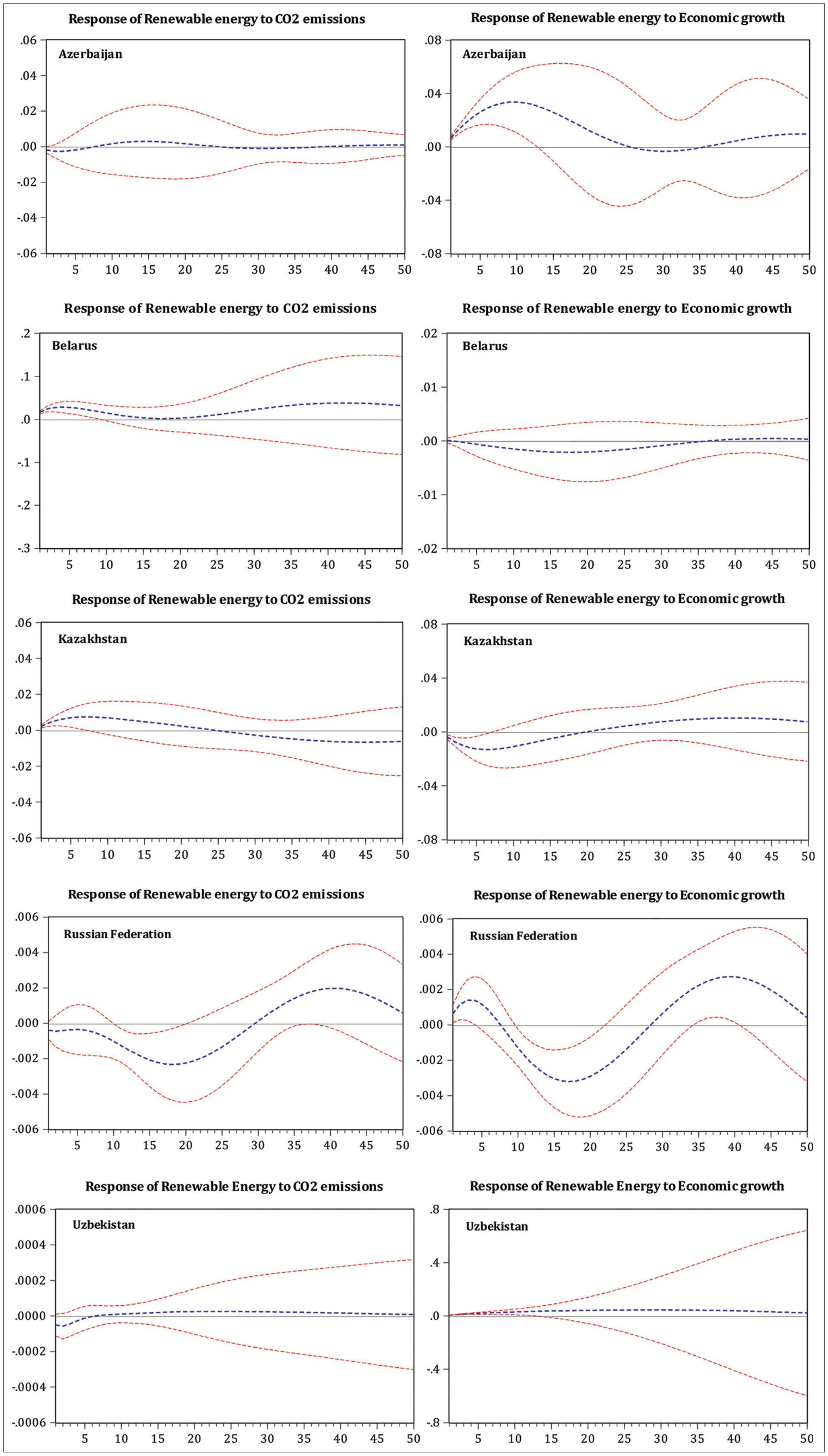
Market	Variable	Coefficient	Probability
Azerbaijan	C	–0.0020	0.2840
	DLCO_POS	–1.3430	0.0317
	DLCO_POS(–1)	0.0045	0.0942
	DLCO_NEG	0.7096	0.6411
	DLC0_NEG(–1)	0.0603	0.9007
	DLGDP_POS	0.2343	0.0044
	DLGDP_NEG	–0.8622	0.9099
	DLGDP_NEG(–1)	0.0827	0.8023
	ECT(–1)	–0.0379	0.0000
Belarus	C	0.0144	0.0005
	DLCO_POS	–5.6110	0.0040
	DLCO_POS(–1)	1.3443	0.0771
	DLCO_NEG	7.4630	0.6000
	DLGDP_POS	0.8250	0.0080
	DLGDP_POS(–1)	–0.6497	0.3106
	DLGDP_NEG	–0.0388	0.9057
	ECT(–1)	–0.0307	0.0000
Kazakhstan	C	–0.0008	0.4611
	DLCO_POS	–0.0914	0.0008
	DLCO_NEG	0.3215	0.8228
	DLC0_NEG(–1)	0.0289	0.8897
	DLGDP_POS	0.0831	0.0619
	DLGDP_NEG	–0.5342	0.6023
	DLGDP_NEG(–1)	–0.1510	0.3666
	ECT(–1)	–0.0384	0.0000
Russian Federation	C	0.0008	0.1474
	DLCO_POS	–0.9193	0.0000
	DLCO_NEG	–2.4507	0.1001
	DLC0_NEG(–1)	–0.3558	0.5717
	DLGDP_POS	0.1279	0.0826
	DLGDP_POS(–1)	0.0290	0.0637
	DLGDP_NEG	0.3886	0.6001
	DLGDP_NEG(–1)	–0.0288	0.7668
	ECT(–1)	–0.0314	0.0000
Uzbekistan	C	0.0003	0.9187
	DLCO_POS	4.2051	0.0011
	DLCO_POS(–1)	–0.9076	0.0353
	DLC0_NEG	–0.1431	0.7845
	DLGDP_POS	–0.3048	0.0543
	DLGDP_NEG	0.6235	0.5007
	ECT(–1)	–0.0151	0.0913

Here, DLCO and DLGDP represent carbon emission and economic growth, respectively. ECM (–1) is the error correction term, that is, the residual with a one-period lag, respectively

positively asymmetric in both the short-run and the long-run; the coefficients of the generation of renewable energy's impact on carbon emissions in Azerbaijan and Belarus, Kazakhstan, Russia, and Uzbekistan are insignificant asymmetric effect in the long-term.

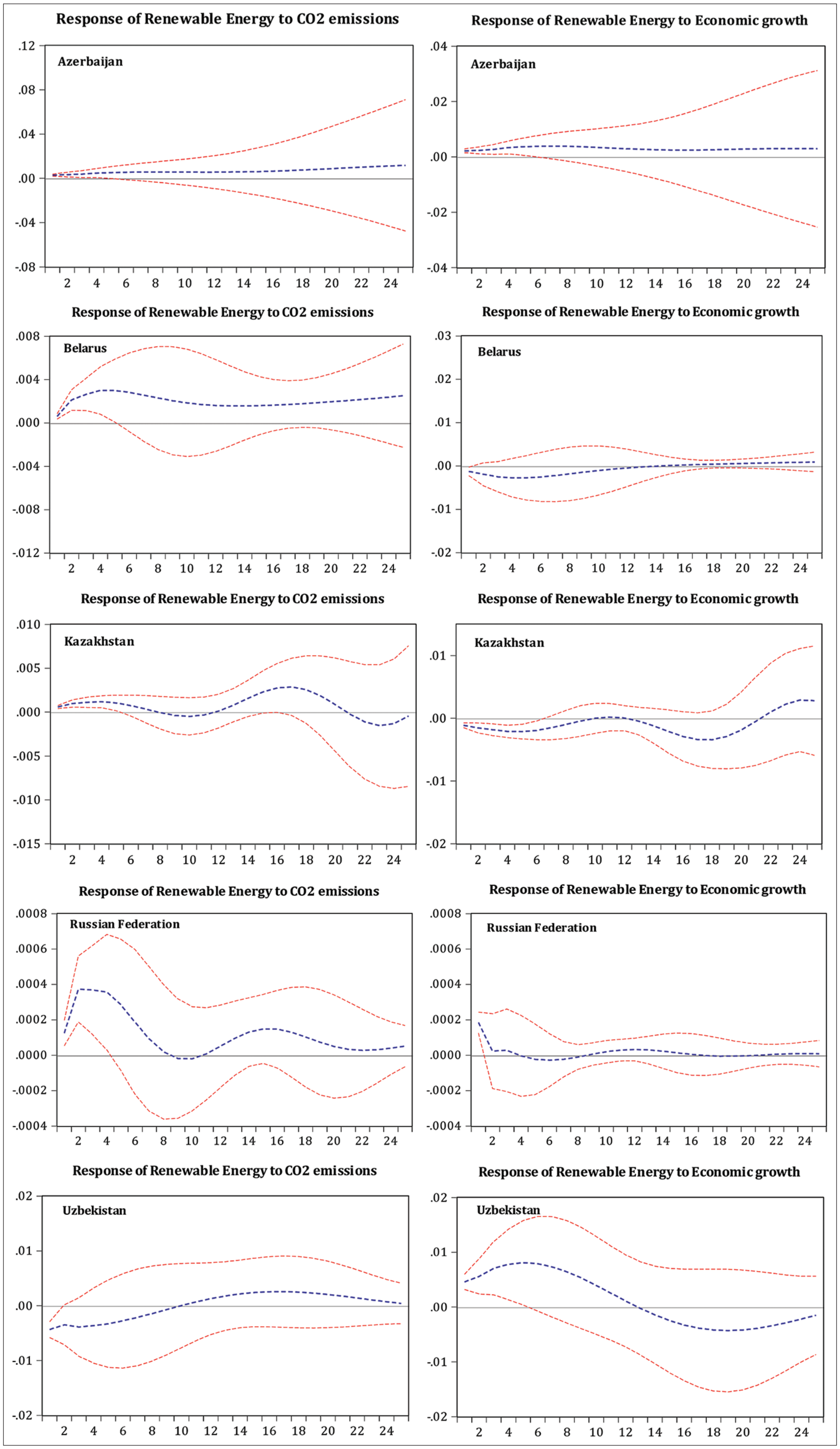
As mentioned above, as we pointed out in the section of empirical methodology that the analytical framework of the GIRF of renewable energy generation to one standard deviation shocks of CO_2 emissions and economic growth under the vector autoregression process of the respective economies under concern are illustrated in Figure 1. We employ GIRF analysis for monthly sample periods for all selected series from January 01, 2015, to December 31, 2018, for the proxy for the pre-pandemic periods. The impulses responses to a unit of shock innovations for the for pandemic periods starts from January 01, 2019, to December 31, 2020, respectively.

Figure 1: GIRF of Renewable energy generation under VAR process to a unit shock of CO_2 emissions and economic growth. (a) The analytical framework of impulse responses for the pre-pandemic period starts from 2015 to 2018



Referring to Figure 1, the solid blueline is the response to a unit of shock innovations, while the dashed redlines are the confidence intervals; each unit time horizon denotes a monthly series. The results in Figure 1, Panel (a) suggests that

Figure 1: GIRF of Renewable energy generation under VAR process to a unit shock of CO_2 emissions and economic growth. (b) The analytical framework of impulse responses for the pandemic period starts from 2019 to 2020



the innovation shocks of renewable energy generation have positive steady-state impact on CO_2 emissions in the economies of Azerbaijan, Belarus, and Uzbekistan. Though renewable energy generation has a negative effect on CO_2 emissions, the negative innovation shocks have approximately the 2017 and 2018 periods in Kazakhstan.

Table 6: Wald test for long-run and short-run

Market	Variable	Long-run (coefficients)	Short-run (coefficients)
Azerbaijan	LCO_POS	0.9587	11.023***
	LCO_NEG	–3.3857***	6.3265***
	LGDP_POS	3.1066***	0.2343***
	LGDP_NEG	4.3204***	22.097***
Belarus	LCO_POS	–0.9258	11.258***
	LCO_NEG	–1.8471*	7.4630***
	LGDP_POS	2.9067***	0.8637**
	LGDP_NEG	3.1566***	–0.0388*
Kazakhstan	LCO_POS	–0.0977	–0.0914**
	LCO_NEG	2.7918***	5.9546***
	LGDP_POS	1.8003*	0.0831**
	LGDP_NEG	–1.0556	40.317***
Russia	LCO_POS	–0.0977	–0.9193*
	LCO_NEG	2.7918***	46.594***
	LGDP_POS	1.8003*	7.3506***
	LGDP_NEG	–1.0556	36.879***
Uzbekistan	LCO_POS	–0.0977	9.1663***
	LCO_NEG	2.7918***	–0.1431**
	LGDP_POS	1.8003*	–0.3048***
	LGDP_NEG	–1.0556	0.6235***

Here, LCO and LGDP represent carbon emission and economic growth.
***, **, *indicate 1%, 5% and 10% significance level, respectively

In Russian Federation, renewable energy harms CO_2 emissions, full recovery requires up to 27–29 months from the beginning of 2015. After negative impacts, renewable energy has had a steady significant positive impact on CO_2 emissions from 2017 to the end of 2018, respectively. Furthermore, the innovation shocks of renewable energy have had a steady state positive, and negative impact on economic growth for all selected countries under study. The negative effects takes around 15–20 months for fully dissipate in pre-pandemic sample periods.

Evidence for pandemic sample periods shows (Figure 1, panel (b)) that renewable energy generation has a steadily significant positive impact on CO_2 emissions and economic growth reaches up to 0.004% point of the initial unit shocks within full sample pandemic periods in Azerbaijan, Belarus and Russian Federation. Indeed, the response of renewable energy generation has a significant negative effect on CO_2 emissions first 10 months of the pandemic period of January 2019 in Uzbekistan. After negative effects, innovations shocks have steadily positive effects on CO_2 emissions for the last year of pandemic sample periods. For the case of Kazakhstan, renewable energy generation effects on CO_2 emissions reached up to 0.004% point of the initial unit shock till last 4 months of selected sample pandemic periods. However, innovation shocks of renewable energy have an unsteadily negative and positive effect on economic growth in Kazakhstan.

6. CONCLUSION AND POLICY RECOMMENDATIONS

As mentioned above, despite the improvement in empirical literature over the last decade on renewable energy, CO_2 emissions, and economic growth, limited research scholars have examined these relationships, especially by using a Nonlinear ARDL approach for the Commonwealth of Independent States (CIS countries). This paper explores the long-run and short-run impacts of renewable energy generation on CO_2 emissions and economic growth in selected CIS countries, namely Azerbaijan, Belarus, the Russian Federation, Kazakhstan, and Uzbekistan.

The results of empirical model estimation reveal that renewable energy generation has a significant long-run positive effect on CO_2 emissions and economic growth in the economies under study (except Kazakhstan). From a different point of view, renewable energy has an insignificant negative long-run effect on the economic growth in Kazakhstan. Renewable energy generation has a positive and negative insignificant long-run impact on carbon emission in Azerbaijan. Our empirical results summarized that the short-run coefficients of renewable energy generation have a significant steadily positive effect on carbon emission and economic growth in all selected countries under study.

Finally, with our last research objectives, the computed Generalized impulse response function analysis suggests that the innovation shocks of renewable energy generation have positive steady-state impact on CO emissions in the economies of Azerbaijan, Belarus, and Uzbekistan, except Kazakhstan and Russian Federation. The innovation shocks for pandemic sample periods show that renewable energy generation has a steadily significant positive impact on CO_2 emissions and economic growth reaches up to 0.004 percent point of the initial unit shocks within full sample pandemic periods in Azerbaijan, Belarus and Russian Federation. However, the response of renewable energy generation has a significant negative effect on CO_2 emissions first 10 months of the pandemic period of January 2019 in Uzbekistan. After negative effects, innovations shocks have steadily positive effects on CO_2 emissions for the last year of pandemic sample periods. For the case of Kazakhstan, renewable energy generation effects on CO_2 emissions reached up to 0.004% point of the initial unit shock till last 4 months of selected sample pandemic periods.

From these conclusions, some implications emerge. From a policy perspective, energy policy must be designed with the development of the economy, the development of the environment, and the use of energy sources in the country in mind. Furthermore, the promotion of renewable energy sources benefits not only the environment, but also the economic conditions of the country. Thus, economic growth is essential to generate the necessary resources for the research and development of renewable energy technologies and related infrastructure. Accordingly, policy makers need to establish appropriate incentive mechanisms for the development and market entry of renewable energy. Establishing public-private partnerships also facilitates technology transfer to bring renewable energy projects to market. From a practical standpoint, our research supports the idea that renewable energy offers so many benefits, from reducing carbon emissions and cleaning the air to increasing economic growth. In spite of these benefits, the growth of renewable energy can create positive “ripple effects” in the economy. For instance, businesses supplying renewable energy will benefit, and unrelated local businesses will benefit from increased business and household income (Environmental Protection Agency, 2010). Likewise, private investors can become more involved in the broader renewable energy field by encouraging more public-private partnership (PPP) initiatives and identifying barriers to increased investment in renewable energy. Private investors have expressed their concerns about governance risks, which may increase pressure on governments to make changes (Schwerhoff and Sy, 2017).

We recommend for future research could extend this study by using the VECM and the Cobb–Douglas production mechanism through the nonlinear ARDL models to examine policy thresholds and critical masses at which renewable energy could increase economic growth without negative effects on the environment.

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