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IMPACT OF RENEWABLE ENERGY CONSUMPTION ON CO2 EMISSIONS IN TÜRKIYE: EVIDENCE FROM ARDL AND BAYER-HANCK COINTEGRATION TECHNIQUES

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Abstract. The present study aims to investigate the effects of economic growth, imports, exports, and renewable energy consumption on CO2 emissions in Türkiye using time series data ranging from 1990 to 2020. Stationarity of series was verified by using unit root tests including ADF and PP, while an autoregressive distributed lag (ARDL) model was used to check the dynamic association amid prescribed variables with long-run analysis. Additionally, the Bayer-Hanck (2013) method was used for the cointegration relationship between variables. The estimation results present that (i) economic growth and imports increase carbon emissions; (ii) renewable energy consumption reduces carbon emissions; (iii) export reduces carbon emissions. Based on the findings of this study, relevant policy recommendations are also presented at the end of the study.

Keywords: *Renewable energy consumption, ARDL Bound test, CO2, Bayer-Hanck cointegration.*

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1. Introduction

Fossil fuels were used intensively for 200 years until the 1973 oil crisis. The post-oil crisis period has been characterized by an environment of uncertainty regarding energy resources. This uncertainty regarding the use of fossil fuels led to insecurity. Thus, this insecurity stemming from fossil fuels has led to a global shift towards renewable energy sources. The widespread use of energy resources has revealed the need to ensure energy security. Due to the necessity of ensuring energy security, energy diversification has become one of the most important elements of energy policies. In addition, the rise in natural gas and oil prices in today's world has also brought the issue of energy diversification to the forefront. For these reasons, there is a rapid increase in the focus on renewable energy sources, which are essential for enhancing energy diversity. The inclination towards renewable energy sources gained momentum in the 1990s with the emergence of environmental awareness. Traditional energy production and consumption from fossil fuel sources contribute to regional and global greenhouse gas emissions, leading to global warming and ultimately climate change. Therefore, energy derived from renewable sources, which does not emit greenhouse gases into the atmosphere at least during the production phase, is referred to as 'clean energy.' (Çağlar, 2006; Çağlar & Mehmet, 2017).

In a broad sense, renewable energy sources are a continuously replenishing and less polluting energy system. Unlike fossil fuels, these sources do not contain CO2 emissions. Renewable energy sources are depicted in Figure 1. The fundamental advantage of renewable energy sources is their availability worldwide, depending on their geographic and geopolitical context. In other words, they are natural energy resources. Countries do not need to import them, and these sources help alleviate energy dependency issues (Çoban, 2015).

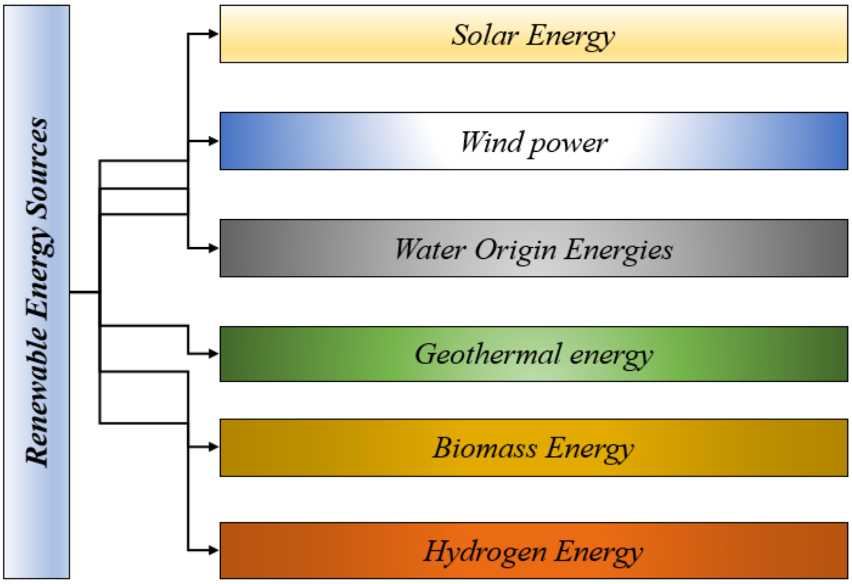

Fig. 1. Renewable energy sources

In this study, the impact of renewable energy consumption, exports, economic growth, and imports on carbon emissions in Turkey is investigated. There are numerous studies that examine the effect of renewable energy consumption on carbon emissions in Turkey. The distinctive feature of this study is the use of up-to-date data and the application of the Bayer-Hanck and ARDL cointegration methods together, which is expected to contribute to the literature. After the introduction section, the second section of the study provides a summary of the relevant literature. In the third section, the econometric model and variables are introduced. The fourth section presents information about the econometric methods used in the study. In the fifth section, the results obtained from the econometric methods are interpreted. Finally, in the sixth section, policy recommendations are presented based on the results.

2. Literature Review

There are numerous studies investigating the impact of renewable energy consumption on carbon emissions for Turkey and other countries. These studies employ various econometric methods and incorporate different variables into the econometric models. Table 1 presents previous studies on the effect of renewable energy consumption on carbon emissions. First, the focus is on studies conducted for Turkey. Using ARDL cointegration methods, Karaaslan and Çamkaya (2022), Raihan and Tuspekova (2022), and Pata and Yurtkuran (2018) have all concluded that renewable energy consumption reduces carbon emissions in Turkey. In another study conducted by Pata (2018), it was concluded that renewable energy consumption in Turkey does not have a significant impact on carbon emissions using Gregory-Hansen and Hatemi-J structural break cointegration tests. In many studies conducted for Turkey, it is observed that renewable energy consumption reduces carbon emissions, as indicated by Qashou et al. (2022), Abumunshar et al. (2020), Shan et al. (2021), and Çomuk et al. (2023).

Studies conducted for other countries also show that renewable energy consumption reduces carbon emissions. In the study by Pata et al. (2023), it was found that short-term renewable energy consumption reduces carbon emissions in ASEAN countries using the panel ARDL method. Bekun (2022) used the Johansen cointegration method and found that renewable energy consumption reduces carbon emissions in India. Mukhtarov et al. (2022), using the DOLS long-term forecasting method, concluded that renewable energy consumption reduced carbon emissions in Azerbaijan from 1993 to 2019. However, another study conducted for Azerbaijan by Hasanov et al. (2023) found no significant relationship between renewable energy consumption and carbon emissions. In another study, Hasanov et al. (2021) utilized the panel Westerlund cointegration method and reached the conclusion that renewable energy consumption reduces carbon emissions in BRICS countries. In studies conducted for various other countries, researchers such as Voumik et al. (2023), Apergis et al. (2023), Naseem and Guang (2021) generally find that renewable energy consumption reduces carbon emissions. This study aims to contribute to the literature by simultaneously employing the Bayer-Hanck and ARDL methods to examine the impact of renewable energy consumption on carbon emissions in Turkey, taking into account GDP, imports, and exports.

Table 1. Literature on the relationship of renewable energy consumption with the environment

Author	Countries	Data	Variables	Method	Result
Panel A: Studies focusing on Turkiye.					
Karaaslan and Çamkaya (2022)	Türkiye	1980-2016	CO2 || NREC, GDP, REC, HE	ARDL	REC reduces CO2 emissions in the short term.
Qashou et al. (2022)	Türkiye	1988-2018	CO2 || R, REM, REC, NREC	BARDL	REC reduces CO2 emissions.
Pata (2018)	Türkiye	1974-2014	CO2 || Y, Y2, URB, FD (REC, AEC, HEC)	ARDL, Gregory-Hansen and Hatemi-J	REC have no effect on CO2 emissions.
Abumunshar et al (2020)	Türkiye	1985-2015	CO2 || GDP, GDP2, OP, REC, NREC	BARDL, Bayer-Hanck, Hatami-j	REC reduces CO2 emissions.
Shan et al. (2021)	Türkiye	1990-2018	CO2 || POP, NREC, REC, PI, ENG, GTI	BARDL	REC reduces CO2 emissions.
Raihan and Tuspekova (2022)	Türkiye	1990-2020	CO2 || GDP, RNE, URB, IND, TR, AVA, FA	ARDL	REC reduces CO2 emissions.
Çağlar ve Mert (2017)	Türkiye	1960-2013	CO2 || GSYH, GSYH2, YEN	Gregory-Hansen and Hatemi- J	REC reduces CO2 emissions.
Pata and Yurtkuran (2018)	Türkiye	1981-2014	CO2 || Y, Y2, REC, FD, PD	ARDL	REC reduces CO2 emissions.
Çomuk et al. (2023)	Türkiye and EU countries.	2002-2019	CO2 || FDI, RE, GDP	FGLS	REC reduces CO2 emissions.

Panel B: Studies focusing on other countries.					
Pata et al. (2023)	ASEAN	1995-2018	CO2 || TOUR, FDI, GDP, REC, TO	panel ARDL	REC reduces CO2 emissions in the short term.
Bekun (2022)	India	1990-2016	CO2 || REC, NREC, GDP, IEC	Johansen	REC reduces CO2 emissions.
Mukhtarov et al. (2022)	Azerbaijan	1993-2019	CO2 || RE, Y, EXP, IMP	DOLS	REC reduces CO2 emissions.
Hasanov et al. (2021)	BRICS	1990-2020	CCO2 || X, M, Y, TFP, ER	Westerlund and Edgerton, Westerlund	REC reduces CO2 emissions.
Al-Mulali and Ozturk (2016)	27 advanced economies	1990-2012	CO2 || GDP, GDP2, RE, NR, TD, UR, PC	panel Kao and Fisher	REC reduces CO2 emissions.
Dogan and Seker (2016)	European Union	1980-2012	CO2 || REC, NREC, GDP, GDP2, TR	LM bootstrap panel cointegration	REC reduces CO2 emissions.
Adams and Acheampong (2019)	46 Sub-Saharan African countries	1980-2015	CO2 || RGDPG, RGDPG2, DEMO, REW	IV-GMM	REC reduces CO2 emissions.
Pata and Kartal (2023)	South Korea	1977-2018	CO2 || GDP, GDP2, REC, NEC	Bayer-Hanck and ARDL	REC have no effect on CO2 emissions.
Hasanov et al. (2023)	Azerbaijan	1991-2019	CO2 || EX, IMP, GDP, NEC, TFP	Johansen and ADL	REC have no effect on CO2 emissions.
Voumik et al. (2023)	SAARC	1982-2021	GHG || GDP, GDP2, REN, FOS, NUC	Westerlund	REC reduces CO2 emissions.
Apergis et al. (2023)	Uzbekistan	1985-2020	CO2 || HYD, COAL, OIL, GAS	ARDL	REC reduces CO2 emissions.
Naseem and Guang (2021)	SAARC	2000-2017	CO2 || REC, GDP, AG	GMM	REC reduces CO2 emissions.
Dong et al. (2018)	128 countries	1990-2014	CO2 || PS, GDP, RE	CCEMG	REC reduces CO2 emissions.
Wang et al. (2022)	Next-11 countries	1990-2015	CO2 || GDP, REC, FD, GLO	Driscoll–Kraay	REC reduces CO2 emissions.

3. Model and Data

The model described in Equation 1, as presented in the studies by Hasanov et al. (2021) and Mukhtarov et al. (2022), was established to investigate the influence of renewable energy consumption, economic growth, exports, and imports on carbon emissions within the Turkish context.

$$LCO2_t = \beta_0 + \beta_1 LREN_t + \beta_2 LGDP_t + \beta_3 LEX_t + \beta_4 LIMP_t + u_t \qquad (1)$$

In Equation 1, β_0 represents the constant term, and u_t denotes the error term. The definitions of the CO2, REN, GDP, EX, and IMP variables in the model are provided in Table 2. β_1, β_2, β_3, and β_4 indicate the elasticities of renewable energy consumption, real GDP per capita, export, and import, respectively. The analysis proceeded by taking the logarithm of all variables. The logarithmic form has been applied to all variables, and the dataset spans from 1990 to 2020 on an annual basis.

In Figure 2, time series graphs of the variables used in the study are presented. When examining the graphs, it can be observed that there is an increasing trend in all variables except for renewable energy consumption in Turkey. Additionally, there are breakpoints occurring over time. It is observed that macroeconomic variables in Turkey experienced abrupt breaks due to the 2000 and 2008 crises. The presence of increasing and decreasing trends in the variables' graphs indicates that relying on trend stationary unit root tests would be more accurate.

Table 2. Variable details

Variable	Symbol	Unit	Source
CO2 emissions	CO2	Metric tons per capita	World Bank (2023)
Imports of goods and services	IMP	Constant 2015 US$	World Bank (2023)
Exports of goods and services	EX	Constant 2015 US$	World Bank (2023)
GDP per capita	GDP	Constant 2015 US$	World Bank (2023)
Renewable energy consumption	REN	% of total final energy consumption	World Bank (2023)

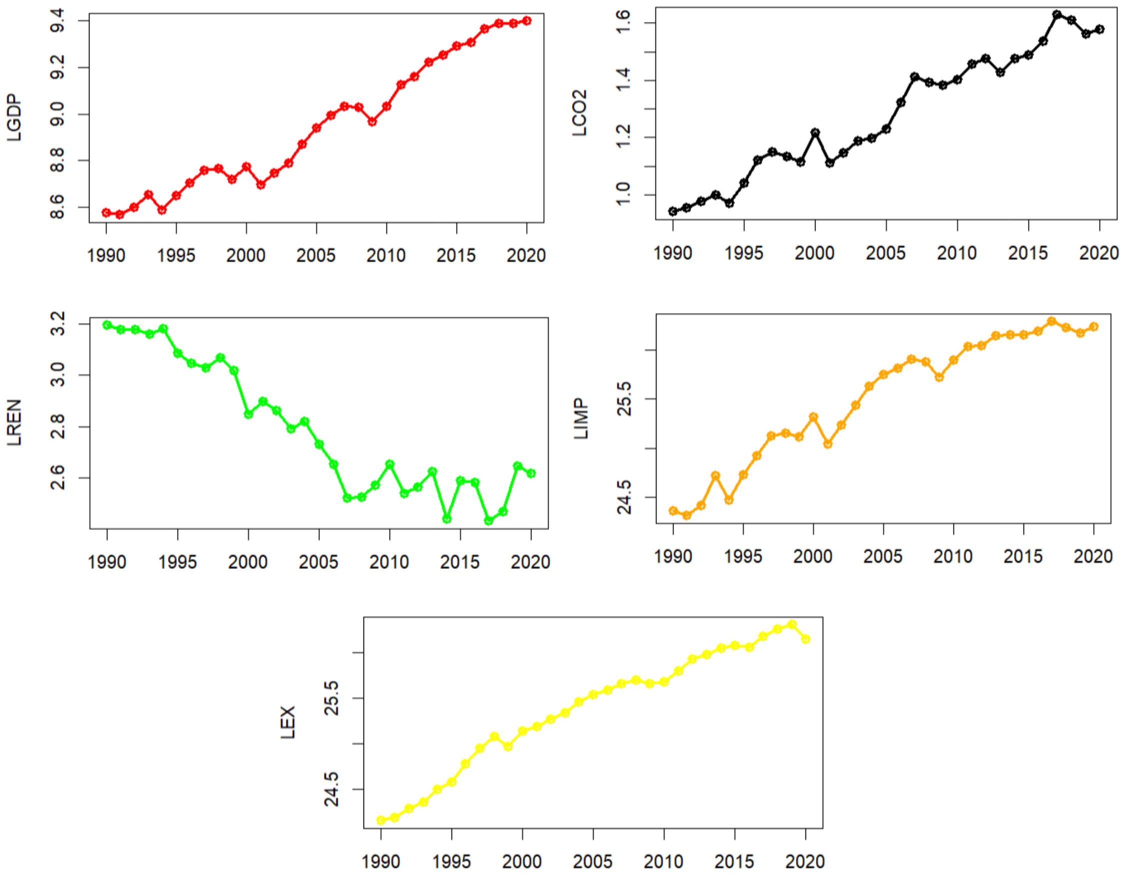

Fig. 2. Time course of variables

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Table 3. Descriptive statistics

	CO2	EX	GDP	IMP	REN
Mean	3.675330	1.27E+11	7989.096	1.42E+11	16.84194
Median	3.420478	1.23E+11	7648.305	1.48E+11	15.34000
Max	5.093179	2.66E+11	12072.40	2.62E+11	24.37000
Min	2.562358	3.08E+10	5256.926	3.61E+10	11.40000
Std. Deviation	0.788115	7.16E+10	2284.945	7.57E+10	4.417619
Skewness	0.216426	0.347921	0.521750	0.066423	0.493154
Kurtosis	1.753812	1.943460	1.886000	1.537220	1.750453
Jarque-Bera	2.247947	2.067277	3.009442	2.786607	3.273305
Probability	0.324986	0.355710	0.222079	0.248254	0.194630
Observation	31	31	31	31	31

Table 4 presents the correlation matrix for the variables. As indicated by the findings in Table 4, a strong correlation exists between the variables. Specifically, there is a significant positive correlation among exports, economic growth, imports, and carbon emissions variables, while there is a notable negative correlation between renewable energy consumption and carbon emissions. These correlation results from Table 4 are visually represented in Figure 3 using a pie chart.

Table 4. Correlation matrix

	CO2	EX	GDP	IMP	REN
CO2	1	0.975	0.975	0.980	-0.909
EX	0.975	1	0.986	0.976	-0.882
GDP	0.975	0.986	1	0.974	-0.838
IMP	0.980	0.976	0.974	1	-0.924
REN	-0.909	-0.882	-0.838	-0.924	1

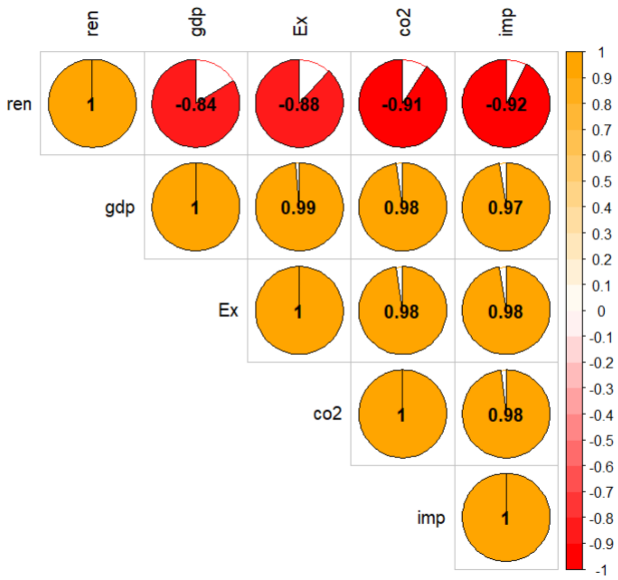

Fig. 3. Correlation pie graph

4. Methodology

In this study, the empirical analysis consists of five stages. The empirical approach is shown in Fig. 4. Initially, we employed ADF and PP unit root tests to assess the degree of stationarity of the variables. Subsequently, we examined the existence of cointegration among the variables through the application of ARDL and Bayer-Hanck cointegration tests. Lastly, we estimated the influence of GDP, exports, imports, and renewable energy consumption on carbon emissions using the ARDL long-run estimation methodology. The following section provides a concise exposition of the econometric methodologies utilized.

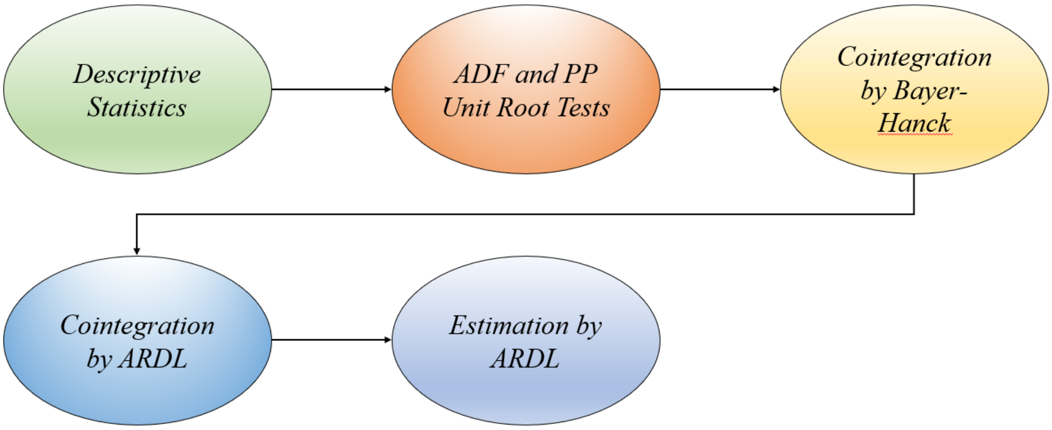

Fig. 4. Empirical methodology

4.1. Augmented Dickey-Fuller Unit Root Test

In econometric time series investigations, stationarity of variables is crucial. There are a growing number of unit root tests in the literature that look at whether a variable has a unit root or not. The suitable co-integration methodologies to be applied in the study are also guided by these unit root tests. Unit root tests developed by Dickey and Fuller (1979) and Dickey and Fuller (1981) are frequently used in studies. The ADF unit root test differs from the DF unit root test since it includes lags of the dependent variable into the model to address the autocorrelation problem. Here is a representation of the regression equation for the ADF unit root test using LNCO2, one of the study's variables.

None $\Delta LNCO2_t = \phi LNCO2_{t-1} + u_t$ (2)

Intercept: $\Delta LNCO2_t = \beta_0 + \phi LNCO2_{t-1} + u_t$ (3)

Intercept and trend: $\Delta LNCO2_t = \beta_0 + b_t + \phi LNCO2_{t-1} + u_t$ (4)

For all three models shown above, the null hypothesis of a unit root will be rejected if the test statistic for the first lag of the dependent variable is significantly greater in absolute value than the critical values. This result indicates that the variable is stationary at level (Aliyev *et al.*, 2022; Gasim & Şenyay, 2023).

4.2. Phillips-Perron Unit Root Test

The Phillips-Perron (1988) test is another unit root test that is frequently used in time series econometrics literature. The autocorrelation assumption of the ADF test is expanded upon by this test. The equation for regression suggested for the PP test is presented below.

$$Y_t = \hat{\mu} + \hat{\alpha} y_{t-1} + \hat{u}_t \qquad (5)$$

$$Y_t = \tilde{\mu} + \tilde{\beta}\left(t - \frac{1}{2}\lambda\right) + \tilde{\alpha} y_{t-1} + \tilde{u}_t \qquad (6)$$

The null hypothesis suggesting the existence of a unit root, as in the ADF unit root test, will be rejected if the statistical value calculated in the PP test is greater in absolute value than the critical values.

4.3. Bayer-Hanck Cointegration Test

This cointegration test evaluates Engle and Granger (1987), Johansen (1995), Boswijk (1994) and Banerjee et al. (1998) cointegration tests together. Bayer and Hanck (2013) use the Fisher formula to combine the probability values of these cointegration tests. The probability values and formula of the single cointegration test are given below:

$$G - JOH = -2\left[\ln(P_{EG}) + \ln\left(P_{JOH}\right)\right] \qquad (7)$$

$$EG - JOH - BO - BDM = -2\left[\ln(P_{EG}) + \ln\left(P_{JOH}\right) + \ln(P_{BO}) + \ln(P_{BDM})\right] \qquad (8)$$

The probability values of the different individual cointegration tests are denoted by P_{EG}, P_{JOH}, P_{BO}, and P_{BDM}, respectively. If the calculated test statistic is greater than the critical values calculated by Bayer and Hanck (2013), the null hypothesis of no cointegration relationship will be rejected. This means that there is cointegration among the variables.

4.4. ARDL Cointegration Test

The ARDL cointegration method, which is widely used in time series econometrics, was developed by Pesaran et al. (2001). Unlike cointegration tests such as Johansen (1988), Hansen (1994), Shin (1994), Maki (2012), ARDLBT cointegration test does not require all variables to be stationary at first difference. The ARDL Bound Test is generally used by researchers when the variables are stationary at different degrees. If the dependent variable is stationary in the first difference and any of the independent variables are stationary at the level (they should not be stationary at second order), the ARDL Bound test gives reliable results. In this study, ARDL Boundary Test is used even if all variables are stationary at first difference. In his study, Narayan (2005) produced critical values for the ARDL Boundary Test that enable it to give good results even in small samples. For this study, the ARDL bounds test is expressed as follows:

$$\Delta LCO2_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta LCO2_{t-i} + \sum_{i=1}^{p} \beta_{2i} \Delta LGDP_{t-i} + \sum_{i=0}^{p} \beta_{3i} \Delta LEX_{t-i} + \sum_{i=0}^{p} \beta_{4i} \Delta LIMP_{t-i} + \sum_{i=0}^{p} \beta_{5i} \Delta LREN_{t-i} + \gamma_1 LCO2_{t-1} + \gamma_2 LGDP_{t-1} + \gamma_3 LEX_{t-1} + \gamma_4 LIMP_{t-1} + \gamma_5 LREN_{t-1} + \varepsilon_t \qquad (9)$$

In Equation 9, Δ denotes a first difference operator. Within the framework of the ARDL cointegration test, the existence of a cointegration relationship between variables is found when $H_0: \gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = \gamma_5 = 0$ is rejected. The null hypothesis is rejected whenever the F test value exceeds the upper critical value, indicating the existence of a cointegration relationship among the variables (Eylasov et al., 2023). The error correction equation, which reflects the process of returning the short-run deviations between the dependent and independent variables to the long-run equilibrium value, is expressed as follows.

$$\Delta LCO2_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta LCO2_{t-i} + \sum_{i=1}^{p} \beta_{2i} \Delta LGDP_{t-i} + \sum_{i=0}^{p} \beta_{3i} \Delta LEX_{t-i} + \sum_{i=0}^{p} \beta_{4i} \Delta LIMP_{t-i} + \sum_{i=0}^{p} \beta_{5i} \Delta LREN_{t-i} + \theta ECT_{(t-1)} + \varepsilon_t \quad (10)$$

The fact that the error correction coefficient θ in Equation 10 is negative and statistically significant indicates that the error correction model works. This means that disequilibrium from the short-run will reach the long-run equilibrium.

5. Empirical results

Table 5 presents the results of the ADF and PP unit root tests. According to the results of both tests, all variables are found to be non-stationary at the level. However, they become stationary after taking the first differences. Thus, all variables are I(1). Since all variables are determined to be I(1) according to the ADF and PP unit root tests, cointegration relationships among the variables can be explored.

Table 5. ADF and PP unit root test results

Tests	ADF		PP	
Variables	Constant	Constant and Trend	Constant	Constant and Trend
LCO2	-0.842 (0.835)	-2.819 (0.202)	-0.772 (0.812)	-3.176 (0.108)
ΔLCO2	-6.005*** (0.000)	-5.917*** (0.000)	-8.438*** (0.000)	-8.312*** (0.000)
LGDP	0.107 (0.961)	-2.577 (0.292)	0.420 (0.980)	-2.601 (0.282)
ΔLGDP	-5.525*** (0.000)	-5.436*** (0.000)	-6.141*** (0.000)	-6.371*** (0.000)
LEX	-2.219 (0.203)	-0.858 (0.948)	-6.166*** (0.000)	0.814 (0.999)
ΔLEX	-4.210*** (0.000)	-4.320** (0.010)	---	-7.938*** (0.000)
LIMP	-1.429 (0.554)	-2.083 (0.533)	-1.804 (0.371)	-1.959 (0.599)
ΔLIMP	-6.811*** (0.000)	-5.842*** (0.000)	-6.958*** (0.000)	-12.498*** (0.000)
LREN	-1.493 (0.523)	-1.921 (0.618)	-1.474 (0.532)	-1.664 (0.742)
ΔLREN	-5.881*** (0.000)	-6.292*** (0.000)	-6.505*** (0.000)	-7.363*** (0.000)

Note: *** denote significance at 1% level.

Table 6. Bayer-Hanck (2013) Cointegration test results

Constant Model Results		Critical Value			Results
	Fisher Type Test statistics	%1	%5	%10	Cointegration
EG-JOH	56.187***	15.845	10.576	8.301	✓
EG-JOH-BO-BDM	71.089***	30.774	20.143	15.938	✓
Trend Model Results		Critical Value			Results
	Fisher Type Test statistics	%1	%5	%10	Cointegration
EG-JOH	55.855***	15.973	10.532	8.272	✓
EG-JOH-BO-BDM	66.689***	30.836	20.44	16.086	✓

Note: *** denote significance at 1% level.

In this study, both the Bayer-Hanck cointegration test and the ARDL bounds test were employed to investigate the cointegration relationship among variables. Firstly, Table 6 presents the results of the Bayer-Hanck cointegration test. According to the results of the Bayer-Hanck cointegration test, Fisher-type test statistics are greater than the 1% critical value for both the constant model and the trend model. This indicates the presence of cointegration among the variables.

The results of the second cointegration test, the ARDL bounds test, are presented in Table 7. According to the results of the ARDL bounds test, there is a cointegration relationship among the variables. The statistics for both the F and t tests are greater than the upper critical values, leading to the rejection of the null hypothesis that states 'there is no cointegration.

Table 7. ARDL Bound test results

Model	Model		F		t	Results	
LCO2 = f(LGDP, LREN, LEX, LIMP)	ARDL(2,0,4,3,4)		***13.143******		***-4.021*****	Cointegration	
CV	%1		%5			%10	
Tests	Lower	Upper	Lower		Upper	Lower	Upper
F	4.59	***6.368***	3.276		4.63	2.696	3.898
t	-3.43	-4.6	-2.86		***-3.99***	-2.57	-3.66
Diagnostic Check							
Tests	F			Prob			
BPG	2.787			0.128			
LM	1.819			0.181			
JB	0.142			0.931			
Ramsey-Reset	0.094			0.766			
CUSUM	Stable						
CUSUMsq	Stable						

Note: *** and ** denote significance at 1% and 5% levels, respectively.

In order for the results of the ARDL test in Table 7 to be considered valid, certain diagnostic tests need to be satisfied. Additionally, the results of diagnostic tests are provided in Table 7. According to these test results, there are no issues such as autocorrelation, non-normality, or heteroscedastic in the residuals of the model. The probability values for all tests are greater than 5%. Furthermore, in Figure 5, it can be observed that the CUSUM and CUSUMsq charts exhibit stability.

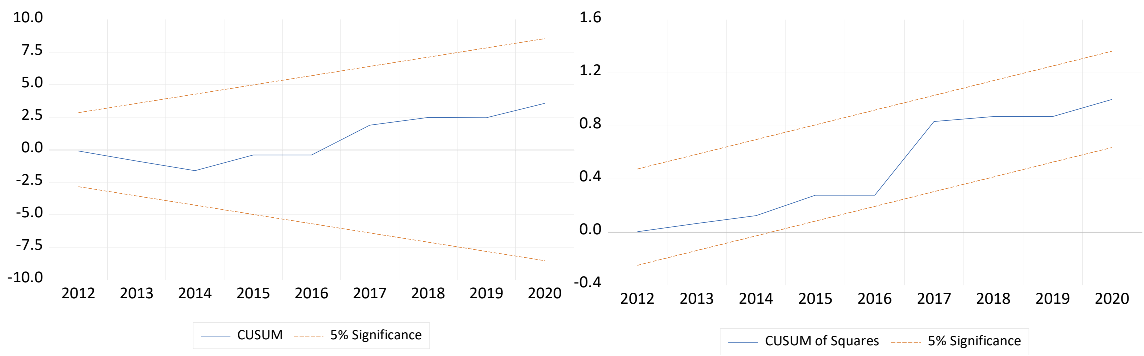

Fig 5. CUSUM and CUSUMsq Graphs

According to both the Bayer-Hanck and the ARDL bounds test results, there exists a cointegration relationship among the variables. Once cointegration is established, long-term estimation results among the variables can be reported. Table 8 presents the ARDL long-run estimation results. According to the ARDL long-run estimation results, the impact of renewable energy consumption on carbon emissions is negative and statistically significant. Holding other variables constant, a 1% increase in renewable energy consumption will lead to a 0.30% decrease in carbon emissions. Our findings align with the findings reported by Qashou et al. (2022), Abumunshar et al. (2020), Pata and Yurtkuran (2018), Shan et al. (2021), and Raihan and Tuspekova (2022). Furthermore, we revealed that GDP has a positive and statistically significant effect on CO_2 emissions. A 1% increase in GDP will increase carbon emissions by 0.83%. Our findings align with economic theory. Theoretically, an uptick in production or income corresponds to heightened consumption of intermediate and final goods and services, ultimately leading to an increase in CO2 emissions (Mukhtarov *et al.*, 2022). Conversely, the study observed that the export variable has a negative impact on carbon emissions, while imports have a positive effect. A 1% increase in exports will reduce carbon emissions by 0.35%. A 1% increase in imports will increase carbon emissions by 0.31%. In conclusion, Table 8 illustrates a statistically significant negative error correction model. Short-term imbalances are expected to converge to long-term equilibrium at a rate of 96%. Furthermore, a visual summary of the empirical findings is presented in Figure 6.

Table 8. ARDL Long-run estimation results

Variables	Coefficient	St. Error	t-statistics	Prob
LREN	-0.307**	0.109	-2.806	0.020
LGDP	0.831***	0.102	8.138	0.000
LEX	-0.354***	0.066	-5.306	0.000
LIMP	0.318**	0.109	2.917	0.017
Error Correction Model				
ECT_{t-1}	-0.961***	0.098	-9.742	0.000

Note: *** and ** denote significance at 1% and 5% levels, respectively.

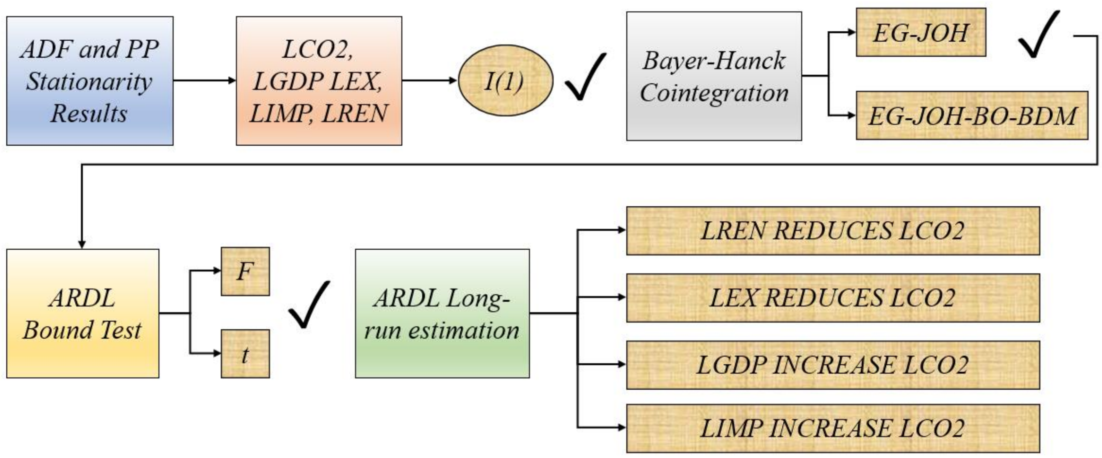

Fig 6. Summary of the empirical outcomes

6. Conclusions and recommendations

In this study, the impact of renewable energy consumption, exports, imports, and economic growth on carbon emissions in Turkiye is investigated. Firstly, the stationarity of the variables was examined using ADF and PP unit root tests, and it was found that all variables were stationary at the first difference. Cointegration among the variables was tested using the Bayer-Hanck and ARDL cointegration methods, revealing a cointegration relationship among the variables. Finally, the results were reported using the ARDL long-run estimation method. According to the ARDL long-run estimation results, a 1% increase in renewable energy consumption and exports reduces carbon emissions by 0.30% and 0.35%, respectively. On the other hand, a 1% increase in imports and economic growth increases carbon emissions by 0.31% and 0.83%, respectively. The negative coefficients of renewable energy consumption and export variables indicate that they are associated with a decrease in carbon emissions, while the positive coefficients of GDP and import variables indicate that these factors are associated with an increase in carbon emissions. Recommendations that policy makers should consider for successfully addressing carbon emissions are as follows:

Support the use of renewable energy sources: Support the use of and growth in the use of renewable energy sources like wind, solar, and hydropower. Implement measures to promote research and investment in renewable energy. Provide financial rewards, tax breaks, and subsidies to individuals, firms, and families who make investments in renewable energy technologies in order to minimize carbon emissions.

Invest in energy-saving measures: To reduce energy use and hence carbon emissions, energy-saving measures programs should be created and implemented across all industries. Develop energy-saving measures requirements for furniture, structures, and vehicles to guarantee that infrastructure and products are created with reduced carbon emissions in mind.

Green export projects: Support and encourage the export of sustainable and environmentally friendly goods and technologies. Motivate businesses to use greener production techniques. Create trade agreements that encourage nations to cut their carbon emissions and implement environmentally sound practices.

Mechanisms for Pricing Carbon: For internalization of the external costs of carbon emissions, think about establishing carbon pricing mechanisms like carbon taxes or cap and trade programs. These systems offer financial incentives for companies to lessen their carbon footprints.

Investment in green infrastructure: Invest in the construction of green infrastructure such as public transport, bicycle lanes and energy-efficient buildings to reduce dependence on energy and transportation systems that produce large amounts of carbon dioxide. Ensure that public money is used for environmentally friendly and low-carbon infrastructure projects.

Support development and research: Invest resources for research and development projects targeted at creating novel carbon capture and storage (CCS) technology and other methods of reducing emissions. Encourage collaborations between government, business, and academic institutions to advance technology in the renewable energy sector.

International Cooperation: Make efforts to facilitate international cooperation to address global carbon emissions. Participate in global activities and agreements on climate change aimed at reducing greenhouse gas emissions. Share knowledge, best practices and technological advances with other countries to accelerate the world's transition to renewable energy.

Public Education and Awareness: Support initiatives to raise public awareness and educate people about the effects of carbon emissions on the environment and the value of taking individual and communal action. It is necessary to promote sustainable lifestyle choices including cutting back on trash production, using public transportation, and limiting energy consumption.

Reporting and Monitoring: Establish reliable procedures for recording and reporting carbon emissions information at the national and local levels. Monitoring the development of emission reduction targets requires accountability and transparency.

Policy Flexibility: Policies for reducing carbon emissions must be continuously assessed and modified in light of the changing economic and environmental conditions as well as fresh information from continuing research.

These recommendations can help mitigate the negative environmental effects of economic growth while advancing sustainable development. They should be incorporated into a comprehensive carbon emission reduction strategy. With a long-term commitment to reducing carbon emissions for the benefit of present and future generations, policymakers should take into account a combination of these policies that are adapted to the particular conditions of their nations.

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