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Carbon, Growth and Clean Energy: Decoding Bulgaria's Sustainability Equation

Farrukh Nawaz Kayani[1]*, Misbah Sadiq[2], Magdi El-Bannany[2,3]

[1]Faculty of Business Studies, Arab Open University, Riyadh, Saudi Arabia, [2]College of Business Administration, Umm Al Quwain University, United Arab Emirates, [3]Faculty of Business, Ain Shams University, Cairo, Egypt. *Email: f.kayani@arabou.edu.sa

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ABSTRACT

Carbon emissions represent a critical and pressing challenge in the 21st century. This study examines the impact of economic growth on carbon emissions in Bulgaria, an emerging economy in Eastern Europe. Utilizing annual time series data spanning from 1990 to 2020, we analyzed the relationship between carbon emissions and key explanatory variables, including GDP growth and renewable energy consumption. To investigate the long-term dynamics among the variables, the study employed the autoregressive distributed lag (ARDL) Bounds testing approach for co-integration. The empirical findings confirm the existence of a long-run relationship among the model variables. Notably, economic growth was found to have a significant positive effect on carbon emissions in Bulgaria. Conversely, renewable energy consumption exhibited an insignificant negative impact on emissions, indicating that the renewable energy sector remains underdeveloped and insufficiently integrated into the national energy mix. These findings carry important implications for policymakers. To balance economic growth with environmental sustainability, it is essential to promote and invest in renewable energy sources. Strengthening this sector could help mitigate the environmental consequences of economic expansion in Bulgaria.

Keywords: Bulgaria, Economic Growth, Carbon Emissions, Renewable Energy
JEL Classifications: F43, Q42, Q48, Q53, Q58

1. INTRODUCTION

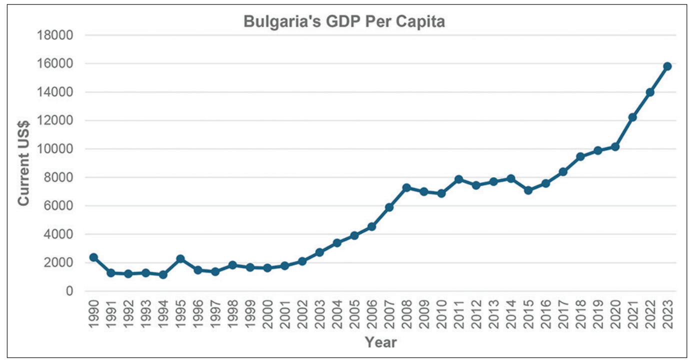
The interdependence between economic development (ED), renewable energy (RE) integration, and carbon dioxide (CO_2) emissions is an essential area of concern in recent studies on environmental and economic systems. This nexus is important to grasp as nations of the world attempt to navigate and foster their ED while at the same time protecting the environment. In this context, Bulgaria, being a European Union (EU) member state and a country in transition, can be scrutinized in detail to set it as an example for other transiting economies. The country has been through a process of economic and energy reforms in the past three decades, moving from a centrally planned economy to a market-oriented economy as well as dealing with environmental issues (Simionescu et al., 2019). The purpose of this research is to analyze the link between Bulgaria's ED path, the country's endeavors towards the use of RE sources, and the consequent effect on CO_2 emissions. Furthermore, the factors of energy efficiency and human capital in the formation of the environmental quality will be discussed in detail to give an overall view of Bulgaria towards sustainability. Thus, this work seeks to contribute to the existing knowledge concerning transition economies and their efforts towards economic development, energy policy and environmental management to increase the knowledge base. Hence, the results of this study will not only be significant for Bulgaria but also provide recommendations for other countries which encounter similar issues in their process of sustainability.

However, the task of unlinking ED from CO_2 emissions has been a difficult one even with all the efforts that have been made across the globe to curb climate change and shift to the use of cleaner sources of energy. Like any other emerging and transition economy, Bulgaria has the challenge of sustaining its ED and at the same time managing its environmental impact. The country's energy sector, which was once dominated by coal and nuclear power, is in the process of transformation to meet the EU climate targets (Popescu et al., 2022). However, the rate of this shift and its implications on the ED as well as emissions cut are not well understood. Also, the contribution of energy efficiency enhancements and human capital development to this change process is usually not well understood even though they can have a great impact on both the economic and environmental performances. In view of these, this study aims to fill these gaps through the evaluation of the interconnections between ED, RE, energy efficiency, human capital, and CO_2 emissions in Bulgaria. Consequently, comprehending these dynamics can help in the formulation of precise policies that can enable sustainable ED as well as the protection of the environment. The challenge is to find out how these factors can be managed in the best possible manner and how they interrelate in the case of Bulgaria's economic and environmental conditions. Through identifying these challenges, this research intends to contribute to the understanding of the policymakers and other stakeholders who are involved in the process of defining Bulgaria's sustainable development strategy.

Nonetheless, the present work is based on the Bulgarian case for several reasons. Firstly, Bulgaria, which is a post-communist country that has adopted a market economy and has joined the EU may provide valuable lessons on the issues that arise in such economies. Secondly, Bulgaria has defined a rather aggressive roadmap concerning the development of RE and emissions reduction as a part of the country's commitments to the EU on climate change, which makes Bulgaria a pertinent country to study the efficiency of such policies (Markov, 2023). Thirdly, the country's energy matrix that combines a large role of nuclear power along with plans to expand the use of RE sources offers a chance to look at how various energy sources correlate with economic development and emissions. Furthermore, there is also an opportunity to look into how energy efficiency and human capital development within the framework of the country's ED strategy affect both economic and environmental aspects. Thus, due to the emphasis on Bulgaria, this study may help to extend the knowledge on how other countries with similar backgrounds can find their way through the challenging process of sustainable development while striving for economy growth and meeting environmental and climate change commitments.

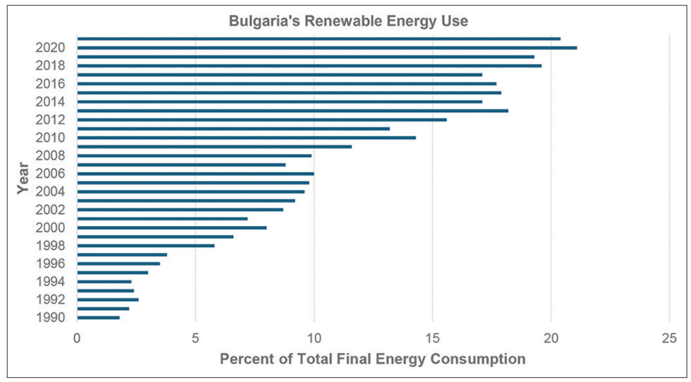
Since becoming a member state of the EU in 2007, Bulgaria has recorded impressive ED, the gross domestic product (GDP) per capita for instance rising from $1,621.3 in 2000 to $15,797.6 in 2023 (World Bank, 2024), as can be evidenced in Figure 1. Concerning RE, Bulgaria has made steps forward: For instance, if we see Figure 2, the share of renewable energy in the total final energy use has grown from 1.8% in 1990 to 21.1% in 2020 which is higher than the target of 2021. This has mainly been due to increased spending on wind, solar and bioenergy sources. Bulgaria is another country that has achieved a decrease in its GHG emissions which stands at 44% less than the 1990 levels as of 2018 (European Environment Agency, 2022). Still, Bulgaria could be considered one of the most carbon-intensive economies in the EU

Figure 1: Economic growth per capita in Bulgaria



Data Source: (World Bank, 2024)

Figure 2: Green energy consumption in Bulgaria



Data Source: (World Bank, 2024)

(International Energy Agency, 2021). Yet, the energy sector is the biggest contributor to the GHG emissions in Bulgaria (UNFCCC, 2020). These figures show the achievements of Bulgaria in recent years; however, they also reveal the difficulties in shifting to a low-carbon economy. Due to the country's strategy on how to achieve both ED and environmental conservation, it becomes a good study model to understand the interconnection between ED, RE, and CO_2 emissions.

Energy efficiency and human capital development are vital in enhancing the standards of the environment and boosting the sustainable development of the economy. Improved energy efficiency results in energy saving and minimizing emissions while at the same time improving the economic outcome by minimizing the costs (Ürge-Vorsatz et al., 2020). In Bulgaria, the enhancement of energy efficiency including the residential and industrial sectors has been considered as the main measure to control emissions and energy dependency (Konidari and Nikolaev, 2022). Education, skills, and knowledge or what is referred to as human capital are also as important. They have more knowledge and training to maintain design and come up with cleaner technologies and practices. In addition, (Meyer, 2015) revealed that high levels of human capital are linked with increased environmental consciousness and approval of environmental measures. For Bulgaria, it means that more attention should be paid to education and training that would help the country to switch to a green economy faster and achieve better economic results. To this end, energy efficiency improvement and human capital development can be synergistic to foster both ED and environmental protection in the process of Bulgaria's transition towards a green economy.

Following the backdrop, the purpose of this research is to develop a system of interactions between economic, energy, and development-related factors with the environmental quality of Bulgaria. Specifically, this research intends to analyze the nexus of ED and CO_2 emissions in one of the EU's emerging economies. Also, this research is intended to analyze the influence of RE on CO_2 emissions. Although the existing literature is rich regarding the nexus between these variables. Still, the mixed or inconclusive relationships motivate this research to comprehensively explore the relationship between them. In addition, this research also concentrates on the importance of energy efficiency and human capital in environmental quality as the rising attention from scholars and policymakers towards the enhancement of efficient energy systems and developed human capital could offer in-depth indications of the environmental quality in Bulgaria. The ultimate objective of this research is to consider all these variables in a single model to develop appropriate and efficient policies that could target environmental recovery without sacrificing economic prosperity. Thus, fulfilling these objectives, the study aims to discuss the comprehensive outlook of Bulgaria's sustainable development concerns and prospects and to contribute to the existing literature on the growth-energy-emissions relationship in transition countries.

This work offers the following new insights into literature. Firstly, although many studies analyze the connections between ED, RE, and CO_2 emissions in different countries, there is a lack of studies that have explored Bulgaria or other similar transition economies in Eastern Europe. This research will help to fill this gap by presenting a detailed description of these dynamics in the Bulgarian context. Secondly, the study also includes energy efficiency and human capital in the analysis while conventional models usually focus only on environmental quality and economic growth. This approach goes further than the standard growth-energy-emissions models (Ozturk, 2010). Thirdly, using time-series data and state-of-the-art econometric tools, this study will not only offer more effective evidence on the existence and direction of the causal links between the chosen variables but also contribute to the current discussion in literature. Lastly, the policy implications that can be generated from this research will be useful for Bulgaria and other transitional economies, as they try to seek the right balance between the ED and the protection of the environment, thus increasing the benefits of academic research.

2. LITERATURE REVIEW

In this section, the study gathered and presented relevant research studies covering the connection between economic prosperity, green energy, and pollution emissions. The following subsections demonstrate the nexus of each variable with emissions. This paper aims to explore the correlation between the two widely used variables namely economic growth and pollution emissions whereby the two are analyzed in various countries and environments. This review establishes that ED is associated with higher levels of pollution emission; however, this nexus may be conditioned by several factors such as governance, technology, and geography. This paper therefore aggregates the findings of different research to explain the impact of ED on pollution emissions. In this context, (Guo et al., 2024) claimed that ED is usually accompanied by an increase in pollution emissions due to the enhancement of industrial production and energy utilization for economic expansion. This can be observed in China where the scholars noted that pollution emissions increase with the growth of the economy as investment in pollution control measures is cut back and urban green innovation is limited. Likewise, (Ali et al., 2023) analyzed Africa and it has been revealed that the ED has a strong positive relationship with environmental degradation since the CO_2 emissions rise with economic growth.

Generally, the nexus of ED and CO_2 emissions relates to the Environmental Kuznets Curve (EKC) Hypothesis in existing literature. This hypothesis postulates that an inverted U-shaped relationship exists between pollution emissions and ED where the latter leads to an increase in emissions before a certain level of development is attained and then decreases as more efficient and less polluting technologies are adopted (Grossman and Krueger, 1995). This pattern has been reported in many studies, including those that have concentrated on EU economies and African countries, among others, where a 1% increment in the GDP per capita at first increases emissions and then decreases them as the GDP per capita grows (Espoir et al., 2023; Mohammed et al., 2024). In South Asia, (Islam, 2021) asserted that environmental quality is first harmed by ED and then improved after reaching a certain level of GDP. In the case of China, (Huangfu et al., 2020) demonstrate that the interaction between ED and pollution is conditioned by local government and economic development. The authors described that a higher level of ED will lead to enhanced environmental quality in the cities while a lower level of ED will lead to worsened pollution in the cities. Furthermore, (Wang et al., 2021) indicate that the government's expectations regarding ED are known to contribute to air pollution especially when growth targets are met or even exceeded.

Due to rapid economic growth the natural resources have been adversely affected around the globe (Suleman et al., 2024; Kayani, 2025; Kayani, 2024; Nawaz et al., 2025; Tariq et al., 2025), and the developing countries are trying to achieve development by skipping the usual long process of industrialization (Nawaz et al., 2024 and Kayani, 2022). There is no clear relationship between growth and pollution in various countries and the Nexus may differ from one country to the other. For instance, (Espoir et al., 2021) conclude that some countries have a bilateral causal relationship between growth and emissions while other countries have a unidirectional relationship either from growth to emissions or from emissions to growth. Therefore, it may be pointed out that the successful management of economic expansion and the use of RE could support minimizing the impacts of ED on the environment (Espoir et al., 2023). Nonetheless, economic prosperity is one of the most important factors that affect pollution, but the quality of governance plays a significant role in this regard. Thus, in the cities whose mayors have higher education levels, the negative impacts of the growth targets on pollution are negligible (Guo et al., 2024). Similarly, there is evidence that shows that the increased efforts towards good governance may also have long-term effects on emissions reduction (Espoir et al., 2023).

Along the same line, technological advancement and green technologies are also important in the process of dematerializing the economy and decoupling the GDP from pollution emissions. However, as per the study of (Wang et al., 2021), economic expectations may hinder technological advancement which in turn leads to pollution. Not all the sectors are the same in terms of contributing to the pollution of emissions. For instance, (Ali et al., 2023) argued that agriculture production plays a role in decreasing pollution in Sub-Saharan Africa while non-renewable energy investments play a role in increasing pollution. However, ED is not the sole determinant of emissions since other determinants including the governance, technological advancement, and characteristics of the region may also determine environmental quality.

The assessment of the impacts of RE on pollution emissions is an important subject, considering the current trends towards sustainable development and the decrease of greenhouse gases (GHG). The literature review also supports the idea that RE has the potential to reduce pollution emissions, including CO_2. To achieve this objective of the study, this review compiles the results of various prior research to establish the overall effect of RE on pollution emissions. In recent research, (Adanma and Ogunbiyi, 2024) demonstrates that the use of RE has a positive impact on the reduction of GHG emissions, especially CO_2. This has been a global trend, especially in the energy sector where RE sources are replacing conventional sources, which are fossil fuels thus lowering emissions. Research on the EKC model highlighted that RE has been observed to help decrease emissions in many cases. In a recent study work of (Mahmood et al., 2023), the authors claimed that 64 out of 69 studies are in support of the EKC hypothesis whereby RE results in emission reductions, this was well confirmed in both panel and country-specific analysis. As per (Skowron et al., 2023), the correlation between RE and CO_2 emission demonstrates the negative correlation between the two indices of which the production of RE leads to the decrease of CO_2 emission. This correlation highlights the role of RE in the SDGs and the Paris Agreement which were set to be achieved by the year 2030 and 2050 respectively.

The efficiency of RE in the reduction of CO_2 emission highly depends on human capital. According to the study (Shabani, 2024), human capital indices enhance the effect of RE towards emissions reduction especially in countries with a high human capital index. Real income is also another economic factor that also influences RE consumption and emissions. In lower-income nations, using RE, emissions are cut down but the interplay with real income may be ambiguous, indicating that economic measures should consider these interconnections to yield the best environmental results (Ehigiamusoe and Dogan, 2022). The research of (Chen et al., 2023) has also established that RE in China has the potential to decrease air pollution even though the country's economic activities still depend on fossil energy. This shows that more funding and development should be made on RE to enable the attainment of carbon neutrality. In the African regions, (Aouini et al., 2023) revealed that as the levels of development increase, the consumption of RE is also on the rise and this has been associated with the reduction of CO_2 emissions thus supporting the EKC hypothesis. This implies that renewable energy can be useful in the reduction of pollution, especially in the developing world.

Technological development in RE is important to minimize the emission of GHGs and encourage sustainability. These innovations assist in switching from the use of carbon-based fossil fuels that contribute to the emission of GHGs which are the major causes of pollution to cleaner sources of energy (Medvedkina and Khodochenko, 2020). The literature review also stresses that support from the government and international organizations plays a crucial role in the switch to renewable energy. Regarding, (Adanma and Ogunbiyi, 2024) asserted that the strategic recommendations include increasing technological advancement and increasing globalization initiatives. On the positive side, the utilization of RE sources has been proven to reduce pollution but certain issues still exist. The costs of RE technologies may prevent their use in many areas to optimize the production of energy. Also, the interdependence between renewable energy and other economic indicators, for instance, income levels, makes it hard to establish the link between energy usage and emissions. Hence, the need to integrate both the environmental and economic factors to foster a sustainable energy transition cannot be overemphasized (Freires et al., 2023).

Energy efficiency and human capital as factors affecting pollution emissions is a rather complex issue that has attracted much interest in recent literature. Energy efficiency and human capital can be considered effective factors in pollution emissions reduction as they facilitate the shift towards sustainable energy use and enhance environmental standards. In this section, the study compiles the conclusions of the different works to understand the way in which all these factors influence the levels of pollution emissions. Research has indicated that enhancements in energy efficiency can result in a large cut in CO_2 emissions. For example, (Zhang et al., 2022) examined RCEP economies and the results indicated that energy efficiency and environmental-related technological innovations help to cut down CO_2 emissions. But in certain areas including Angara-Yenisey Siberia, energy efficiency had no relation with air pollution, which could be attributed to path dependence and gradual shifts to the green economy (Pyzheva et al., 2021). The energy efficiency, of which the main role belongs to renewable energy sources, is also discussed. Some regional evidence for the EU and Central Asia indicates that RE consumption strongly and negatively affects CO_2 emissions, thus underlining the need for the development of the necessary infrastructure to support emission reductions, which is the global motive against climate change (Kuziboev et al., 2023).

In the same line, human capital is a key factor in controlling pollution emissions as demonstrated in the literature. Several works have shown that increased levels of human capital, which can be defined as education and skills, are linked to reduced emissions. For instance, (Rahman et al., 2024) inspected the South Asian region and concluded that human capital can be detrimental to

CO_2 emissions, which means that education and health expenditure can enhance environmental standards. Similarly, (Zhang et al., 2023) claim that human capital is evidenced to have effects in China where human capital particularly through education has been seen to decrease CO_2 emissions by replacing energy use. In the corporate world for instance, (Umar et al., 2022) argued that the management of human capital leads to a reduction in carbon footprint through the transition to clean energy sources. Human capital is also related to RE in a meaningful way. In a study of 67 countries, (Shabani, 2024) noted that the effect of RE on CO_2 emissions reduction is considerably higher at certain thresholds of the human capital index.

There are several research which demonstrate the synergetic effect of energy efficiency and human capital. For example, (Zhang et al., 2022) analyzed the RCEP economies and revealed that energy efficiency and human capital are the significant elements that have a negative impact on CO_2 emissions, which underlines the need to include these factors in the policies. In the case of the developing countries, (Zhang and Xu, 2023) conclude that human capital and RE have been seen to enhance environmental standards through reduced CO_2 emissions. This means that any policies which aim at improving energy efficiency and human capital may help in the reduction of pollution emissions. Some of the previous studies have established that energy efficiency and human capital have a positive relationship with the reduction of pollution emissions, but the current literature shows that the impacts of these factors may differ across regions and economic development levels. For instance, in the USA, no statistically significant correlation was identified between the human capital and the environment meaning that in some circumstances other factors like migration and financial development may be more important (Dedeoğlu et al., 2021). This shows that it is important to develop specific strategies that consider local factors and circumstances in view of policy formulation for controlling pollution emissions.

The link between ED, RE, and CO_2 emission has been of interest to many scholars in recent years. Several authors have established that adopting green energy has the potential of lowering emissions while enabling economic prosperity (Apergis et al., 2010; Bildirici, 2013). For instance, (Shafiei and Salim, 2014) showed that green energy consumption leads to the reduction in CO_2 emissions in the OECD countries. But the findings are not the same for all the economies and time horizons. Apart from ED and RE, energy efficiency has been recognized as an important element for reducing emissions while sustaining ED (Rajbhandari and Zhang, 2018). Besides, human capital has turned out to be another critical factor that influences the environment. In their study, (Bano et al., 2018) also established that human capital development helps to minimize CO_2 emission through innovation and awareness. However, the relationship between these factors is not entirely clear and may well be context-specific, thus requiring country-level research to guide policy making.

Nonetheless, there are some research gaps which can be identified from the literature on economic expansion, green energy and CO_2 emissions. Firstly, most of the works' concern developed countries or large emerging markets, whereas only a few investigate transition economies such as Turkey (Ozturk and Acaravci, 2010). Secondly, it is possible to emphasize energy efficiency as a factor that may influence the relationship between ED and emissions, although this factor can have substantial importance (Proskuryakova and Kovalev, 2015). Thirdly, how human capital affects environmental quality and especially green energy is still a relatively uncharted area of research (Zafar et al., 2019). In addition, only a handful of previous studies has aimed at incorporating all these aspects - economic expansion, green energy, energy efficiency and human capital - within a single model estimating the state of the environment. This research intends to fill these gaps by offering a systematic examination of these interdependencies within the Bulgarian context with the intention of advancing theoretical knowledge as well as policy recommendations for other transition economies.

3. DATA AND METHODOLOGY

3.1. Data and Variables

We took carbon dioxide emissions (CO_2) as dependent variable and GDP growth and renewable energy consumption as independent variables. We extracted the annual time series data for our variables from World Development Indicators and the data is ranging from the period 1990-2020. The further description of the variables is shared below in the Table 1.

3.2. Econometric Model

Our purpose is to measure the impact of GDP growth and renewable energy consumption upon the carbon emissions of Bulgaria. Theoretically, GDP has significant positive impact upon CO_2 (Kasperowicz, 2015; Gonzalez-Álvarez and Montanes, 2023; Ameyaw and Yao, 2018). Whereas renewable energy consumption has significant negative impact upon CO_2 (Mukhtarov et al., 2022; Gyimah et al., 2024). So, CO_2 is dependent upon GDP growth and renewable energy consumption as in our model below.

$$CO2_t = (GDP_t, REW_t) \quad (1)$$

The general model to be estimated is shared below

$$CO2_t = b_0 + b_1 GDP_t + b_2 REW_t + e_t \quad (2)$$

Where

CO_2 = C02 Emissions (metric tons per capita)

GDP = GDP growth (annual %)

REW = Renewable Energy Consumption

t = time from 1990 to 2020

et = error term.

Table 1: Data and variables description

Variables	Symbols	Description and measurement scale	Data source
Carbon emissions	CO_2	CO_2 emissions (metric tons per capita).	WDI, 2024.
GDP growth	GDP	GDP growth (annual %).	WDI, 2024.
Renewable energy consumption	REW	Renewable energy consumption (% of total final energy consumption).	WDI, 2024.

Table 2: Summary statistics for the selected variables

Variables	Mean	Median	Maximum value	Minimum value	Standard deviation	Skewness
CO_2	6.181818	6.164795	8.442677	4.923280	0.641847	1.109561
GDP	0.997065	2.745927	7.056350	−14.11538	5.497099	−1.145833
REW	10.25484	9.600000	21.10000	1.800000	6.128776	0.202092

The long-run relationship can be specified via auto regressive distributed lag model equation as below:

$$CO2_t = b_0 + b_1 CO2_{t-1} + b_2 GDP_{t-1} + b_3 REW_{t-1} + e_t \quad (3)$$

Whereas b_1, b_2 and b_3 are the long-run coefficients and e_t is the error term. We apply ARDL bounds test when the variables are having mixed stationary. But for sure, no variable can be stationary at I(2) as the F-Stats get invalid if any of the variable is I(2).

4. EMPIRICAL RESULTS AND DISCUSSION

4.1. Descriptive Statistics

As a preliminary analysis, we analysed the statistical properties of the variables in Table 2. The results are reporting the means, standard deviation, minimum, maximum and standard deviation. The statistics for the variables indicate that data is normal and there is no issue of outliers or the missing variables.

The mean value of CO_2 is 6.18 with a minimum value of 4.9 in 2020 and a maximum value of 8.44 in 1990. The mean of GDP is 0.99, with a minimum value of −14.11 in 1997 and a maximum of 7.05 in 2005. The lowest recorded GDP is −14.11, indicating that some observations are negative, likely representing periods of economic contraction or downturns. Finally, the minimum and maximum values of renewable energy consumption are 1.80 and 21.10 in the years 1990 and 2020 respectively.

4.2. Augmented Dicky Fuller (ADF) Unit Root Test

To find the stationary of the variables, we use the Augmented Dicky Fuller (ADF) unit root test as was being proposed by Dickey and Fuller (1979). Determining the stationary of the variables is one of the important requirements for applying ARDL Bounds test; the purpose is to make sure that variables are not integrated of second order I(2). After applying ADF unit root test we found that our variables are stationary at I(0) and I(1). The results of ADF root test are presented below in Table 3.

Table 3: ADF unit root test for stationary

Variable	Symbol	ADF (level)	ADF (1st difference)
Carbon emissions	CO_2	Stationary	N/A
GDP growth	GDP	Non-stationary	Stationary
Renewable energy consumption	REW	Non-stationary	Stationary

4.3. ARDL Bounds Test

The ARDL bounds test is used to estimate the long-run relationship between variables in a model. Additionally, it addresses the issue of spurious regression. Traditional time series tests, such as those by Engle and Granger (1987) and Johansen (1988), were initially applicable only when variables were integrated of the same order. However, these tests failed with variables of different integration orders, leading to the introduction of the ARDL co-integration model by Pesaran et al. (2001).

The ARDL model provides a solution to spurious regression and is effective even when dealing with variables with mixed co-integration. Long-run relationships are indicated if the F-statistics exceed the upper bound value. If the F-statistics are below the lower bound, it suggests no co-integration. If the F-statistic falls between the upper and lower bounds, the result is in-conclusive.

Table 4: ARDL bounds test results

Test statistics	Value	K
F-statistics	13.37147	2
	Critical value bounds	
Significance level	I (0)	I (1)
10%	3.17	4.14
5%	3.79	4.85
2.5%	4.41	5.52
1%	5.15	6.36

Table 4 shows that the F-statistics exceed both the lower and upper bound values, indicating the presence of co-integration in our model. The calculated F-statistic (13.37) is greater than the critical value for the 1% significance level (6.36) and the 5% significance level (4.85). This suggests that the null hypothesis of no long-run relationship can be rejected. Thus, based on this test, there is evidence of a long-run relationship between the variables in the model, as the F-statistic exceeds the critical bounds at the typical significance levels.

Table 5: ARDL long-run estimate results

Variable	Coefficient	Standard error	T-statistics	P-value
GDP	0.072244	0.034844	2.073396	0.0486
REW	−0.036580	0.021034	−1.739079	0.0943

Dependent variable = CO_2 and Independent variables = GDP and REW

4.4. ARDL Long-run Estimates

After employing unit root tests (ADF), we applied the Autoregressive Distributed Lag model (ARDL) to investigate the long-run relationships between the dependent and independent variables (CO_2, GDP, REW). Table 5 below is representing the results being generated from applying the ARDL Bounds test; GDP has a significant positive impact upon CO_2 and renewable energy consumption has insignificant negative impact upon CO_2 of Bulgaria. The coefficient of GDP (0.072244) is indicating that a 1-unit increase in GDP is associated with a 0.072 increase in CO_2 in the long run, assuming all other factors remain constant. Since the $P < 0.05$, we can reject the null hypothesis and conclude that

Figure 3: Cumulative sum of recursive residuals

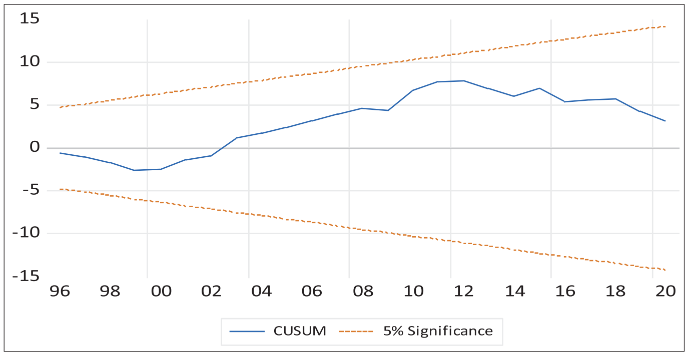
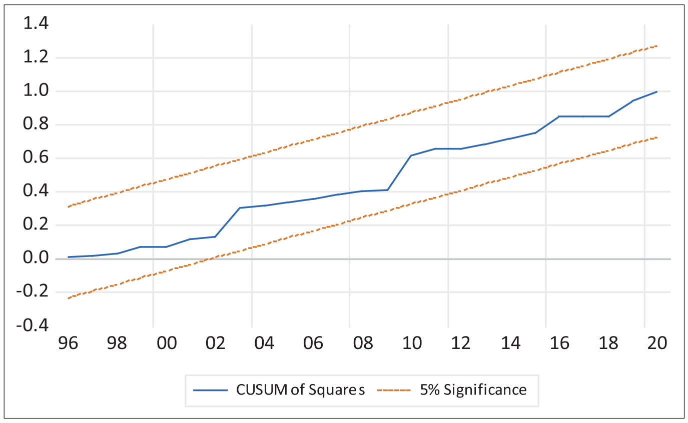


Figure 4: Cumulative sum of squares of recursive residuals



GDP has a statistically significant positive effect on CO_2 at the 5% significance level. The coefficient of REW (0.036580) indicates that a 1-unit increase in REW is associated with a 0.037 decrease in CO_2 in the long run, assuming all other factors remain constant. This suggests a negative relationship between REW and CO_2. This P-value is slightly above 0.05, meaning that the REW variable has a marginally significant negative relationship with CO_2. It's not statistically significant at the 5% level, but it could be at the 10% significance level. If the significance threshold were set at 10%, we would consider this negative relationship to be significant.

4.5. Stability Diagnostic Test

For gauging the stability of long-run coefficients we used the cumulative sum and cumulative sum of square test of recursive residuals (Brown et al., 1975). From Figures 3 and 4 we can see that coefficients are stable at a 5% confidence interval.

5. CONCLUSION AND RECOMMENDATIONS

We examined the impact of economic growth and renewable energy consumption upon the carbon emissions of Bulgaria. We found that there is a valid long-run relationship between the variables of our model under the ARDL-bound testing approach. The results showed that GDP has significant positive impact upon the CO_2 of Bulgaria; renewable energy consumption has insignificant negative impact upon CO_2 of Bulgaria. This shows that renewable energy sector is bit ignored in Bulgaria now; although Bulgaria is committed to achieve the goal of using renewables by around 27% by 2030. Bulgaria has also committed to decarbonize the economy by 2050 under the National Energy and Climate Plan as a part of European Green Deal.

The Russia-Ukraine war could be a blessing in disguise for Bulgaria; it could help Bulgaria for reducing the excessive dependence on fossil fuel energy consumption. As the Moscow's decision to halt the gas exports to Bulgaria and Southeast European economies created a vital opportunity for them to switch towards renewables and to invest more in the energy-efficient solutions. It is a proven fact that electricity generation with renewable energy produces minimal or even zero CO_2 emissions; thus, positioning renewable energy as a greener alternative to fossil fuels. According to the estimates, Bulgaria needs about USD 08 Billion to replace the coal plants energy with renewable energy within the next 10 years. The low wages and the pensions are also contributing to greenhouse gases emissions (GHGs) in Bulgaria as most of the people are unable to afford the sustainable means of cooking and heating especially in the winter.

We suggest that Bulgaria needs to promote clean and environmentally friendly technologies to promote the sustainable development. The government also needs to monitor and regulate the highly polluted foreign investment inflows and to impose the environmental tax upon the domestic carbon emitting firms. To promote green development, subsidies need to be provided upon renewable energy consumption to reduce the dependence upon fossil fuel energy consumption. The investors should be encouraged to finance the various research projects that focus upon developing clean technologies. To promote renewable energy consumption, there is also a need to promote education and awareness among the common masses about the benefits of renewable energy consumption. By adopting this approach, Bulgaria would be able to build a well informed and the engaged society, thus accelerating the efforts of transition towards a more sustainable and a greener society. Preferential treatment is also recommended for those investors who consider the adoption of green technologies and sustainable production. The developed economies of European Union also need to share the technological knowledge that would help the Bulgaria and the East European economies to produce the quality and cost-efficient clean technologies.

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