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THE RELATIONSHIP BETWEEN RENEWABLE ENERGY CONSUMPTION AND CARBON EMISSIONS IN TURKEY: AN ARDL BOUNDS TESTING APPROACH

Abstract:

This paper deals with the relationship between renewable energy consumption and carbon emissions by incorporating economic growth, population density and trade openness as potential determinants of environmental pollution function in case of Turkey over the period 1960 to 2010. The ARDL bounds testing approach to cointegration and vector error correction model (VECM) are used to investigate the long-run and causal relationships between the variables. The empirical results reveal that there exist a long-run equilibrium relationship between renewable energy consumption, economic growth, population density, trade openness and carbon emissions. The empirical results also reveal that renewable energy consumption has a negative long run effect on carbon emissions. There exists an evidence supporting the presence of a positive relationship between carbon emissions and the other variables in the long run. However, there exists no evidence of short run relationship between renewable energy consumption and carbon emissions. The results show bi-directional long run Granger causality between trade openness, population density and carbon emissions and also uni-directional Granger causality running from economic growth and renewable energy consumption to carbon emissions in the long run. Besides, the findings present some policy implications for Turkish economy.

Keywords:

Carbon emissions, Renewable energy consumption, ARDL bounds test, VECM Granger causality, Turkey

JEL Classification: Q50, Q20, Q40

Introduction

The first global attempts in the direction of reducing carbon dioxide (CO_2) emissions began in the 1990s. Rio Summit in 1992 and the Kyoto Protocol in 1997 are the first global efforts relating to climate change issues (Jonghe et. al., 2009). The most important cause of global warming and climate change as expressed in the empirical results of academic studies (Menyah and Wolde-Rufael, 2010; Apergis and Payne, 2014; Shafiei and Salim,2014; Al-mulali, 2014; Baek, 2015) and in United Nations Panel on Climate Change (IPCC)'s reports (IPCC, 2007; IPCC, 2014) is Greenhouse Gases (GHGs). In particular, the rapid increase in carbon dioxide emissions is cited as the major cause of environmental degradation. Use of lower-carbon (such as biomass) or zero-carbon (such as wind and solar) energy resources instead of fossil fuels used in the production of energy will help to reduce CO_2 emissions of the countries. Moreover, countries can both protect the environment and provide unsustainable economic growth by using renewable energy (Baek, 2015).

In this study, combustible renewable and waste data are used representing renewables energy sources in Turkey. According to the World Bank definition; combustible renewables and waste consists of biogas, biomass (liquid or solid) and industrial and municipal waste. Although these energy resources are cleaner than non-renewable energy sources (fossil fuels, such as coal), they are not as clean as renewable energy sources (solar and wind) (Jebli and Youssef, 2014). Combustible renewables are seen to have some production advantages and to be more preferable compared to renewable energy sources. In particular, reasons for the growing interest in biomass energy in the world are as follows (Bilgili and Ozturk, 2015): i) less carbon dioxide emission ii) reducing dependence on foreign energy sources iii) reducing poverty by the help of labor-intensive manufacturing technique iv) meeting the security of energy v) being able to be used in electricity generation.

Air pollution is an important environmental problem in Turkey. Therefore, renewable energy sources are very important for the safety of Turkey's future energy supply in terms of both being sustainable source of energy and environmentally friendly. In addition, Turkey's geographical location and climatic conditions provide important advantages in terms of renewable energy sources (Keles and Bilgen, 2012). A large part of the renewable energy sources in Turkey consists of water power (hydro-power) and biomass sources. Approximately two-thirds of these resources consist of animal derived biomass and wood mostly not used for commercial purposes. One-third of the rest are the hydropower sources. Although the amount of energy production based on solar and wind is at unsatisfactory levels, a rapid increase has been seen in recent years (Celiktas and Kocar, 2009).

Table 1: Total energy consumption in Turkey (Mtoe).

Energy sources	*2008*	*2010*	*2020*	*2030*
Coal and lignite	30.21	39.70	107.57	198.34
Oil	33.16	51.17	71.89	102.38
Gas	33.65	49.58	74.51	126.25
Nuclear	--	--	7.30	14.60
Hydropower	3.66	5.34	10.00	10.00
Geothermal	0.74	0.97	1.71	3.64
Wood and Biomass	5.10	5.12	4.96	4.64
Solar/Wind/other	0.78	1.05	2.27	4.28
Total consumption	107.30	152.93	280.21	464.13

Source: Keles and Bilgen, 2012.

On the other hand, the supply of renewable energy has decreased in recent years due to the decrease in the supply of biomass energy in Turkey. In Table 1, the use of geothermal, solar, wind and nuclear energy sources are estimated to increase as renewable energy sources as seen in the 2030 projection of Turkey's energy.

This study deals with the relationship between renewable energy consumption and carbon emissions by incorporating economic growth, population density and trade openness as potential determinants of environmental pollution function in the case of Turkey over the period 1960 to 2010. The ARDL bounds testing approach to cointegration and vector error correction model (VECM) are used to investigate the long-run and causal relationships between the variables. The empirical results reveal that there exist a long-run equilibrium relationship between renewable energy consumption, economic growth, population density, trade openness and carbon emissions. The empirical results also reveal that renewable energy consumption has a negative long run effect on carbon emissions. There exists evidence supporting the presence of a positive relationship between carbon emissions and the other variables in the long run. However, there is no evidence of short run relationship between renewable energy consumption and carbon emissions. We find bi-directional long run Granger causality between trade openness, population density and carbon emissions. We also find unidirectional Granger causality running from economic growth and renewable energy consumption to carbon emissions in the long run. Besides, the findings present some policy implications for Turkish economy.

The rest of the study is organized as follows: Section 2 reports the literature; Section 3 describes model and data; Section 4 reveals econometric methodology; Section 5 provides empirical findings and Section 6 presents concluding remarks.

2. Literature Review

Substitution of renewable energy sources instead of traditional energy sources is seen as the most effective method against the threat of climate change and global warming. However, both the policy practices and empirical researches on this issue are not sufficient yet (Ozbugday ve Erbas, 2015). Despite the presence of different studies with different methods in the literature, only some of the empirical studies performed using econometric methods will be analyzed in this section.

Apergis and Payne (2014), one of the major empirical studies in recent years, examines the determinants of renewable energy consumption per capita for a panel of seven Central American countries for the period 1980 to 2010. The results show that a long-run co-integrated relationship exists between renewable energy consumption per capita, real GDP per capita, carbon emissions per capita, real coal prices, and real oil prices with the respective coefficients positive and statistically significant. Menyah and Wolde-Rufael (2010) deals with the relationship between carbon dioxide emissions, renewable and nuclear energy consumption and real GDP for the US over the period 1960–2007. Using a modified version of the Granger causality test, they found a unidirectional causality running from nuclear energy consumption to CO_2 emissions without feedback but no causality running from renewable energy to CO_2 emissions. Empirical results suggest that nuclear energy consumption can help to mitigate CO_2 emissions.

On the other hand, Shafiei and Salim (2014) explore the determinants of CO_2 emissions using the STIRPAT model and the period 1980-2011 for OECD countries. The empirical results show that non-renewable energy consumption increases CO_2 emissions, whereas renewable energy consumption decreases CO_2 emissions. According to the authors, policy makers should focus on urban planning and clean energy development to make substantial contributions to mitigating climate change. Sadorsky (2009a) estimates an empirical model of renewable energy consumption for the G7 countries. The results show that real GDP per capita and CO_2 per capita are major drivers behind per capita renewable energy consumption. In addition Sadorsky (2009b), using panel cointegration model for emerging economies, find that increases in real per capita income have a positive and statistically significant impact on per capita renewable energy consumption.

Al-mulali (2014) investigates the relationships between nuclear energy, GDP growth and CO_2 emission by using panel data methodology for the period 1990-2010. The results show that nuclear energy consumption has a positive long run effect on GDP growth while it has no long run effect on CO_2 emission. On the other hand, the Granger causality test results show that nuclear energy consumption has a positive short run causal relationship with GDP growth while it has a negative short run causal relationship with CO_2 emission. Using a panel co-integration analysis, Baek (2015) explores the impact of nuclear energy, energy consumption and income on CO_2 emissions in 12 major nuclear generating countries. The results indicate that nuclear energy consumption reduce CO_2 emissions but also CO_2 emissions decrease monotonically with income growth. Baek and Pride (2014) use a multivariate cointegrated vector autoregression model in order to investigate the relationship between nuclear energy and CO_2 emissions for the top six nuclear generating countries. The results indicate that nuclear energy tends to reduce CO_2 emissions. Farhani and Shahbaz (2014) examine the causal relationship between renewable and non-renewable electricity consumption, output and CO_2 emissions. FMOLS DOLS is applied to 10 MENA countries during the period of 1980–2009. The results reveal that renewable and non-renewable electricity consumption add in CO_2 emissions and the short-run dynamics show the unidirectional causality running from renewable and non-renewable electricity consumption and output to CO_2 emissions.

Using a novel approach to decide prediction input variables of wind and/or temperature forecasting models for Turkey, Hocaoglu and Karanfil (2013) find that bidirectional causal relationships exist between the variables and that short-run dynamics differ with respect to location. Lin and Moubarak (2014) investigates the relationships between renewable energy consumption and economic growth in China over the period 1977–2011 by using ARDL and Johansen cointegration methodology and Granger causality. The results indicate that labor affects renewable energy consumption in the short term but there is no evidence of long or short run causality between carbon emissions and renewable energy consumption.

Sebri and Ben-salha (2014) deals with the relationship between economic growth, CO_2 and renewable energy consumption in the BRICS countries over the period 1971–2010 by using ARDL bounds testing, VECM and Granger causality methodology. Empirical results show that there exist long-run equilibrium relationships among the variables and bi-directional Granger causality exists between economic growth and renewable energy consumption. Salim et. al. (2014) explores the causal relationship between renewable and non-renewable energy consumption and industrial output and GDP growth in OECD economies using the panel cointegration technique during 1980-2011. The results reveal that there exist a long-term equilibrium relationship among non-renewable and renewable energy sources, industrial output and economic growth. In addition, the causality analyses indicate bidirectional causality between industrial out-put and both renewable and non-renewable energy consumption in the short and long run.

Lastly, Jebli and Youssef (2015) examine the relationships between per capita CO_2 emissions, GDP, renewable and non-renewable energy consumption and international trade in Tunisia over the period 1980–2009. Using the ARDL bounds testing approach for cointegration with structural breaks, VECM and Granger causality approach the results indicate the existence of a short-run unidirectional causality running from trade, GDP, CO_2 emission and non-renewable energy to renewable energy. In addition, the long-run estimates reveal that non-renewable energy and trade have a positive impact on CO_2 emissions.

The empirical studies clearly indicate that carbon dioxide emissions decrease significantly with the use of renewable energy sources. In addition, these results emphasize the need to increase the use of renewable energy sources instead of non-renewable energy sources in order to prevent the environmental degradation and global climate change.

3. Model specification and data

Following Hossain (2012), Sebri and Ben-Salha (2014), and Begum et al. (2015), the relationship between renewable energy consumption and carbon emissions are empirically examined by using the log-linear equation as follows:

$$\ln co_t = \alpha_0 + \alpha_1 \ln ren_t + \alpha_2 \ln gdp_t + \alpha_3 \ln tr_t + \alpha_4 \ln pd + \varepsilon_t \quad (1)$$

This study uses annual time series of carbon dioxide emissions (*co*), renewable energy consumption (*ren*), per capita real gross domestic product (*gdp*), trade openness (*tr*) and population density (*pd*) for Turkish economy derived from 1960 to 2010. The data is gathered from the World Development Indicators online data base of the World Bank (http://data.worldbank.org/indicator). *co* is measured in per capita metric ton; *gdp* represents economic growth (measured in constant 2005 US $); *ren* is expressed by the combustible renewables and waste (measured in 1000 metric tons of oil equivalent); *tr* is defined as the sum of imports and exports divided by the GDP; population density is described as the number of people living per square kilometer of land area. The term ε_t is a random error term. The parameters, α_i, i=1, 2, 3, 4 indicate the long-run elasticities of carbon emissions with respect to the independent variables. Table 1 presents descriptive statistics and correlation matrix of the variables.

Table 1. Descriptive statistics and correlation matrix

(Time series data: 1960-2010)

Statistics	*lnco*	*lnren*	*lngdp*	*lntr*	*lnpd*
Mean	0.698	8.781	8.380	3.170	4.115
Median	0.774	8.790	8.340	3.416	4.157
Std. dev.	0.529	0.151	0.346	0.657	0.292
Min.	-0.493	8.424	7.745	1.744	3.583
Max.	1.418	8.994	8.966	4.006	4.540
Skewness	-0.632	-0.453	-0.060	-0.379	-0.263
Kurtosis	2.426	2.422	2.042	1.720	1.795
Observations	51	51	51	51	51
lnco	1.000				
lnren	-0.007	1.000			
lngdp	0.979	-0.176	1.000		
lntr	0.913	-0.010	0.906	1.000	
lnpd	0.982	-0.070	0.985	0.942	1.000

4. Methodology

The aim of the study is to investigate the long run and causal links between the variables. In the first step, we apply unit root tests to investigate stationarity properties of the series. In the second step, we investigate the long run relationship by using ARDL bounds testing approach to cointegration. In the third step, the long and short-run elasticities are estimated. In the final step, causal relations between the variables are examined by VECM Granger causality approach.

4.1. Unit root tests

We begin our analysis by using the standard unit root tests developed by Phillips and Perron (1988) (PP) and Kwiatkowski, Phillips, Schmidt and Shin (KPSS) (1992) to determine the order of integration for the respective variables. According to Shi et al. (2012) PP test, a non-parametric approach, is more powerful than ADF test. In addition, PP test is more robust to serial correlation. In PP test the null hypothesis means that the series are not stationary. This test is based on the first order auto-regressive (AR(1)) process as follows:

$$\Delta y_t = \alpha + \beta y_{t-1} + \mu_t \tag{2}$$

Where y_t is the variable of interest, Δ is the difference operator, *α* is the constant, *β* is the slope and *t* is a subscript for time. This test proposes three statistics known as Z_ρ, Z_t and MSB. They can be expressed as follows:

$$Z_\rho = T(\hat{\rho}-1) - \frac{T^3}{24D_x}(S^2 - S_\delta^2) \tag{3}$$

$$Z_t = \frac{S_\delta}{S} t_{\hat{\rho}} - \frac{T^3}{\sqrt[s]{24D_x}}(S^2 - S_\delta^2) \tag{4}$$

$$MSB = \left[24D_x / T^6 S^2\right]^{1/2} \tag{5}$$

The number of lag truncation in the PP test is determined automatically by Newey and West Bandwidth using Barlett Kernal Spectral estimation method.

KPSS test uses the null hypothesis is that the series are stationary. This test uses LM statistic to test the unit root. In this test, the following specifications are employed:

$$y_t = \delta_t + \varsigma_t + \varepsilon_t \tag{6}$$

$$\varsigma_t = \varsigma_{t-1} + u_t \tag{7}$$

The null hypothesis is $H_0 : \sigma_u^2 = 0$. $u_t \sim IID(0, \sigma_u^2)$ with the test statistic given as:

$$LM = \sum_{t=1}^{T} S_t^2 / S_\delta^2 \qquad (8)$$

S_t is the partial sum of the error terms defined as $S_t = \sum_{j=1}^{t} \varepsilon_j$. The null hypothesis of stationarity is accepted if the value of the KPSS test statistic is less than it is critical value.

4.2. ARDL bounds testing approach to cointegration

We apply ARDL bounds testing approach to cointegration to test the long run relationship between the variables. This approach is preferred because of its several advantages. Firstly, in this test variables may have mixed in order of integration such as I(0) or I(1) or I (0)/I(1). Secondly, it can provide more efficient and consistent findings for a small sample. Thirdly, the unrestricted error correction model (UECM) obtained from the ARDL bounds testing presents the long and short run dynamics. The equation of UECM is modeled as follows:

$$\Delta \ln co_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta \ln co_{t-i} + \sum_{i=0}^{p} \beta_{2i} \Delta \ln ren_{t-i} + \sum_{i=0}^{p} \beta_{3i} \Delta \ln gdp_{t-i} + \sum_{i=0}^{p} \beta_{4i} \Delta \ln tr_{t-i} + \beta_{5i} \Delta \ln pd_{t-i}$$

$$+ \lambda_1 \ln co_{t-1} + \lambda_2 \ln ren_{t-1} + \lambda_3 \ln gdp_{t-1} + \lambda_4 \ln tr_{t-1} + \lambda_4 \ln pd_{t-1} + \varepsilon_t \qquad (9)$$

where *Δ* is the first difference operator and ε_t is error term. The Akaike information criterion (AIC) or Schwarz-Bayesian criterion can be used to examine the appropriate lag structure of the first difference regression. The *F*-test developed by Pesaran et al. (2001) is applied to determine the existence of a long run relationship between the variables. The null hypothesis of no cointegration in Eq. (9) is $H_0 : \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = 0$ against the alternative that $H_1 : \lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq \lambda_5 \neq 0$. Pesaran et al. (2001) generated the critical bounds such as the upper critical bound (UCB) and lower critical bound (LCB). The computed *F*-statistic is compared with the critical bounds. There exists a long run relationship between the variables, if the calculated *F*-statistic is greater than UCB. It is concluded that there exists no long run relationship between the variables, if the calculated *F*-statistic does not exceed LCB. If the calculated *F*-statistic lies between LCB and UCB, the result is inconclusive. After the determination of the ARDL model, the long-run relationship between the variables is estimated. On the other hand, the short run dynamics of the variables are investigated by using error correction model (ECM) as follows:

$$\Delta \ln co_t = \gamma_0 + \sum_{i=1}^{p} \gamma_1 \Delta \ln co_{t-i} + \sum_{j=0}^{q} \gamma_2 \Delta \ln ren_{t-j} + \sum_{k=0}^{r} \gamma_3 \Delta \ln gdp_{t-k} + \sum_{l=0}^{s} \gamma_4 \Delta \ln tr_{t-l}$$

$$+\sum_{m=0}^{t}\gamma_5 \Delta \ln pd_{t-m} + \phi ECM_{t-1} + \mu_t \tag{10}$$

where Δ is first difference operator. The error correction term (*ECM* $_{t-1}$) is derived from the estimated long run model and presents an evidence for the presence of the long run relationship between the variables.

The diagnostic and stability tests are applied to check the robustness of the ARDL model. The diagnostic tests cover the serial correlation, functional form, normality of error term and heteroskedasticity tests. On the other hand, the CUSUM and $CUSUM_{SQ}$ tests presented by Brown et al. (1975) are applied to determine the existence of parameter's stability.

4.3. VECM Granger causality test

The Granger causality test based on VECM procedure developed by Engle and Granger (1987) can be employed to indicate the direction of causality between variables. In this approach error correction term (ECT) is included to the VAR system as an additional variable. The empirical equations of this approach are expressed as follows:

$$(1-L)\begin{bmatrix}\ln co_t\\ \ln ren_t\\ \ln gdp_t\\ \ln tr_t\\ \ln pd_t\end{bmatrix} = \begin{bmatrix}\lambda_1\\ \lambda_2\\ \lambda_3\\ \lambda_4\\ \lambda_5\end{bmatrix} + \sum_{i=1}^{p}(1-L)\begin{bmatrix}a_{11i}a_{12i}a_{13i}a_{14i}a_{15i}\\ a_{21i}a_{22i}a_{23i}a_{24i}a_{25i}\\ a_{31i}a_{32i}a_{33i}a_{34i}a_{35i}\\ a_{41i}a_{42i}a_{43i}a_{44i}a_{45i}\\ a_{51i}a_{52i}a_{53i}a_{54i}a_{55i}\end{bmatrix}$$

$$x\begin{bmatrix}\ln co_{t-1}\\ \ln ren_{t-1}\\ \ln gdp_{t-1}\\ \ln tr_{t-1}\\ \ln pd_{t-1}\end{bmatrix} + \begin{bmatrix}\alpha\\ \beta\\ \delta\\ \phi\\ \lambda\end{bmatrix} ECT_{t-1} + \begin{bmatrix}\varepsilon_{1t}\\ \varepsilon_{2t}\\ \varepsilon_{3t}\\ \varepsilon_{4t}\\ \varepsilon_{5t}\end{bmatrix} \tag{11}$$

where, (1-L) is the lag operator and ECT_{t-1} is the lagged residual derived from the long run relationship. The long run causality is found by a significant *t*-statistic on the coefficient of ECT_{t-1}. A significant *F*-statistic on the first differences of the variables shows that there exists a short-run causality between the variables.

5. Empirical findings

The results of PP and KPSS unit root tests are presented in Table 2. The results show that except for lntr all the variables have unit root problem at level. But, the variables are stationary at 1st difference indicating that the variables are integrated at *I*(1). Hence, we use the ARDL bounds testing approach to cointegration to test the long run relationship between the variables.

Table 2. The unit root tests results

Regressor	PP test statistics	KPSS test statistics
lnco	-2.502	0.206
lnren	0.816	0.235
lngdp	-3.048	0.077***
lntr	-3.267*	0.119**
lnpd	1.817	0.247
Δlnco	-7.849***	0.082***
Δlnren	-5.549***	0.143***
Δlngdp	-7.233***	---
Δlntr	---	---
Δlnpd	-4.752***	0.180***

Notes: The model with constant and trend is used for unit root analysis. The bandwidth is selected using the Newey-West method. ***, ** and * denote the significant at 1%, 5% and 10% level of significance, respectively.

After examining the stationarity, properties of the variables we investigate the presence of cointegration between the variables. Bounds F test results are reported in Table 3. The results show that calculated *F* statistic is greater than UCB. This indicates that there exists evidence of a long-run relationship between the variables at 1% significance level in Turkey. The results also show that the ARDL model passes several diagnostic tests.

Table 3. Bounds *F*-test results

Bounds testing approach to cointegration		
Model		Calculated *F*-statistics
F(lnco/lnren, lngdp, lntr, lnpd)		9.657***
Peseran et al. (2001) critical value bounds of the *F*-statistic: unrestricted intercept and no trend		
Significance level	Lower bounds, *I*(0)	Upper bounds, *I*(1)
1%	3.74	5.06
5%	2.86	4.01
10%	2.45	3.52
Narayan (2005) critical value bounds of the *F*-statistic: unrestricted intercept and no trend (T = 51)		
Significance level	Lower bounds, *I*(0)	Upper bounds, *I*(1)
1%	4.30	5.87
5%	3.13	4.41
10%	2.61	3.74
Diagnostic tests		
R^2		0.928
Adjusted-R^2		0.850
F-statistic		11.887**
Breusch-Godfrey LM test		0.447(0.510)
ARCH LM test		1.620(0.210)
J-B normality test		0.774(0.678)
Ramsey RESET test		1.953(0.167)

Notes: The model with constant is used for cointegration analysis. Optimal lag order is selected based on AIC. The values in parentheses indicate the probabilities. ***, ** and * represent 1%, 5% and 10% level of significance, respectively. The critical values for bounds testing are based on case III in Pesaran et al. (2001) and Narayan (2005).

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The long run results are reported in Table 4. According to the results, renewable energy consumption, real GDP per capita, trade openness and population density significantly affect carbon emissions in the long run. Renewable energy consumption has a negative impact on carbon emissions. The other variables have a positive effect on carbon emissions in the long run. The results indicate that renewable energy consumption, economic growth, trade openness and population density are very important determinants of carbon emissions in Turkey. Our long run model passes the diagnostic and stability tests successfully at 5% significance level. Hence, the empirical results can be employed for policy implication.

Table 4. Long-run estimates based on selected ARDL model

Regressors	Coefficient	*t*-statistic
lnren	-0.554	-1.841*
lngdp	2.067	6.338***
lntr	0.254	2.732***
lnpd	4.113	2.855***
Constant	-26.703	-8.659***
Diagnostic test statistics		
R^2	0.996	
Adj-R^2	0.996	
F-statistic	1872.544[0.000]	
J-B normality test	0.636[0.727]	
ARCH LM test	0.871[0.355]	
Ramsey RESET test	2.435[0.100]	
B-G LM test	0.228[0.635]	

Notes: The long-run coefficients are estimated on the basis of ARDL (2,0,0,0,0) model, decided by the AIC. Values in brackets are *p*-values. ***, ** and * represent 1%, 5% and 10% level of significance, respectively.

Table 5 reports the short run results. The results reveal that there exists a statistically significant and positive relation between economic growth and carbon emissions in the short run. The results also reveal that trade openness has a positive effect on carbon emissions in the short run. The estimate of ECM_{t-1} is found to be statistically significant with negative sign in Turkey. This implies that there exists a long run relationship between the variables.

Table 5. Short-run estimates based on selected ARDL model

Regressors	Coefficient	*t*-statistic
Δlnren	-0.066	-0.348
Δlngdp	0.982	9.173***
Δlntr	0.110	3.763***
Δlnpd	1.622	1.188
ECT(-1)	-0.428	-7.349***
Constant	-0.042	-1.646
Diagnostic test statistics		
R^2	0.777	
Adj-R^2	0.745	
F-statistic	34.419***	
RSS	0.033	
SE of regression	0.028	

Notes: The short-run coefficients are estimated on the basis of ARDL (2,0,0,0,0) model, decided by the AIC. Δ denotes the first difference operator. ***, ** and * represent 1%, 5% and 10% level of significance, respectively.

We apply Granger causality test within the VECM approach to examine the causal relationship between the variables. The results of VECM Granger causality analysis are presented in Table 6. The results reveal that there exists a bidirectional causal link between trade openness and carbon emissions in the long run. The results also reveal that there exists a bidirectional causal relationship between population density and carbon emissions in the long run. We find a long run causal link running from renewable energy consumption and economic growth to carbon emissions.

Table 6. Granger causality analysis

Dependent variable	Short-run (*F*-statistic)					Long-run (*t*-statistic)
	Δlnco	*Δlnren*	*Δlngdp*	*Δlntr*	*Δlnpd*	
Δlnco	-	0.283	1.146	0.887	0.756	-3.531** *

Δlnren	2.076**	-	1.906*	0.741	4.064***	-0.396
Δlngdp	1.361	0.426	-	0.333	0.089	-0.186
Δlntr	0.728	0.706	1.150	-	0.589	2.779***
Δlnpd	0.739	1.547	1.746*	3.303***	-	-3.328***

***Notes*:** ***, ** and * represent 1%, 5% and 10% level of significance, respectively.

6. Conclusion and policy implication

This study investigates the relationship between renewable energy consumption and carbon emissions by including economic growth, trade openness and population density as potential determinants of carbon emissions in Turkey from 1960 to 2010. The ARDL bounds testing approach to cointegration is employed to analyze the long-run relationship between the variables. The causal relationships between the variables are examined by the VECM Granger causality procedure.

We find a long-run relationship between renewable energy consumption, economic growth, trade openness, population density and carbon emissions. We also find that renewable energy consumption has a negative impact on carbon emissions in the long run. In this study, there exists a positive long run relationship between carbon emissions and the other variables. Bidirectional long run Granger causality is found between trade openness, population density and carbon emissions. Unidirectional Granger causality running from economic growth and renewable energy consumption to carbon emissions is found in the long run. As a result, the findings of the study are generally consistent with the previous studies in the literature. While the use of renewable energy sources reduces carbon dioxide emissions; GDP, population and increases in foreign trade increase the carbon dioxide emissions. However, in this study, on the contrary to the findings that the increases of the foreign trade increase the carbon dioxide emissions (pollution haven effect), some studies in the literature have shown that the foreign trade can have negative impact (pollution halo effect) on the carbon dioxide emissions.

Turkey has a significant potential in terms of combustible renewables and waste energy sources. The findings of the study showed that the use of these kinds of energy sources may contribute to the reduction of carbon dioxide emissions. Therefore, policy makers should conduct new incentive policies and investments for combustible renewables (biogas and biomass), the municipal waste and industrial waste, as well as measures to encourage renewable energy sources. In particular, the use of agricultural areas in this way with the technological developments and evaluation of the waste can be estimated to be much more effective. In summary, Turkey with large farmlands and great population should use the advantages of energy production based on combustible renewables and wastes and develop policies in this direction.

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