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The Impact of Renewable Energy Sources on the Sustainable Development of the Economy and Greenhouse Gas Emissions

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Abstract: Growing population and limited energy resources have impacted energy consumption. Limited fossil fuel resources and increased pollution threaten national and human societies. These elements emphasize energy sources. Renewable energy use affects growth. All new energy sources, including renewables, are crucial for global economic growth. Economic and environmental issues have led to new approaches in international environmental law, including the green economy. This study employs structural vector auto-regression (SVAR) to compare the effects and outcomes of increasing the use of renewable energy in the context of economic growth and greenhouse gas emissions in middle income countries (MICs) and high income countries (HICs). The results show that these indicators demonstrate that the production of energy from renewable sources has positive short-term and long-term economic effects with varying contributions. However, renewable energies have a greater impact on the green economy in selected MICs than in selected HICs. Therefore, the promotion of macroeconomic indicators is viewed as one of the reasons for the development of policies to increase energy production from renewable sources in selected countries.

Keywords: renewable energy source; GDP; CO_2 emission; economy

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1. Introduction

The subject of climate change is a significant one that has led to a great deal of difficulty globally [1–3]. The burning of fossil fuels contributes to the acceleration of climate change [4,5]. As a result, the utilization of environmentally friendly and renewable energy sources (RESs) can be a suitable alternative to the utilization of fossil fuels. [6]. These resources are replenishable, and in addition, they do not produce any pollution; as a result, they contribute to the conservation of the environment [7,8].

Investment in renewable energy can become a new stimulus for economic growth, increase in national income, improvement of trade balance, development of industries, and increase in employment [9]. Some countries with a low and middle economic growth rate can provide the basis for its improvement and promotion through the adoption of optimal policies for the development of renewable energies. For this purpose, first of all, there should be a correct understanding of the economic value of the development of renewable energies and its value-adding parts [10]. Therefore, it is necessary to identify the influencing variables in the first step and then evaluate the contribution of each of them in the value chain of renewable energy development [11]. Value creation, from the perspective of the traditional definition of economy, includes a wide range of economic benefits for countries with a sustainable development approach. In other words, value creation includes job creation, improvement of health and education, reduction in poverty, and reduction in negative environmental effects [12,13]. The development of renewable energy has created millions of jobs directly and indirectly [14].

It Is very difficult and complex to conceptualize economic works in a comprehensive and complete framework that can be measured, collected, and compared, as numerical measurement of some variables, such as education, is very difficult [15]. On the other hand, the prioritization between variables is not the same for different countries, and as a result, the effects of project changes will also be different [16].

Many economic systems are dynamic, complex, unpredictable, and sensitive to the initial conditions [17]. Therefore, using mathematical and econometric models, it is not possible to achieve a correct understanding of economic and social systems and to analyze and predict the relationships between them. Most of the time, one of the two modeling-based econometric methods or economic analysis are used in economic studies and reviews to look at how indicators affect each other [18]. Valid international reports, databases, and existing articles should answer this basic question: what has the development of renewable energies done to macroeconomic indicators in different countries? The effects of the development of renewable energies on each of them have been studied [19].

Although the benefits of renewable energy development are increasing significantly, few economic analysis studies have been undertaken in this field. In this article, we have discussed the potential capacities in different parts of the renewable energy value chain, focusing on the development of solar and wind energy [20]. In the following, we have discussed the impact of the development of renewable energies on employment and the added value resulting from the development of renewable energies. Furthermore, how the development of renewable energy affects the GDP and the impact of renewable energy on public welfare have also been investigated [21].

The economic and social effects of renewable energy development are divided into four main sections: economic effects, distribution effects, energy system development effects, and other effects [22]. In order to examine each of these works, it is necessary to identify the main and influential indicators. Some of the most important indicators are: employment, added value, gross domestic product, and economic prosperity [23].

Most of the studies conducted regarding the impact of the development of renewable energies on the mentioned indicators are limited to the estimation and analysis of the changes made in economic growth due to the use of renewable energies, some of which are mentioned below.

Some researchers have investigated the relationship between the development of renewable and non-renewable energy consumption on economic growth in different countries. The results show the existence of a positive and significant relationship between the consumption of renewable energy and economic growth in the long term [24–26]. Furthermore, there is a two-way causal relationship between non-renewable energy consumption and economic growth in the long and short term [27].

Wang et al. [28] determined if and how trade decouples carbon emissions. To analyze and quantify the impact, Tapio decoupling and structural threshold models are combined. The analysis includeed panel data from 2000 to 2018 for 124 countries. Results revealed a weak dissociation between trade openness, economic growth, and carbon emissions. Using the EKC theory, Wang et al. [29] evaluated trade openness, human capital, renewable energy, and natural resource rent on carbon emissions. Second-generation econometric tests, GMM, and FMOLS were developed from 1990 to 2018. Open trade, human capital, renewable energy consumption, and natural resource rents confirm EKC. Wang et al. [30] studied income inequality's impact on the EKC hypothesis. Income inequality is the threshold variable, economic growth is the explanatory variable, and carbon emission is the explained variable. The threshold panel model was created utilizing the data of 56 economies. The empirical results revealed that income inequality has shifted the link between economic growth and carbon emissions from an inverted U-shaped to an N-shaped curve, which increases the complexity of decoupling economic development and carbon emissions. Li et al. [31] investigated the impact of structural changes on per capita carbon emissions from energy, trade, society, and economics. From 1990 to 2015, 147 countries and four income categories were evaluated using OLS, FMOLS, and the Granger causality test. Global carbon emissions were most affected by economic growth and structure.

In addition, by using the panel co-accumulation method, Pao et al. investigated the relationship between economic growth and the demand for renewable energy and environmental pollutants in the countries of Mexico, Indonesia, South Korea, and Turkey [32]. The results show that the long-term causal relationship is from the side of renewable energy demand towards economic growth, and the relationship between them is positive in the short term.

Based on the cointegration technique and the panel vector error correction model, Cho et al. investigated the relationship between renewable energy consumption and economic growth [33]. By examining the causality between the variables of renewable energy consumption and economic growth, they concluded that there is a long-term equilibrium relationship between the variables of renewable energy consumption, economic growth, capital, and labor.

In South America, a specific study regarding the impact of renewable energy development on macroeconomic indicators has not been conducted in a consistent manner. Furthermore, considering the environmental concerns caused by the consumption of fossil fuels, it is inevitable to choose appropriate policies for the development of investment and consumption of renewable energies [34]. The requirement of this important matter is the awareness of the policy makers and planners regarding how the development of renewable energies affects macroeconomic variables in order to make appropriate decisions. The evidence shows that although the potential for middle income countries to use renewable resources is very high, they have not been properly exploited so far [35].

Making significant investments in the field of renewable energy has caused many changes in the global energy industry and the rapid growth of the global share of renewable energy in the total amount of electricity production. Although dealing with climate change is one of the main and important goals of renewable energy development, decentralization of energy systems and the resulting positive economic effects are the most important goals of renewable energy development. On the other hand, the evaluation of the actions resulting from the economic effects of renewable energies on the development of regions is faced with many methodological and experimental limitations. Investigating the added value of renewable energy development is one of the proposed solutions to measure its economic impact on different societies [36].

This study aims to investigate and compare the effects and results of increasing the use of renewable energy in the process of economic growth and gas emissions in middle income countries (MICs) and high income countries (HICs) using the structural vector auto-regression (SVAR) model. The next section is devoted to the review of the subject literature and the introduction of the research method, in the third section, the experimental model and the results of this research are presented, and finally, the conclusion and recommendations will be found in the fourth section.

2. Method

Investigating the development of renewable energies on macroeconomic indicators has received increasing attention in recent years. In this research, based on the economic analysis method and according to the identified macroeconomic indicators, the impact of the development of renewable energies on each of these indicators is scientifically analyzed and investigated. Using theoretical foundations and empirical study to investigate the impact of renewable energies on the green economy, 3 variable (CO_2, RES, and GDP) SVAR models have been used with adjustments.

In this study, the long-term limitation method was used, and the X_t vector included the considered variables in the form of the following relationship, in which Equation (1) exists:

$$X_t = (LRES, LGDP, LCO_2) \tag{1}$$

where, $LRES$, $LGDP$, and LCO_2 are the logarithm of renewable energy source consumption, gross domestic product, and carbon dioxide emissions (the main greenhouse gas) as an indicator of the green economy, respectively.

The data of renewable energy consumption and greenhouse gas emissions have been collected from the Energy Information Administration (EIA). The statistical population was selected based on the criteria of the World Bank. The World Bank classifies countries according to geographic regions or according to income level. The selected countries in this study were selected based on income level. The World Bank has classified countries based on per capita income into low-income, middle-income, and high-income countries [37]. In addition, in order to compare the impact of renewable energies on the green economy in 2 different structures, another group has been selected in this article. This group includes countries with HICs. It should be noted that in the selection of selected MICs and HICs, the selected countries are producers and consumers of renewable energy. In addition, the statistical data of the variables used in this article were available.

In economic data, it is assumed that there is a long-term and balanced relationship between the variables mentioned in an economic theory. In applied econometric analysis, in order to estimate long-term relationships between variables, their mean and variance are considered constant over time and independent of the time factor, and as a result, behavioral stability is implicitly assumed for them. However, it has been found in applied research that in most cases the stability of behavior with time series variables is not realized.

It is possible to interpret the model by forming orthogonal structural impulses. In this study, 3 structural impulses are formed in the form of a matrix, which are presented in Equation (2):

$$\varepsilon_{\mathrm{t}} = \left(\varepsilon^{LRES}, \varepsilon^{LGDP}, \varepsilon^{LCO_2}\right) \tag{2}$$

where, ε^{LRES}, ε^{LGDP} , and ε^{LCO_2} are the impulses of renewable energy source consumption, gross domestic product, and carbon dioxide emissions, respectively. Based on this, Equation (1) can be expressed in matrix form as follows:

$$\begin{bmatrix} LRES \\ LGDP \\ LCO_2 \end{bmatrix} = \begin{bmatrix} M_{11}(L) & M_{12}(L) & M_{13}(L) \\ M_{21}(L) & M_{22}(L) & M_{23}(L) \\ M_{31}(L) & M_{32}(L) & M_{33}(L) \end{bmatrix} \begin{bmatrix} \varepsilon^{LRES} \\ \varepsilon^{LGDP} \\ \varepsilon^{LCO_2} \end{bmatrix} \tag{3}$$

In this matrix, $M(L) = \sum_{J=0}^{\infty} M_J(L)$ represents the long-term matrix $M(L)$. The variables are arranged as CO_2, GDP, RES and it is assumed that the first variable, that is, RES, affects GDP and CO_2 variables, but does not receive any effect from these variables. The second variable, GDP, only received a shock from the first variable and has no effect on the first variable, but it can affect the CO_2 variable. In this order, the matrix of long-term coefficients will be formed in the form of a lower triangular matrix:

$$\begin{bmatrix} M_{11}(L) & 0 & 0 \\ M_{21}(L) & M_{22}(L) & 0 \\ M_{31}(L) & M_{32}(L) & M_{33}(L) \end{bmatrix} \tag{4}$$

2.1. The Granger Causality Test

The Granger causality test was used to find the direction of causality between the gross domestic product and the amount of renewable energy consumption [38]. After confirming the existence of the causal relationship and determining its direction, we will model and examine the relationship between the above variables. In the regression method, the main goal is to check if there is a relationship between the dependent variables and between the independent variables of the research [39,40]. In addition, the data analysis will be undertaken in the descriptive statistics section by calculating the central indices including mean, median, and dispersion indices of the standard deviation of skewness and skewness elongation.

First, due to the importance of the validity of the data in the reliability of the results of statistical tests, we have checked the validity of the data. In the following and after proving the existence of the relationship of causality and its direction, mixed data and methods of fixed effects and random effects were used to test the hypotheses.

Granger causality test results are very sensitive to the choice of lag length; if the length of the selected interval is less than the length of the actual interval, the removal of appropriate intervals causes bias, and if the length of the selected interval is longer than the length of the actual interval, the additional intervals in the VAR model make the estimates ineffective. Therefore, the main problem of the standard Granger causality test is the great sensitivity to the choice of the interval length, so that different interval lengths will lead to different results in most cases [41]. For this reason, in order to solve the problem and choose the optimal interval length for each of the variables, it was introduced the method of systematic self-explanation

Choosing the optimal interval length in Granger causality tests is undertaken in 2 steps. In the first step, sums of self-explanatory regressions on the dependent variable are estimated [42]. In the regression equations of this step, the dependent variable interval is started from 1, and then an interval is added to each regression compared with the next regression. It is better to increase the length of the break as much as possible.

The regressions that are estimated will be as follows:

$$\alpha \pm \left| \sum \sim \beta\gamma + (\varepsilon_{it}) \right. \tag{5}$$

After all the regressions are estimated, the final prediction error (FPE) measure is calculated for each regression equation.

$$\text{FPE(m)} = \frac{T+m+1}{T-m-1} \cdot \frac{ESS\ (m)}{T} \tag{6}$$

Where T is the sample size and ESS is the sum of squared residuals. The interval that produces the minimum FPE criterion will be the optimal interval length. The test ends with the determination of the first rank M In the second step, and other variable intervals enter the regression equations.

Sometimes the data that we are dealing with include both time series and cross-sectional data. Such a set of data is generally known as a panel of data or data panel.

2.2. F-Limmer Test

In estimating the panel data model, we face 2 general situations. The first case is that the width from the origin is the same for all sections, in which case we are faced with the data pool model [43]. In the second mode, the width from the origin is different for all sections, which is called data panel mode. To identify the above 2 cases, a test called F-Limmer is used. The F-Limmer test is used to choose between pool data and panel data (combined) regression methods.

The statistics of this test are as follows:

If the calculated values of F are less than the value of the table, the null hypothesis of F is accepted if the calculated values are calculated as F and only one width from the origin should be used. However, if it is a table, the null hypothesis is rejected and group effects are accepted, and the width of F more than different origins should be included in the estimation.

$$\text{F} = \frac{\left(R^2_{fe} - R^2_{pool}\right)/(n-1)}{\left(1 - R^2_{fe}\right)/\ (n-t-k)} \tag{7}$$

3. Results and Discussion

Reliability Test of Variables

Before estimating the model, it is necessary to be sure about the reliability of the variables, because unreliable variables cause false regression. For this reason, the Granger and F-Limmer tests are used to check the reliability of the variables. The results of the test show that all the variables were at a reliable level and were identified as non-significant depending on the level of zero. There is no differentiation in the variables. The results of this test are presented in Tables 1 and 2.

Table 1. Granger causality test result.

Effect	Cause: LRES		LGDP		LCO_2	
	MIC	**HIC**	**MIC**	**HIC**	**MIC**	**HIC**
LRES	-	-	-	-	-	-
LGDP	1.33 (0.38)	1.38 (0.103)	-	-	-	-
LCO_2	4.78 (0.22)	5.39 (0.44)	6.92 (0.11)	5.51 (0.29)	-	-

Parentheses are *p*-values.

Table 2. F-Limmer test result.

	F Value	*p* Value
MIC	66.29	0.193
HIC	51.55	0.202

Considering that the F-statistic of the research model is not significant at the 1% error level, the tabular data method is not preferred over the consolidated data method.

Instantaneous response functions actually show the dynamic behavior of variables over time and when an impulse as large as one standard deviation occurs. By using this tool, it is possible to analyze the interrelationships between variables in the SVAR model. Figures 1 and 2 show the reaction of system variables due to structural impulses equal to one standard deviation for the next 18 periods for MICs and HICs, respectively. The changes in GDP in response to the RES shock in MICs were unchanged until the first period and since then it has shown a positive response; this positive response is not only a fluctuating state, but it continues until the end of the period and also shows an increasing trend. This was consistent with the results of Wang and Wang's [44] findings. The positive response in HICs is constant and does not increase (Figure 2a). In the final estimate, the response of the changes to the GDP shock in MICs is estimated to be positive.

Figures 1b and 2b show the effect of GDP shock and the response of CO_2 changes to this shock in up to 18 periods in MICs and HICs, respectively. In MICs and HICs, changes in GDP did not change in the beginning until the second period, and in the third period, it shows a positive change. This response has also fluctuated, and its effect continues even until the end of the 18th period. A positive value has also been evaluated in the estimation of the relationship between GDP changes and RES. This shock for HICs has a positive change in the first period. However, it was constant in the other periods.

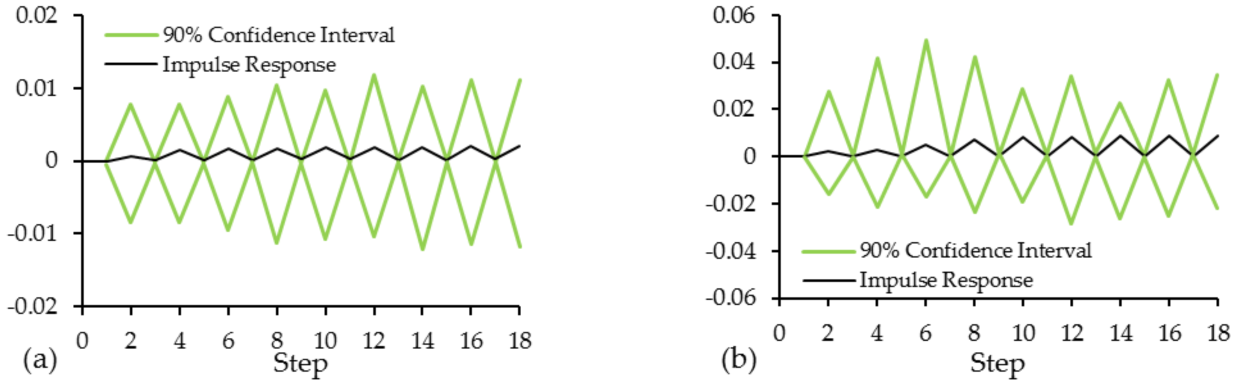

Figure 1. Analysis of the instantaneous response of (**a**) LGDP to the LRES shock, and (**b**) LCO2 to the LGDP shock for MICs.

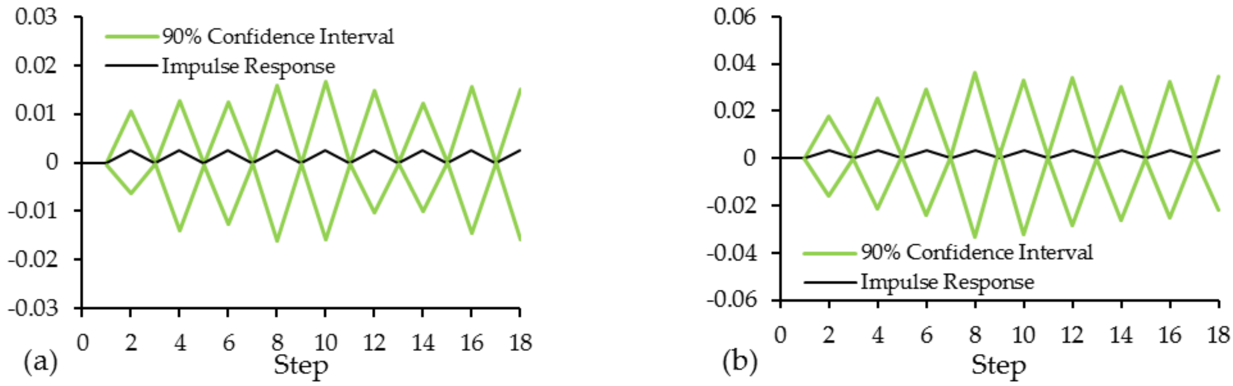

Figure 2. Analysis of the instantaneous response of (**a**) LGDP to the LRES shock, and (**b**) LCO2 to the LGDP shock for HICs.

In Figure 3, the RES shock effect on CO_2 changes up to 18 periods is shown. This Figure shows that up to the first time period, CO_2 did not show any response to the RES shock, and from the first period to the third period, it has an upward trend. From this stage onwards, it shows an increasing trend, and the shock will continue to do so until the end of the period. This was equal in MICs and HICs; however, this shock has more effect on the CO_2 in MICs than HICs. In the final estimate, as shown, the response of CO_2 changes to the RES shock in MICs is estimated to be positive.

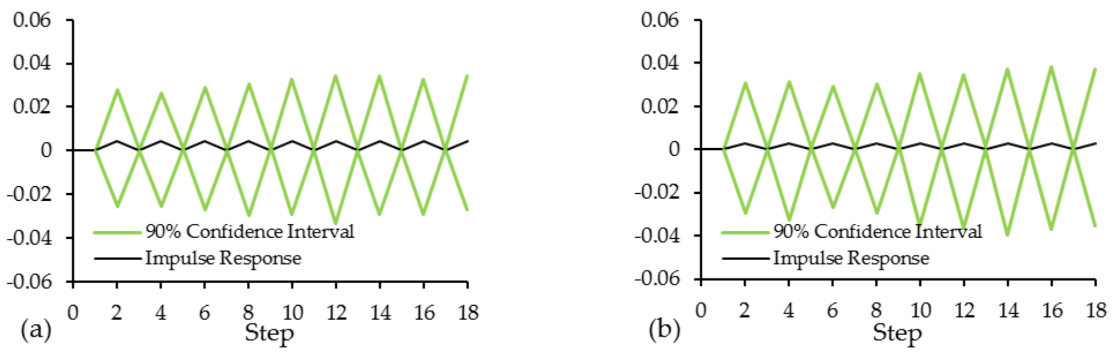

Figure 3. Analysis of the instantaneous response of LCO_2 to the LRES shock for (**a**) MICs and (**b**) HICs.

Instantaneous feedback functions are used to check the sign and how each variable changes due to different structural shocks; however, each of the shocks in the fluctuations of the variables have a different degree of importance. Therefore, in order to compare the importance of each of the shocks, the method of variance analysis can be used. This method explains the contribution of each of the structural shocks in the variance of the variables in the short term and the long term. It can be concluded to what extent the forecast error variance in the two variables, GDP and CO_2, is explained by the shocks imposed on the variables in the model for MICs and HICs (Figure 4). Based on this, it is observed that during this 18-year period, the shock of real production makes the largest contribution to its fluctuations. The CO_2 shock provided a higher explanatory power compared with other shocks, and GDP and RES shocks are in the following ranks, so that during this 18-year period, the contribution of GDP explanation is always higher than RESs. As a result, it will also have a higher contribution.

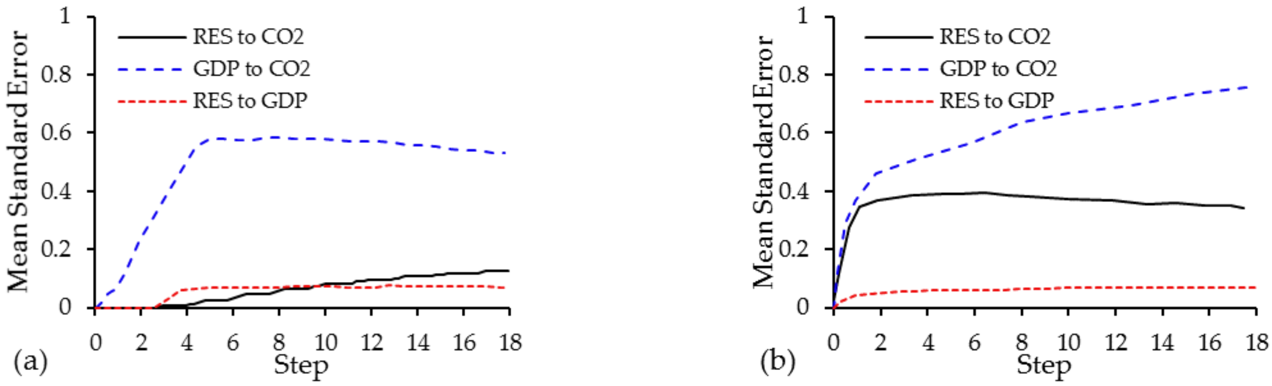

Figure 4. Variance analysis of (**a**) MICs and (**b**) HICs forecast error.

4. Conclusions

In recent years, concerns about the depletion of non-renewable energy resources and the pollution caused by the consumption of these types of resources have led many countries to consider RESs. For this reason, extensive studies have been conducted in relation to RESs and the methods of obtaining them, which has led to an increase in the production of renewable energy in developed and developing countries. For this purpose, our goal was to analyze the effect that increasing the share of renewable energy sources in the production of electricity can have on gross domestic product and the emission of greenhouse gases. In order to analyze the problem, we used several methods, including the SVAR method because this method pays attention to the interrelationships of all variables and is able to predict the effects of policies and important economic changes. Thus, in this study, a three-variable SVAR model (RESs, GDP, CO_2) was formed for MICs and HICs. In future research, this issue will be investigated using this model alongside instantaneous reaction functions and variance analysis.

The results of estimating the structural model of GDP and CO_2 show an effect on the autocorrelation vector that a positive shock in RESs has a positive effect on changes in economic growth. Since energy is a driving force in economic growth and development, it is expected that a positive relationship will be established. However, contrary to expectations, it was observed that the positive participation in RESs has a positive effect on CO_2 emissions, and we can see that in the economy of MICs the use of renewable energy has not reduced CO_2 emissions; the reason for this can be attributed to the low share of this type of energy in the total energy portfolio of the country searched so that despite the high capacity of RESs in MICs, very limited use of this energy source has been made. On the other hand, weak and old technology in the domestic production process has led to more CO_2 emissions and more energy use. This can become an important factor in neutralizing the positive effect of using RESs. In addition, variance analysis shows that the contribution of RESs in explaining the variance of GDP and CO_2 prediction error is at a low level.

Based on the obtained results, it is recommended that increasing the share of renewable energy from the total energy produced should be on the work horizon of politicians. Despite the high initial cost of renewable energy production, the jump in the GDP as a result of using this energy is obtained, and it can compensate the initial costs and bring more stable and reliable economic growth due to the stable nature of renewable energy. Regardless of economic fluctuations, it is important to use energy in the direction of growth and provide economic development. In addition to increasing energy security by increasing diversity in the country's energy portfolio, this will lead to improved population health due to its compatibility with the environment.

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