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The Impact of Population Growth and Economic Growth on Carbon Emissions in Turkey: Stirpat Model in ARDL Form

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Abstract

The main objective of this study is to determine the effect of population growth and economic growth on carbon emissions in Turkey. The STIRPAT ARDL model was used to analyze the effect of population growth and economic growth on carbon emissions for this purpose. The STIRPAT ARDL (4,0,4), the STIRPAT ARDL (4,4,3), and the STIRPAT ARDL (1,4,3) models were developed for this purpose. These models provide appropriate answers for the study's objective. As a result, population growth and economic growth are associated with increased carbon emissions in Turkey. These results are statistically significant and consistent with the literature. As a result of the results, policy makers will be able to identify two important factors when formulating sustainable environmental policies. The STIRPAT ARDL (4,4,3) model, however, failed to provide an adequate answer to the study's questions.

Keywords: Carbon Emissions, Population, Economic Growth, STIRPAT, ARDL

1. INTRODUCTION

In today's world, economic growth and population growth are the two main causes of global warming and climate change. Increasing environmental degradation and global concerns have led to numerous studies on the environmental effects of economic growth and population growth.

Several studies have suggested that environmental quality deteriorates during the early stages of economic development and improves during the later stages of economic development. In the early stages of economic growth, degradation and pollution increase. Nonetheless, beyond a certain level of per capita income, which will differ for different indicators, the trend reverses, so that economic growth at higher income levels can contribute to environmental improvement (Dinda, 2004; Stern, 2004; Zhang and Cheng, 2009). This phenomenon is known as the environmental Kuznets curve (EKC), which hypothesizes an inverted U-shaped relationship between environmental degradation and economic development. In the early stages of economic growth, industries often prioritize production and expansion over environmental concerns, leading to increased pollution and resource depletion. However, as economies grow and prosper, the effects of environmental degradation become more understood, leading to a shift towards pollution regulation and environmentally friendly technologies.

In contrast, fossil fuels such as coal, oil and natural gas lead to global climate change (Anser, 2020). The classical economic approach suggests that carbon emissions are positively related to economic growth (González-Álvarez and Montañés, 2023). More clearly, environmental degradation is seen as a result of human activities. According to Dietz and Rosa (1997) the most significant anthropogenic factors are (i) population, (ii) economy activity, (iii) technology, (iv) political and economic institutions and (v) attitudes and beliefs. In most countries, rapid prosperity has led to carbon emissions and the over-consumption of natural resources (Streimikiene et al. 2019).

Environmental degradation is also associated with the first of anthropogenic factors, population. The increasing population, on the one hand, contributes positively to economic growth, while on the other hand, it creates the greatest negative impact on the environment (Martínez-Zarzoso and Maruotti, 2011). Along with population growth, rapid urbanization, aging and changes in the size of individuals forming families are one of the main reasons for greenhouse gas emissions increase (O'Neill et al., 2010). Environmental management says global warming and climate change are caused by increasing energy demand (Alam et al. 2016). As a result, the rapid increase in energy demand, especially global climate change as a consequence of carbon dioxide (CO2) emissions from burning fossil fuels, has presented environmental challenges (Dong et al. 2018). However, there are arguments to the contrary that population growth increases carbon emissions. According to Casey and Galor (2017) developed countries with low fertility rates emit more carbon than countries with high fertility rates.

Generally, there has been a large amount of research concerning the effects of economic growth and population growth on carbon emissions. Some of these studies have been conducted in Turkey. However, the findings of studies focusing solely on economic growth and population growth are ambiguous and limited. As a result, a more detailed analysis of the issue specific to Turkey is required.

This study aims to examine the impact of population, affluence, and technology factors on environmental impacts by using the IPAT (Impact = Population . Affluence . Technology) models and STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) model to analyze short and long term impacts. Additionally, the study includes solutions for the future that aim to promote both economic growth and environmental protection.

2. THEORETICAL FRAMEWORK

SPIRTAT is a model used to measure environmental impact. The model is based on the IPAT formula proposed by Ehrlich and Holdren (1971). The formula describes environmental impact as a function of population, wealth, and technology. However, this formula was later converted to stochastic form by Dietz and Rosa (1997), allowing it to be applied in nonlinear relationships. The SPIRTAT model has become a widely used model for measuring human activities and their impact on the environment.

$$I = P.A.T \qquad (1)$$

$$I = a.P^{b}.A^{c}.T^{d}.\ e \qquad (2)$$

In this equation

I: Environmental impact (e.g. carbon emissions, water pollution).

P: Population size.

A: Wealth or income per capita (e.g. GDP).

T: Factors such as technological impact or energy intensity.

a: Constant term.

b,c,d: Coefficients showing the elasticity of variables on environmental impact.

e: Error term

When we transform this equation into logarithmic form, the model can be written as follows:

$$ln(I) = ln(a) + b \cdot ln(P) + c \cdot ln(A) + d \cdot ln(T) + \grave{o} \qquad (3)$$

The study presents chronologically the studies on economic growth, population growth, and carbon emissions (Knapp and Mookerjee, 1996; Say and Yücel, 2006; Martínez-Zarzoso et al. 2007; Ozturk and Acaravci, 2010; Ohlan, 2015; Begum et al. 2015; Azam et al. 2016; Chen et al. 2016; Aye and Edoja, 2017; Sulaiman and Abdul-Rahim, 2018; Wang et al. 2018; Abdouli et al. 2018; Mikayilov et al. 2018; Acheampong, 2018; Mohsin et al. 2019; Hashmi and Alam, 2019; Mardani et al. 2019; Vo et al. 2019; Mohmmed et al. 2019; Rahman et al. 2020; Odugbesan and Rjoub, 2020; Hussain and Rehman, 2021; Namahoro et al. 2021; Pachiyappan et al. 2021; Yang et al. 2021; Onofrei et al. 2022; Rehman and Rehman, 2022; Uzair Ali et al. 2022; Ahmed et al. 2023; Li et al. 2023; Rehman et al. 2023; Guo et al. 2023; Mitić et al. 2023; Dritsaki and Dritsaki, 2024). There are many studies on carbon emissions in the literature. These studies show that economic growth and energy consumption contribute to carbon emissions. In addition, population growth, urbanization and wealth increase energy demand, which in turn increases carbon emissions. As for the solution, renewable energy sources are suggested.

3. PURPOSE AND SCOPE OF THE STUDY

The present study mainly aims to determine the impacts of population growth and economic growth on carbon emissions in the Turkish economy.

The growth in an economy is typically measured by addressing the increase in a country's GDP, which reflects the total production value of various economic sectors. Energy production and industrial activities are critical components of economic growth, and the increase in these sectors' activities often results in higher carbon emissions. For example, the increase in energy production (fossil fuel use) and the expansion of industrial output not only contribute to the growth of GDP but also increase carbon emissions (Stern, 2004). The transportation sector, which meets the logistics needs of trade and industry, is a key component of economic growth. Transportation activities, particularly the heavy use of motor vehicles and air transport, are significant sources of carbon emissions. Expansion in these sectors, together with economic growth, increases carbon emissions (Schäfer and Victor, 2000). The agriculture and construction sectors are two other important elements of economic growth. Agricultural activities contribute to carbon emissions both directly (e.g., machinery use and fertilization) and indirectly (through land-use changes). The construction sector also increases emissions due to material production (cement, steel) and construction activities (Smith et al. 2014). In this context, economic growth encompasses the effects of sectoral contributions, including carbon emissions. In economic growth analyses, GDP is generally used as an important metric. In this study, per capita GDP was chosen as an indicator of the growth in economy.

Per capita GDP is considered a clearer indicator of economic welfare. Therefore, using per capita GDP captures the effects of individuals' consumption and production habits on the environment more accurately when analyzing the environmental impacts of economic growth (Ravallion, 2012). In countries with rapidly growing populations, the level of income per capita is critically important for environmental sustainability (Perman and Stern, 2003). As per capita income increases, individuals' consumption patterns and energy demand rise, which directly impacts carbon emissions (Stern, 2004).

4. METHODOLOGY

The annual time series data of the period of 1998-2021 were analyzed in this study. The variables examined are greenhouse gas emissions (CO2) (in million tons), mid-year population (in thousands), and per capita GDP (in TRY). The data utilized in the analysis were obtained from the Turkish Statistical Institute (TURKSTAT). The time series were subjected to logarithmic transformation for analysis purposes. The ARDL version of STIRPAT was used in the study. The findings for the standard ARDL model are as follows:

This model analyzes both short-term and long-term relationships within a single framework. As a result, the dynamic interactions between variables can be examined more comprehensively (Pesaran and Shin, 1998). This model can also be used to investigate cointegration among variables, which is particularly important when variables exhibit different stationarity levels (I(0) or I(1)) since the model offers flexibility for such variables (Pesaran et al. 2001). Even with small sample sizes, this model yields reliable results. This is a significant advantage over other time series models, because many economic datasets may contain a limited number of observations (Narayan, 2005). The ARDL model accounts for different lag lengths for each independent variable, enhancing the model's flexibility and allowing for more accurate forecasts (Pesaran and Shin, 1998). However, the process of determining the optimal lag lengths can be complex. If the lag lengths for the independent variables are not specified accurately, then the validity and reliability of the model may be affected (Nkoro and Uko, 2016). The inclusion of lagged independent variables can lead to high multicollinearity among the variables, which can reduce the statistical significance of the estimated coefficients and complicate the interpretation of the model (Zivot and Wang, 2006).

5. STIRPAT MODEL IN ARDL FORM

When the STIRPAT model is implemented with an ARDL model, the model can be written as follows:

$$\Delta \ln(I_t) = \alpha + \sum_{i=1}^{p} \beta_i \Delta \ln(I_{t-j}) + \sum_{j=0}^{q} \gamma_j \Delta \ln(P_{t-j}) + \sum_{k=0}^{r} \delta_k \Delta \ln(A_{t-k}) + \ldots$$

$$\ldots + \sum_{l=0}^{s} \theta_l \Delta \ln(T_{t-l}) + \lambda . ECM_{t-1} + \varepsilon_t \qquad (4)$$

Here:

$\Delta \ln(I_t)$: *The first difference of the environmental impact* (*e.g.* CO_2 *emissions*) *expressed logarithmically*, *i.e. the periodic variation of the environmental impact.*

$\Delta \ln(P_{t-j}), \Delta \ln(A_{t-k}), \Delta \ln(T_{t-l})$: First differences of population, wealth (per capita income) and technology, expressed logarithmically, respectively.

Each represents the short-term impact on environmental impact.

$\beta_i,\ \gamma_j,\ \delta_k,\ \theta_l$: *Coefficients indicating the short* − *run effects of laggedchanges of each independent variable on environmental impact.*

α: *Constant term.*

ECM_{t-1}: *The error correction term reflects long* − *run imbalances and shows how these imbalances are eliminated in the long run.*

λ: *Error correction coefficient*, *which should be in the range* $-1 < \lambda < 0$.
This coefficient indicates how fast the short − *term imbalance will be corrected in the long run*

$\grave{o}_t$: *Error term.*

A STITPAT ARDL model can analyze short-run and long-run relationships between variables.

In this study, the technology variable is excluded from the model to simplify the model and to account for the lack of reliable data measuring the level of technology. The SPIRTAT ARDL model without the technology variable is as follows:

$$\Delta \ln(I_t) = \alpha + \sum_{i=1}^{p} \beta_i \Delta \ln(I_{t-j}) + \sum_{j=0}^{q} \gamma_j \Delta \ln(P_{t-j}) + \sum_{k=0}^{r} \delta_k \Delta \ln(A_{t-k}) + \ldots$$

$$\ldots + \lambda ECM_{t-1} + \varepsilon_t \qquad (5)$$

6. RESULTS

Table 1 summarizes the main statistical characteristics of LOGCO2, LOGPOPULATION, and LOGGROWTH.

Table 1: Statistical Summary

	LOGCO2	LOGPOPULATION	LOGGROWTH
Mean	19.53367	18.11838	9.553095
Median	19.54165	18.10466	9.616482
Maximum	19.96139	18.27781	11.36479
Minimum	19.13610	17.97023	7.049063
Std. Dev.	0.268532	0.098055	1.120131
Skewness	-0.073138	0.229835	-0.562768
Kurtosis	1.709517	1.789605	2.697803
Jarque-Bera	1.686744	1.676353	1.358156
Probability	0.430257	0.432499	0.507084
Observations	24	24	24

According to Table 1, the mean of LOGCO2 was 19.53, LOGPOPULATION was 18.12 and LOGGROWTH was 9.55.Their median values, 19.54, 18.10, and 9.62, are very close to their means, indicating that the distributions of the data are symmetric. The standard deviations are relatively low for LOGCO2 and LOGPOPULATION (0.27 and 0.10), but higher for LOGGROWTH (1.12), suggesting a higher level of variability in the growth rate. While LOGCO2 and LOGGROWTH exhibit negative skewness, LOGPOPULATION demonstrates positive skewness. The kurtosis values are close to normal for all three variables, even though LOGGROWTH has a slightly higher kurtosis (2.70), which may indicate the presence of outliers. Given the results obtained from Jarque-Bera test, all variables satisfy the assumption of normal distribution (p-values greater than 0.05). This analysis, based on 24 observations, provides a foundational assessment of the potential nexus among economic growth, population growth, and carbon emissions.

Table 2 summarizes the results of the SPIRTAT ARDL(4,0,4) model, which was developed to examine the relationship between greenhouse gas emissions (CO2), population and GDP per capita.

Table 2. SPIRTAT ARDL Error Correction Regression

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LOGCO2(-1))	0.466906	0.110200	4.236906	0.0022
D(LOGCO2(-2))	0.260733	0.112703	2.313454	0.0460
D(LOGCO2(-3))	0.263481	0.102463	2.571480	0.0301
D(LOGGROSS DOMESTIC PRODUCT PER CAPITA)	**0.315177**	**0.070221**	**4.488349**	**0.0015**
D(LOGGROSS DOMESTIC PRODUCT PER CAPITA(-1))	0.021612	0.112672	0.191817	0.8521
D(LOGGROSS DOMESTIC PRODUCT PER CAPITA(-2))	-0.380254	0.109997	-3.456937	0.0072
D(LOGGROSS DOMESTIC PRODUCT PER CAPITA(-3))	-0.412386	0.138473	-2.978109	0.0155
CointEq(-1)*	**-1.406583**	**0.233770**	**-6.016964**	**0.0002**
F-Bounds Test				
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	6.788223	10%	2.63	3.35
k	2	5%	3.1	3.87
		2.5%	3.55	4.38
		1%	4.13	5
Breusch-Godfrey Serial Correlation LM Test:				
F-statistic	4.398655	Prob. F(2,7)		0.0579
Obs*R-squared	11.13773	Prob. Chi-Square(2)		0.0538

The long-term nexus between the series was investigated first. Hypotheses formulated for this purpose were “H0: There is no long-term nexus” and “H1: There is a long-term nexus”. As seen Table 1, the calculated F-statistic value was found to be 6.78, which was higher than the upper critical value of I(1) at 3.35, indicating a long-term nexus among the variables. In addition, the lagged error term, CointEq(-1)*, with a value of -1.40, is statistically significant and has a negative coefficient. This finding suggests that the discrepancy between the short- and long-term is reduced by 1.40% each period, gradually disappearing over time. The variable ‘GDP per Capita,’ representing the short-term parameter in Table 2, was also found to be statistically significant. Furthermore, no autocorrelation issue was detected between the series, and no structural changes were identified in the parameters.

Figure 1 CUSUM and Figure 2 CUSUMQ tests show that the system moves within the confidence interval and there is no structural break in the model. These tests were applied to all models and similar results were obtained.

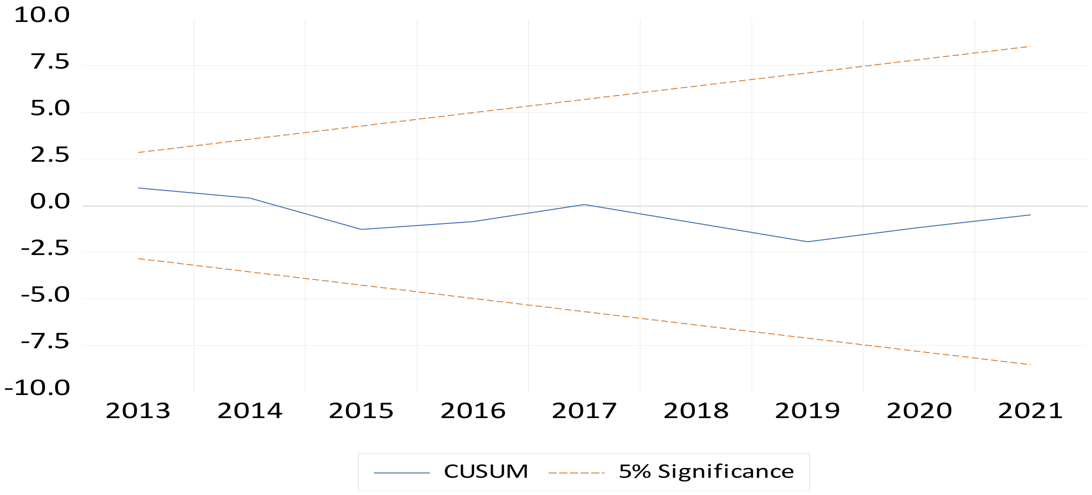

Figure 1: CUSUM

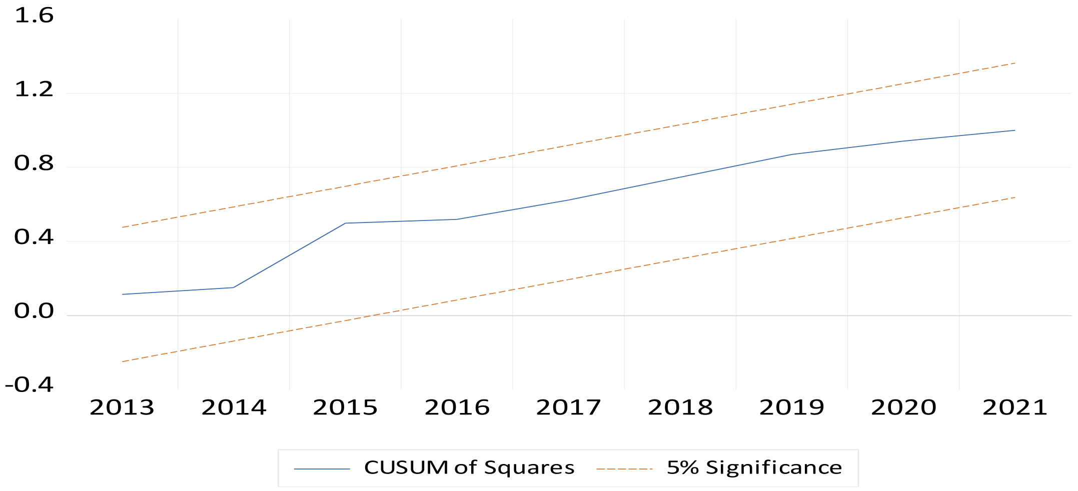

Figure 2: CUSUM of Squares

Based on the SPIRTAT ARDL(4,4,3) model between GDP per capita, population, and carbon emissions, Table 3 summarizes the results.

Table 3. SPIRTAT ARDL Error Correction Regression

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LOGPOPULATION(-1))	1.484185	0.194174	7.643563	0.0003
D(LOGPOPULATION(-2))	-0.309401	0.395535	-0.782235	0.4638
D(LOGPOPULATION(-3))	0.660272	0.280088	2.357371	0.0565
D(LOGGROSS DOMESTIC PRODUCT PER CAPITA)	0.016508	0.008568	1.926629	0.1023

D(LOGGROSS DOMESTIC PRODUCT PER CAPITA(-1))	0.001240	0.008731	0.142013	0.8917
D(LOGGROSS DOMESTIC PRODUCT PER CAPITA(-2))	0.025359	0.009858	2.572529	0.0422
D(LOGGROSS DOMESTIC PRODUCT PER CAPITA(-3))	0.013437	0.007768	1.729849	0.1344
D(LOGCO2)	**0.028484**	**0.014115**	**2.017893**	**0.0902**
D(LOGCO2(-1))	-0.055184	0.016309	-3.383619	0.0148
D(LOGCO2(-2))	-0.028793	0.010618	-2.711800	0.0350
CointEq(-1)*	**-0.438621**	**0.099400**	**-4.412675**	**0.0045**

F-Bounds Test				
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	3.245283	10%	2.63	3.35
k	2	5%	3.1	3.87
		2.5%	3.55	4.38
		1%	4.13	5

Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	3.118461	Prob. F(4,2)	0.2573
Obs*R-squared	17.23639	Prob. Chi-Square(4)	0.2017

The first analysis focused on the long-term nexus between the series. As seen in Table 3, the calculated F-statistic value was found to be 3.24, between the lower (2.63) and the upper (3.35) critical bound. This result introduces uncertainty regarding a long-term nexus between the series, thus findings obtained from other analyses were not included.

Table 4 summarizes the results of the SPIRTAT ARDL(1,4,3) model between GDP per capita, population, and carbon emissions.

Table 4: SPIRTAT ARDL Error Correction Regression

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LOGCO2)	0.539473	0.186394	2.894263	0.0178
D(LOGCO2(-1))	0.299143	0.177801	1.682461	0.1268
D(LOGCO2(-2))	-0.164511	0.154507	-1.064748	0.3147
D(LOGCO2(-3))	-0.452009	0.155062	-2.915016	0.0172
D(LOGPOPULATION)	**6.497350**	**3.649440**	**1.780369**	**0.0087**
D(LOGPOPULATION(-1))	-11.49908	6.394548	-1.798263	0.1057
D(LOGPOPULATION(-2))	-10.86854	5.287504	-2.055514	0.0700
CointEq(-1)*	**-0.612472**	**0.058780**	**-10.41975**	**0.0000**

F-Bounds Test				
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	20.35709	10%	2.63	3.35
k	2	5%	3.1	3.87
		2.5%	3.55	4.38
		1%	4.13	5

Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	4.121644	Prob. F(2,7)	0.0656
Obs*R-squared	10.81563	Prob. Chi-Square(2)	0.0545

As seen in Table 4, the calculated F-statistic value was found to be 20.35, higher than the upper critical bound (I(1)) of 3.35, indicating a long-term nexus between the variables. In addition, the lagged error term, CointEq(-1)*, which was found to be -0.61, is significant and has a negative coefficient. This finding suggests that the short- and long-term discrepancy is reduced by 0.61% each period, gradually disappearing over time. The short-term parameter 'Population' in Table 4 was also found to be statistically significant. Moreover, no autocorrelation issue was observed between the series, and no structural change was identified in the parameters.

Figure 3 CUSUM and Figure 4 CUSUMQ tests show that the system moves within the confidence interval and there is no structural break in the model.

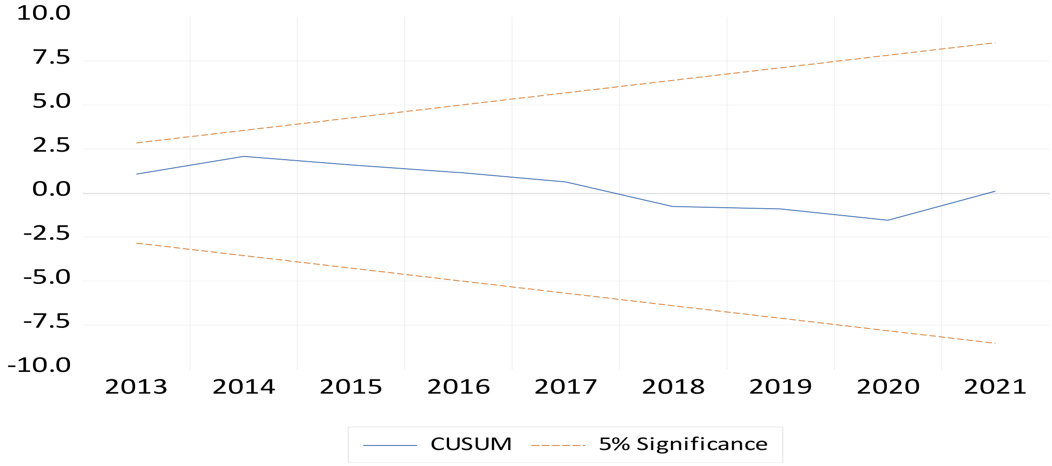

Figure 3: CUSUM

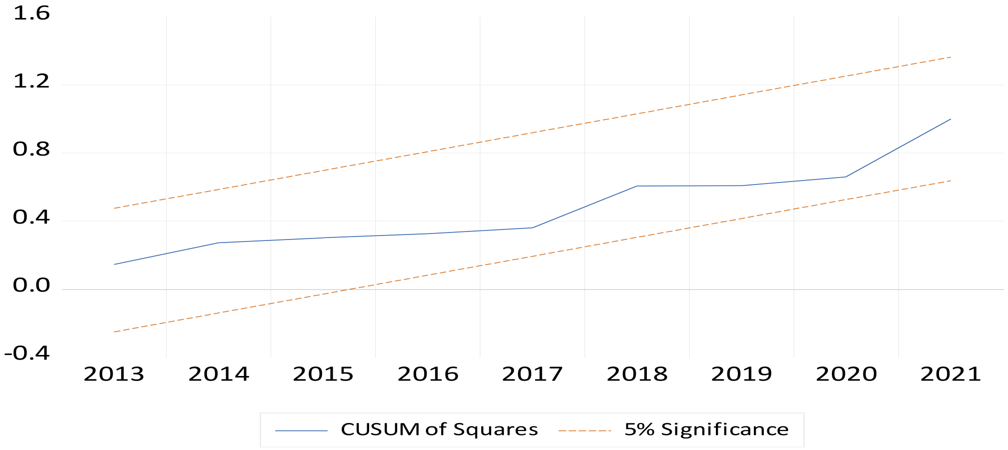

Figure 4: CUSUM of Squares

7. DISCUSSION AND CONCLUSION

This study analyzes how population growth and economic growth affect carbon emissions in Turkey using the SPIRTAT ARDL model. For this purpose, SPIRTAT ARDL(4,0,4), SPIRTAT ARDL(4,4,3) and SPIRTAT ARDL(1,4,3) are used. SPIRTAT ARDL(4,0,4) and SPIRTAT ARDL(1,4,3) models indicate statistically significant and positive relationships between the variables over both the short and long run. A statistically significant error correction coefficient is also found to support the explanatory power and accuracy of these two models, which are attributed to population growth and economic growth in Turkey. A number of factors contribute to the development of environmentally sustainable economic policies in the Turkish economy, including population growth and economic growth. In contrast, the long-run relationship between the variables in the SPIRTAT ARDL(4,4,3) model is uncertain.

Comparing the results of the study with those of previous literature, it is evident that both technical and conceptual consistency exists. According to Zhang and Sharifi (2024), local governments must develop environmentally friendly policies in order to reduce carbon emissions, and economic growth and environmental impacts must be maintained in balance. As argued by Pradhan et al. (2024) energy efficiency and the use of renewable energy sources will play an important role in reducing carbon dioxide emissions. According to Rahman (2017) urbanization policies should be developed to minimize the effects of population growth on environmental degradation. It can be concluded from this standpoint that educating and raising awareness of the environmental damage caused by carbon dioxide emissions and the widespread use of environmentally friendly technologies will prevent environmental degradation and allow economic growth to continue sustainably (Lee and Zhao, 2023).

In conclusion, efficient and effective population growth and economic growth are two vital issues for national economies. The world faces a number of problems, including global warming and climate change. A reduction of carbon emissions can be achieved through energy efficiency and the use of renewable energy. To reduce carbon emissions on a global scale, agreements promoting energy efficiency and renewable energy use, reducing fossil fuel use, and green-friendly tax regulations will be crucial.

A number of renewable energy sources are available in Turkey, including solar power, wind power, sea waves, and organic agriculture with its fertile soils and forests, which have a geographical comparative advantage. In this study, it is recommended not only to increase the share of these investments, but also to convert these investments into commercial products and export them. For this to be achieved, Turkey must adopt policies that are in accordance with international law, transparent, auditable and reliable, and based on social consensus.

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