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Research Article

The Link between Environmental Degradation and Aging: An Application on Türkiye

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Abstract
Discussions on climate change, environmental degradation, and ecological footprint have gained significant momentum. In this sense, understanding the carbon footprint, an essential component of the ecological footprint, is crucial in solving the environmental crisis. An aging population leads to changes in household consumption and economic activity. Especially in developing countries, an aging population has been observed to have a reducing effect on carbon footprint. The impact of the aging process on the carbon footprint has different consequences for different levels and stages of development. This study uses time series analysis to research the connection between carbon footprint and aging, urbanization, and industrialization in Türkiye. Cointegration and coefficient estimation were performed based on data from 1969 to 2022. The FMOLS technique was used in coefficient estimation. The study on the environmental degradation and aging in Türkiye found that urban population and industrial growth increase the carbon footprint, but the footprint of the elderly population decreases.

Keywords: Environmental degradation, carbon footprint, aging, urbanization, industrialization
JEL Classification Codes: Q57, O14, O18, J14

Çevresel Tahribat ve Yaşlanma İlişkisi: Türkiye Üzerine Bir Uygulama

Öz
İklim değişikliği, çevresel bozulma ve ekolojik ayak izi tartışmaları önemli ölçüde ivme kazanmıştır. Bu anlamda ekolojik ayak izinin önemli bir bileşeni olan karbon ayak izinin anlaşılması çevresel krizin çözülmesinde oldukça önemlidir. Yaşlanan nüfus, hane halkı tüketimi ve ekonomik faaliyetlerde değişikliklere neden olmaktadır. Özellikle gelişmekte olan ülkelerde, yaşlanan nüfusun karbon ayak izini azaltıcı bir etkisi olduğu gözlemlenmiştir. Yaşlanma sürecinin karbon ayak izi üzerindeki etkisi farklı gelişmişlik düzeylerine ve kalkınma aşamalarına göre farklı sonuçlar doğurmaktadır. Çalışmada Türkiye'de karbon ayak izi ile yaşlanma, kentleşme ve endüstrileşme arasındaki ilişki zaman serisi analizi ile incelenmiştir. 1969-2022 yılına ait verilerden hareketle eşbütünleşme ve katsayı tahminlemesi yapılmıştır. Katsayı tahminlemesinde FMOLS yöntemi kullanılmıştır. Türkiye'de çevresel tahribat ve yaşlanma üzerine yapılan çalışmada, kentsel nüfus ve endüstriyel büyümenin karbon ayak izini artırdığı, ancak yaşlı nüfusun ayak izini azalttığına dair bulgulara ulaşılmıştır.

Anahtar kelimeler: Çevresel tahribat, karbon ayakizi, yaşlanma, kentleşme, endüstrileşme
JEL Sınıflandırma Kodları: Q57, O14, O18, J14

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1. Introduction

Human expansion and development activities have reached very high levels, which have a high impact on nature. The gases released into the atmosphere due to human activities have started to degrade and threaten life on the planet. Gases released into the atmosphere are known to cause climate change; all these gases are called greenhouse gases. The fundamental and main implication of greenhouse gas emissions is global warming. The phenomenon of global warming has driven countries and non-governmental organizations to examine the negative impact of human activities on the environment. Greenhouse gas emissions, particularly carbon dioxide (CO_2) emissions, are the primary human activities contributing to environmental degradation.

As global warming became an extreme threat, wider discussions on ecological footprints emerged. The ecological footprint mainly represents the land and sea areas that are biologically productive and necessary for the continued existence of the human population. The carbon footprint is defined as a subset of the ecological footprint. The carbon footprint is the land area required to absorb the CO_2 emissions created by human activities (Pandey, Agrawal & Pandey, 2011). The carbon footprint, characterized as one of the concepts representing the excessive burden created by human activities on nature, is one of the highest contributing elements of the ecological footprint. In this regard, solving the degradation and pressure humans create on nature means minimizing carbon emissions.

The carbon footprint is affected by many economic and social factors. In this context, industrialization and urbanization are human activities that create negative externalities in carbon emissions and the environment. Still, studies have proven that urbanization can reduce carbon emissions with appropriate policies. In addition, one of the environmental issues that should be considered is demographic structure and aging, which countries have been addressing as a significant problem area in recent years. When evaluating the issue of demographic transformation, it is noted that the main root of carbon emissions is the young and active population. In this sense, aging can be considered an economic problem. In contrast, in terms of the environment, it can be regarded as a situation that will reduce carbon emissions in the context of the transformation it creates in the labor market and consumption trends.

Carbon emissions, an indicator of carbon footprint, are also an essential topic of discussion in environmental studies, as they are the component of the ecological footprint with the highest impact. In this sense, evaluating the carbon footprint of countries is very important in terms of sustainability. Understanding the effects of urbanization, industrial growth, and aging processes on carbon emissions is crucial for reducing Türkiye's carbon footprint. In this context, time series analysis was carried out in the study to determine the carbon footprint in Türkiye based on data from 1990 to 2020. After theoretically discussing the linkage between carbon footprint and urbanization, industrialization, and aging, and reviewing empirical literature, the study's findings are presented in the empirical results section.

2. Environmental Degradation concerning Aging, Urbanisation, and Industrial Growth

Climate change is characterized as an increasingly significant threat to humanity. Among the environmental pollutants that cause and trigger climate change, CO_2 emissions come first (Zheng, Wang, Mak, Hsu & Tsang, 2021). The literature on environmental degradation also points to CO_2 emissions as the most crucial trigger of environmental degradation, causing damage at the individual, social, and country levels (Ali et al., 2023). Carbon dioxide-based greenhouse gas emissions led to worldwide climate change, which is likely to have broad and irretrievable effects on ecosystems and society (Bolin & Döös, 1986, p. 1-3; Wang, Liu, Liao & Wei, 2021).

The possibility that CO_2 emissions, among the greenhouse gases, may cause climate change is more familiar than thought. Arrhenius first suggested in 1896 that using fossil fuels could increase the amount of CO_2 in the atmosphere and disrupt the radiation balance on the Earth (Bolin & Döös, 1986, p. 2). Greenhouses are inherently much warmer than the outside air. Even unheated greenhouses are warmer than the outside air because glass transmits light but is relatively opaque to re-emitted radiation. The same is true for the atmosphere. Here, the constituents of CO_2 and other atmospheric gases are also transparent to visible light but obscured to long-wave infrared radiation. Therefore, since CO_2 and other atmospheric gases function like glass in a greenhouse (Furman & Yenigun, 1995, p. 132), these gases are called greenhouse gases; since they disturb the radiation balance in the Earth and cause increasingly warmer temperatures, the effect created by these gases is called the greenhouse gas effect.

The rapidly growing human population increases the need for food and energy, leading to anthropogenic degradation. These anthropogenic disturbances are the root cause of all environmental problems. Human activities disrupt the carbon cycle (mainly provided by green plants), the most important cycle for ecological balance and life (Furman & Yenigun, 1995, p. 47, 49). The disrupted carbon cycle is mainly due to increased CO_2 emissions. Many social and economic factors increase carbon emissions. Industrialization, which can be considered the driving force of social development, energy consumption, urbanization, and welfare increase, increases CO_2 emissions, i.e., carbon emissions.

As is known, two fundamental changes in living conditions worldwide pose a danger. The first of these is environmental change related to the global climate, which is the main subject of this research. The other is demographic transformation. The demographic transformation gives rise to changes not only in terms of scale but also in the population age structure. The contemporary and prospective phases of the demographic transition are distinguished by an aging population in a range of developed and developing countries (Menz & Welsch, 2012). The demographic shifts, particularly the aging of the population, give rise to notable divergences in consumer preferences between the older and younger age groups. Changes in household expenditures and consumption structure associated with aging affect household carbon emissions. In consequence of alterations in domestic consumption habits and the aging of the population, there have been notable changes in energy consumption and, thus, in carbon emissions. This phenomenon is more prevalent in developing nations than in developed countries (Fan, Zhou, Zhang, Shao & Ma, 2021).

Carbon emissions and population aging should be considered in the changing demographic structure, in addition to the evaluations focused on in the literature regarding the linkage between emissions and population. Two significant challenges to the sustainable development of human society are the problem of carbon emissions and the issue of population aging. While the world population continues to grow, a significant worldwide trend is that the population is aging. Beyond the trend, the issue of population aging is becoming a substantial difficulty that every region and country is facing. Since the late 19th century, the demographic composition of the population has been increasingly acknowledged as a key demographic factor in the effect of population on emissions (Dalton, O'Neill, Prskawetz, Jiang & Pitkin, 2008; Wang & Wang, 2021). The problem of aging is essential through structural changes in the inhabitants owing to urbanization or drivers of economic growth. However, population composition may also affect consumption patterns due to different energy requirements for various consumer goods (Dalton et al., 2008). Although the detrimental effects of human acts on the ecosystem have been empirically substantiated, the connection between carbon emissions and population aging remains a topic of contention, necessitating further investigation through additional studies. Most studies focus on population size and rural-urban context (Zhang & Tan, 2016). One of the areas that can be presented as a reason for the effects of population aging on the ecosystem is that per capita economic activity depends on age decomposition. Another area is the impact that age structure can have on the sectoral distribution of production through changing demand trends, particularly energy use. Finally, the prospect of an increase in life expectancy will lead to extended planning periods; thus, greater emphasis on sustainability issues is considered a factor in aging affecting environmental degradation (Menz & Welsch, 2012).

According to the literature, urbanization and industrialization are the major drivers contributing to carbon emissions (Ali et al., 2023; Zheng et al., 2021). The increase in the greenhouse effect results from the continuous accretion of carbon emissions from human actions in the historical process (Dong, Wang, Su, Hua & Zhang, 2019). Since the Industrial Revolution, the production of carbon dioxide-intensive greenhouse gas emissions as a consequence of human activities has been relatively high (Wang et al., 2021). Especially since this period, consumption and production patterns in developed countries account for 85.9% of accumulated carbon emissions. Therefore, the primary source of carbon emissions is attributed to the changing production and consumption structure with the industrial revolution (Dong et al., 2019). In addition, with industrialization, people's economic acts and energy use have been concentrated in urban areas, and today, more than half of the world's population lives in cities. Therefore, these metropolises, which account for about 2% of the broad area, make 75% of the globe's CO_2 (Xu, Dong & Yang, 2018). Since urban regions have higher carbon emissions than rural regions, academics agree that urbanization will extend carbon emissions (Liu, Tian, Li, Song & Ma, 2018). For this reason, in 2009, the Worldwatch Institute named cities “keys” that can contribute to solving global warming (Xu et al., 2018).

Urbanization, which is considered to play an indispensable function in the development and progress of the modern economy and society, is seen as one of the basic symbols of modernization (Wang et al., 2021). Urbanization, a key component of modernization, is exacerbating the problem of CO2 emissions, particularly with the rapid growth of urban clusters, which leads to increased population, traffic congestion, and vehicle emissions. Urban clusters are driven by the desire for more employment opportunities, higher wages, and access to better health facilities, moving more people to metropolitan areas (Liu et al., 2018). Since the 1970s, the world has experienced rapid urbanization, and in 2007, for the first time, the urban population surpassed the rural population. Today, more people around the world live in cities. This has given rise to an increase in cumulative CO_2 emissions from human activities, with the cumulative emissions of CO_2 accounting for about 50% of the total emissions since the Industrial Revolution (IPCC, 2014).

Industrialization activities that intensify various regions and countries with developing technologies and economic growth will increase population growth. Therefore, industrialization activities will be followed by an increase in urbanization. In areas where urbanization intensifies, infrastructure and investments will increase in parallel. In this way, industrialization and urbanization for various activities will create an effect that increases environmental destruction, such as water, soil, and air pollution, and population density (Karanfil, 2022). Large-scale urban substructure and housing buildings, encouraged by urbanization and increased residential energy use due to rural-urban migration, prompt a significant increase in energy use in a country and feed carbon emissions that trigger environmental degradation due to available energy resources (Ouyang & Lin, 2017). Similarly, infrastructure requirements created by industrialization play an essential role in increasing the carbon footprint. The fact that the infrastructure stocks needed correspond to approximately 35% to 60% of the carbon budget, as they are placed on a global basis with existing technologies, creates a challenge for both developing and developed nations. It puts pressure on the carbon footprint in ecological terms (Wu, Shen, Zhang, Skitmore & Lu, 2016).

Cities can be characterized as the most crucial CO_2 emitters, but they are also essential policy implementers. Therefore, accomplishing a worldwide carbon emission decrease relies on the joint success of each area. In this framework, the part of the CO_2 emission decrease at the urban district level should be considered. Due to their structure, cities are the main center of production and consumption, so they are significant parameters of CO2 emissions and mitigation (Zhu, Liu, Tian, Wang & Zhang, 2017). Population, especially the urban population, significantly impacts carbon emissions. Especially in developed nations, domestic energy use is constantly increasing with the increasing rate of urbanization due to people's improving living standards (Fan et al., 2021). At some point, for each person, carbon emissions will climax and then enter a downward trend. This tendency is directly related to the population growth rate. If the ratio of population increase is slower than the rate of decline for per-person's carbon emissions, carbon emissions are expected to enter a downward trend at that point. When the population growth rate is zero, total and for each person carbon emissions are expected to climax simultaneously (He, 2014). As a result of developed countries' advanced economic, social, and educational culture, population growth could be faster and more positive. Therefore, carbon emissions have started to increase in developed countries. In most developed countries, carbon emissions have peaked and remained constant. Consequently, it is thought that after this stage, developing countries will produce most of the globe’s carbon emissions due to their pursuit of economic growth (WB, 2009).

It is essential to learn how industrialization affects carbon emissions at various levels of development. In low- and middle-income countries, industrialization has a substantial positive impact on emissions, and this impact is more potent than in high-income countries. At higher income levels, the carbon-emissions-enhancing effect of industrialization starts to decline. A significant portion of developing nations is experiencing the peak period of economic progress, currently at the same stage of growth that advanced economies have undergone since the Industrial Revolution. Therefore, the impact of developing nations on the earth’s emissions is increasing significantly (Dong et al., 2019).

Empirical demonstration emphasizes that urbanization is an essential level in the economic development of countries, as it is a necessary force for a country to move from a rural-agricultural to an urban-industrial base (Ouyang & Lin, 2017). Therefore, while urbanization is inevitable in countries undergoing economic development, empirical findings prove that it creates a carbon footprint. Nevertheless, the influence of urbanization on carbon emissions varies at different levels of intensity of urbanization, as evidenced by empirical findings. As Dong et al. (2019) have demonstrated, there is no significant correlation between urbanization and carbon emissions when the level of urbanization is below the first threshold value; however, once this value is exceeded, the relationship becomes negative, indicating that urbanization has a repressive effect on carbon emissions.

The primary reason for this negative effect is that the improvement in urbanization levels encourages enhanced energy optimization, the development of advanced technology in new energy production strategies, and increased scale effects. Once urbanization has reached the second threshold, it is observed that the population shifts from metropolitan territory to smaller cities, rural areas, and surrounding suburbs as a consequence of suburbanization. This leads to depopulation within the town and a restructuring of the urban area, ultimately leading to increased carbon emissions. As with urbanization, the stage of development in the industrialization process can lead to differentiation in the carbon footprint. Understanding the impact of industrialization at different levels of development on carbon emissions will empower an economy to develop and implement the most appropriate energy conservation and carbon reduction initiative for its particular stage of development. It can thus be posited that the effects of urbanization and industrialization on carbon emissions and energy consumption are subject to variation at the various stages of development and in disparate geographical regions (Ding & Li, 2017). The progress of the urbanization process is influenced by many factors, such as government decision-making, the overall level of the regional and national economy, the structure of regional industry, the level of infrastructure construction, the level of education, and even the global environment. It can be said that the energy use and, thus, the carbon emissions generated during the urbanization and industrialization phases are similar (Ouyang & Lin, 2017).

In brief, industrialization and urbanization contribute to carbon emissions and help control them. Industrialization and urbanization, which change industrial transformation and energy consumption structures, lead to increased economic activities that increase carbon emissions (Zheng et al., 2021). The pace of industrialization and urbanization leads to massive economic growth, significantly increasing fossil energy usage and, thus, carbon footprint (Ding & Li, 2017). In addition, industrialization and urbanization are also causes of carbon emission reduction, as they enable industrial agglomeration and efficient use of urban infrastructure (Zheng et al., 2021). Conversely, although it has been proven that there is a linkage between aging and carbon footprint, the direction of the relationship has not yet been determined (Wang & Wang, 2021). At this point, in addition to the level of development of countries, the stage of urbanization and industrialization, and their environmental sensitivity, the percentage of the elderly in the overall population, and the way the elderly population prefers to live are essential.

3. Empirical Literature

The carbon footprint is one of the most frequently discussed topics in recent years. Carbon emissions have been considered in the writings within the framework of various socio-economic factors. This section includes studies examining the linkage between carbon footprint and aging, urbanization, and industrial growth in the context of the model constructed in this study.

Based on a study examining the linkage between carbon emissions and population aging in the US, Dalton et al. (2008) concluded that aging in energy use reduces carbon emissions by about 40%. In addition, Dalton et al. (2008) examined the impact of demographic structure on carbon emissions in the US. They found that changes in the population's age composition drive total emissions into heterogeneous households. In fact, under the low inhabitant scenario, carbon emissions in heterogeneous households are about 37% lower in the 2100 projection compared to representative households without aging. The authors posit that this discrepancy is attributable to scale effects stemming from alterations in the labour supply concomitant with aging. The study finds that emissions in 2100 for a representative aging household are about 31% lower than for a representative non-aging household. The research indicates that the remaining discrepancy can be attributed to capital flows and general equilibrium effects.

Despite the above findings, Menz and Welsch (2012) examined the linkage between carbon emissions and demographic transformation in OECD countries. They found that emissions increase as the share of the elderly and those born after the year 1960 in the population increases. In a study examining the link between population aging and emissions at the regional level, Zhang and Tan (2016) concluded that the 65+ age group has a negative effect on emissions in the western and eastern regions of China; that is, a higher proportion of the elderly results in lower carbon emissions. In another study examining the link between aging and emissions at the regional level, Fan et al. (2021) discovered that aging in urban areas increases household emissions in China. In the Northern region, where clean forms of heating are used, it was found that population aging contributed to a reduction in emissions. In this sense, although it is seen in the literature that aging has a differentiating influence on emissions, it is also noteworthy that the effect of demographic transformation on the environment is undeniable.

Wu et al. (2016) assessed the effect of urbanization on carbon emissions in China, a country classified as a developing nation. Their findings presented that an elevated urbanization rate, an increased energy carbon emission coefficient, and heightened energy intensity are associated with a rise in carbon emissions. Again, in the study by Ouyang and Lin (2017) examining the linkage between carbon emissions and urbanization in China, it was determined that the urbanization process is one of the significant elements in increasing carbon emissions in China and that China may reach the climax of emissions in 2020. It is also observed that CO_2 emissions in China and Japan have similar growth characteristics in urbanization processes. However, it is concluded that there are differences in other factors affecting CO_2 emissions since Japan is the leading country in energy saving.

The study by Ding and Li (2017) investigating the effect of urbanization on CO_2 emissions at the regional level concluded that the impact of urbanization on carbon emissions in China is contingent upon several factors. It is found that households living in urban areas produce twice as many emissions from energy use as those living in rural areas, so urbanization firstly affects CO_2 emissions through household behavior. Secondly, it is concluded that the intensity in the transportation sector with urbanization increases carbon emissions in the period under review. In addition to increasing carbon emissions, the study also emphasizes that urbanization can create the potential for a low-carbon economic paradigm by leading to the redesigning of the industrial sector. In another study examining the linkage between urbanization and CO_2 emissions at the regional level, Xu, Dong, and Yang (2018) found that economic urbanization has the most significant effect on emissions in the Pearl River Delta region of China, followed by land urbanization. The study further highlights the necessity for a focus on the composition and structure of emissions, with particular emphasis on those emanating from energy use and industrial production within the region.

To determine the impact of urbanization and industrialization on carbon emissions at the city level, Zhu et al. (2017) concluded that both industrialization and urbanization are essential CO_2 sources in Tianjin, China. While it is observed that carbon emissions are high during the transition phase, especially with the shift to information technology, the study determines that the rapid urbanization process increases CO_2 emissions considerably due to the increase in household consumption and demand for urban infrastructure and buildings. Liu and Bae (2018) also examined the impacts of urbanization and industrialization on CO_2 emissions in China, concluding that an increase in industrialization and urbanization will result in a corresponding rise in CO_2 emissions over time.

Meanwhile, Dong et al. (2019), in their study analyzing the linkage between industrialization and urbanization with emissions in China, conclude that the effects of both variables differ at different levels. When the impact of urbanization stages on CO_2 emissions is examined, while urbanization decreases emissions at the intermediate urbanization level, urbanization starts to increase carbon emissions when the second threshold above this level is crossed. In terms of income level, when the linkage between industrialization and carbon emissions is analyzed, it is found that industrialization increases carbon emissions in general; this increasing effect is higher at low and middle-income levels, and the impact that increases carbon emissions weakens at high-income levels. Confirming the results of Dong et al. (2021), Zheng et al. (2021) analyzed CO_2 emissions in China and concluded that industrialization increases CO_2 emissions, while a negative connection was found between urbanization and CO_2 emissions. The study emphasizes that environmental taxes imposed in China and public infrastructure can effectively reduce emissions and address this situation. Similarly, Wang et al. (2021) conclude in their study examining the linkage between urbanization and emissions in OECD countries that urbanization negatively impacts emissions in developed countries, although different countries have different equipment. According to the authors, the findings show that all OECD member countries can decouple urbanization and carbon emissions.

The influence of industrialization and urbanization on ecological footprint in Türkiye was analyzed by Karanfil (2022), and a long-run linkage was found among urbanization, industrialization, and ecological footprint. Ali et al. (2023), examining the impact of urbanization and energy consumption on carbon emissions in Saudi Arabia, similar to the literature, conclude that the expansion of urbanization increases emissions and reinforces environmental damage. In addition, VAR analysis shows that a shock in urbanization and industrialization variables creates a fluctuation of 0.46% and 0.29% on the ecological footprint. The research conducted by Qiao et al. (2024) on the influence of industrialization and urbanization on emissions in China revealed that the main factors of carbon emissions underwent a transition from the agricultural sector to the manufacturing and services sectors. It is also observed that higher emissions from traditional industries offset the initial carbon emission-reducing impacts of innovation in emerging high-technology sectors. In addition, the linkage between emission intensity and urbanization indicates that emission intensity can be significantly reduced if urban settlement areas increase above 10%.

4. Empirical Results

Time series is the combination of past data values to be estimated and past random variations in current and past values (Griffiths, Hill & Judge, 1993). More precisely, time series analysis has a twofold purpose. The first is to model the stochastic mechanism that leads to an observed series. The second objective is to predict the past and future values of this observed series (Cryer & Kellet, 1991, p. 1). Using time-series data allows for the realization of several objectives, which include clustering, classification, forecasting, estimating the impact of an intervention over time, and the discovery of causal links relating to the components of a time series (Moraffah et al., 2021). In this context, estimation was made with data from this study to determine the impact levels of the factors that lead to this problem for policies that can be developed to control the carbon footprint in Türkiye.

The study evaluating Türkiye's environmental degradation conducted analyses based on 1969-2022 data. Carbon footprint is the dependent variable; the elderly population is the independent variable; and urban population and industrial growth are added to the model as moderating variables. The model constructed within the scope of the study is presented below, and Table 1 shows the variables and information on the variables.

$$CF = \beta_0 + \beta_1 AGE + \beta_2 UP + \beta_3 IG + \varepsilon \quad (1)$$

In the equation, β_0 is the constant term, $\beta_{1,2,3}$ are the elasticity coefficients, and ε is the error term. The variables in the model constructed in the study and the calculation methods for them are reported in Table 1 below.

Table-1. Definition of Variables

Variable	Definition	Notation
Carbon footprint	CO_2 emissions associated with fossil fuel use (tonnes per year)	CF
Elderly population	Population ages 65 and above (% of total population)	AGE
Urban population	Urban population (% of total population)	UP
Industrial growth	Industry (including construction) (annual % growth)	IG

Data on carbon footprint were obtained from the Global Footprint Network (GFN), while data on urban population, industrial growth, and elderly population were obtained from the World Bank database. The calculated descriptive statistics associated with the variables are illustrated in Table 2.

Table-2. Descriptive Statistics

	CF	AGE	UP	IG
Mean	1.2834	1.7812	4.2140	5.1641
Median	1.2298	1.7640	4.2172	6.5891
Maximum	1.6498	2.1019	4.3321	19.3273
Minimum	0.9409	1.5533	4.0810	-10.5345
Std. Dev.	0.2210	0.1610	0.0769	6.7706
Skewness	0.0306	0.3487	-0.0927	-0.6319
Kurtosis	1.7101	2.0060	1.7521	3.3278
Jarque-Bera	2.1539	1.9045	2.0560	2.2016
Probability	0.3406	0.3859	0.3577	0.3326

When the descriptive statistics test results of the variables are analyzed, Kurtosis, Skewness, and Jarque Bera probability values show that the dependent (CF), independent variable (AGE), and moderating variables (UP and IG) exhibit a normal distribution.

The hypotheses that need to be tested before proceeding to the model estimation stage are related to multicollinearity and endogeneity problems. The presence of multicollinearity and endogeneity problems in the model affects the reliability of the estimation results and leads to biased results. In this context, multicollinearity, which indicates the correlation levels of independent variables, is tested with the VIF test. In addition, the presence of an endogeneity problem, which suggests the linkage among the independent variables and the model's error term, was tested with Wald and Sargan-Hansen tests. The findings of the VIF test are demonstrated in Table 3, while the results of the Wald and Sargan-Hansen tests are reported in Table 4.

Table-3. Multicollinearity Results

VIF (Variance Inflation Factors)		
Variable	Variance Coefficient	Centered VIF
AGE	6.75E-05	1.1962
UP	0.0188	1.2104
IG	1.16E-06	1.0146

Examining the results of the VIF test, which tests the multicollinearity problem, it was determined that the independent and moderating variables are not multicollinear. Accordingly, using the independent and moderating variables in the model constructed in this study will not pose a problem.

Table-4. Endogeneity Test Results

Block exogenous Wald test.			
Hypothesis - H_0: Exogenous		$X^2(1)$	Prob.
AGE	IG	1.893	0.168
UP	UP	1.077	0.299
	AGE	0.123	0.725
IG	UP	0.418	0.517

Sargan-Hansen Test for Exogeneity of Instruments			
Instrument specification:	Instrument validity	Sargan–Hansen J statistic	Prob(J-statistic)
@DYN(CFP,-2) AGE(-1) IG(-1) UP(-1)	Model A	2.405	0.121
H_0: The instruments used in this model are valid			

According to Table 4 above, no endogeneity problem was found in the variables used in the study. In this context, the model constructed in the study is valid within the scope of multicollinearity and endogeneity results. Another important test for time series analysis is whether the variables are stationary. Accordingly, the stationarity test was performed with the one-break ADF (Zivot & Andrews, 1992) unit root test. The equation for the one-break ADF is formulated as shown below.

$$\Delta y_t = \propto + \beta_t + \theta D_t + \gamma y_{t-1} + \sum_{i=1}^{k} \delta_i \Delta y_{t-i} + \varepsilon_t \quad (2)$$

In the equation, Δy_t is the time series difference, α is the constant term, β is the trend coefficient, γ is the unit root parameter, p is the lag length, γ_i is the coefficients of different lag values, D_t is the break variable, and ε is the error term. The one-break ADF unit root test results for the stationarity test of the series are shown in Table 5.

Table-5. Stationarity Results

	Intercept				Intercept and Trend			
	Level		1st Difference		Level		1st Difference	
	ADF-sta.	Break Date	ADF-sta.	Break Date	ADF-sta.	Break Date	ADF-sta.	Break Date
CF	-4.399	2003	-8.896	1974	-4.308	2005	-9.102	2009
AGE	-3.818	2016	-5.946	1973	-4.500	2016	-6.117	2015
UP	-3.823	1981	-10.241	2001	-4.092	1996	-8.942	2017
IG	-4.446	2001	-6.589	2001	-4.992	1991	-6.621	2001
H_0: Unit root								
Critical Values								
Intercept					Intercept and Trend			
(1%,5%,10%) -5.340, -4.800, -4.580					(1%,5%,10%) -5.570, -5.080, -4.820			

The one-break ADF test results indicate that all the variables are non-stationary (statistic greater than critical value) in the models with constant, constant, and trend. When first-order differences are taken, the series of variables becomes stationary. Therefore, the CF, AGE, UP, and IG variables are I(1).

Time series analysis can reveal the long-term link between the variables. In the constructed model designed to investigate the relationship between environmental degradation and the process of aging within the geographical context of Türkiye, the analysis focuses on the examination of cointegration relationships. The classical Johansen or Engle-Granger cointegration tests ignore structural breaks. Therefore, cointegration tests that include regime changes have been developed. In this context, the cointegration relationship is tested by cointegration tests with regime-switching.

The cointegration tests with regime-switching equations are formulated as follows.

$$\Delta y_t = \mu_0 + \sum_{i=1}^{k} \Gamma_i \Delta y_{t-i} + \Pi Y_{t-i} + D_t + \varepsilon_t \quad (3)$$

In the Johansen cointegration equation, y_t is the time series, Δy_t is the difference of y_t, μ_0 is the constant term, Γ_i is the matrix representing the short-run dynamics, Π is the long-run cointegration matrix, Dt is the variables of the regime change, and ε is the error term. The outcomes from the cointegration tests with structural breaks are reported in Table 6.

Table-6. Cointegration Test Results

	Level	Trend	Level	Trend
Test	Test Stat.	Test Stat.	Test Stat.	Test Stat.
SCols/Clols	0.041	0.032	0.024	0.024
SC(Dols)/Cldols	0.076	0.060	0.021	0.041
1%	0.159	0.110	0.130	0.055
5%	0.105	0.072	0.076	0.042
10%	0.084	0.058	0.059	0.036
H_0: co-integration				

Analysing the results of the cointegration test with structural breaks developed by Carrion-i-Silvestre & Sansó (2006) and Arai & Kurozumi (2007), the statistics SCols and SC(Dols) are less than the critical values in level and trend. Consequently, a long-run cointegration relationship is identified between the series. Similarly, the results of the Fourier cointegration test developed by Tsong, Lee, Tsai & Hu (2016) indicate that Fourier CIols and Fourier CIdols test statistics are smaller than the critical values in level and trend. Consequently, the null hypothesis (H_0) is not rejected. This finding indicates the presence of a cointegration relationship within the series.

Table-7. Multiple Breakpoint Test

Break Test	F-statistic	Scaled F-statistic	Critical Value (5%)
0 vs. 1 *	26.989	107.954	16.190
1 vs. 2 *	5.060	20.241	18.110
2 vs. 3 *	5.207	20.829	18.930
3 vs. 4	2.846	11.385	19.640
Break dates:			
	Sequential	Repartition	
1	1978	1978	
2	1990	1988	
3	2001	2001	

When the results of the Bai-Perron (2003) Multiple Break Test are analyzed, three significant breaks are detected. According to the Sequential F-statistic values, the most appropriate number of breaks is 3. For the 4th break, the F-statistic is below the critical value. Therefore, there is no additional break.

The break dates are determined as 1990, 1978, and 2001. In this sense, it can be assumed that significant regime changes occurred in these years. The year 1978 is crucial as it is the date when the Barcelona Convention (Convention for the Protection of the Mediterranean Sea against Pollution) entered into force in Türkiye. The last breakpoint (2001) can be considered a decisive break since it is consistent in both the Sequential and Repartition methods. The year 2001 is crucial for Türkiye, as it coincides with the country's economic crisis.

Coefficient estimates can be made following the model's detection of a cointegration relationship. In this context, the FMOLS estimator is preferred for coefficient estimation. FMOLS helps to eliminate the parameters that cause endogeneity problems in the model through kernel estimators. In addition, the FMOLS method eliminates the issues arising from the long-run correlations that may arise between cointegration equations and stochastic processes by using the covariance matrices of the error terms (Erdogan, Tiryaki & Ceylan, 2018). The equation for the FMOLS method is given below.

FMOLS equation:

$$Y_t = \propto + \beta X_t + u_t \tag{4}$$

The FMOLS equation, which offers a more efficient estimation opportunity in non-stationary series, represents Y_t as the dependent variable, α as the constant term, β as the regression coefficient, X_t as the independent variable, and u_t as the error term.

Table-8. Equation Results

CF			FMOLS	
Variable	Coeff.	Std. Error	t-stat.	Prob.
AGE	-0.6253	0.2057	-3.0397	0.0039
UP	0.0085	0.0026	3.2216	0.0024
IG	0.0069	0.0009	7.6119	0.0000
DUM1	-0.1381	0.0366	-3.7747	0.0005
DUM2	-0.0278	0.0333	-0.8346	0.4083
DUM3	-0.0426	0.0267	-1.5926	0.1183
R-sqr.	0.4827		Adj. R-sqr.	0.4137

The FMOLS result demonstrates the findings presented in the above table. The analysis reveals that both independent and moderating variables, namely AGE, UP, and IG, are statistically significant. The increase in the elderly population, added to the model to measure the effect of aging, has a decreasing impact on the carbon footprint in Türkiye. In this respect, the living conditions of the elderly population in Türkiye are effective. In addition to the living conditions of the elderly, the consumption tendencies of the elderly are not in a direction that feeds the carbon footprint, so it can be said that aging in Türkiye reduces the carbon footprint rather than increasing it. Although the findings obtained within the scope of the study overlap with the literature, as in the studies of Menz & Welsch (2012) and Zhang & Tan (2016), the findings of specific in-depth studies may show different effects. Various studies suggest that the impact of aging on carbon footprint is related to the transformation in labor supply. According to Dalton et al. (2008), the main argument for the negative linkage between carbon emissions and aging in the US is the transformation in labor supply. From this point of view, the aging issue impacts the environment due to both living conditions and consumption preferences, and the transformation in the labor market. In addition, regional differences within the same country differentiate the influence of aging on carbon emissions. In Fan et al. (2021) study, the demographic transformation in the direction of aging in China's urban areas and regions where protected policies are implemented has different levels of impact. While aging increases carbon emissions in metropolitan regions, aging decreases carbon emissions in protected zones (mainly in delta areas with agriculture).

Following the results in the table, while the urban population and industrial growth act in the direction of increasing CO_2 emissions, the elderly population acts in the direction of decreasing[1] carbon footprint. In this context, the urban population and industrial growth in Türkiye's carbon footprint create a negative externality. A similar effect is also observed in studies by Zhu et al. (2017) and Liu and Bae (2018). However, in the studies of Zheng et al. (2021), industrialization has been identified as a significant contributor to the emission of carbon, which is one of the leading carbon footprint indicators, while urbanization reduces emissions. Similarly, in the study conducted by Wang et al. (2021) for OECD countries, urbanization has a decreasing effect on carbon emissions. Based on Zheng et al. (2021), environmental taxes and the operational implementation of emission-reducing urban infrastructures eliminate the detrimental impact of urbanization on the natural environment.

The table also demonstrates the efficiency of the dummy variables. Only the variable representing the year 1978 is significant among the dummy variables organized according to the break dates. Thus, the Barcelona Convention has a reducing effect on the carbon footprint in Türkiye. This finding provides a compelling response to the prevailing question regarding the effectiveness of international conventions.

[1] York et al. (2003) and Shi (2003) discovered that carbon emissions are higher in countries with a higher proportion of the population in the working age. Farzin and Bond (2006) noted that countries with a high proportion of individuals under the age of 15 in the population have higher carbon dioxide emissions.

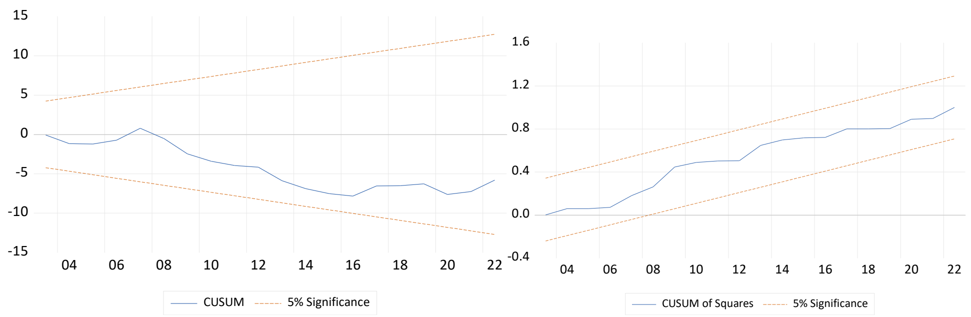

Figure-1. CUSUM Tests

The CUSUM and CUSUM of Squares tests have been demonstrated to be effective indicators of the consistency of the model over time, as evidenced by the analysis of the graphs above. The results indicate that the model demonstrates consistency in both graphs.

Table-9. Diagnostic Test Results

Autocorrelation		Heteroscedasticity		Ramsey-Reset		Jarque-Bera	
F/t stats.	1.0055	F/t stats.	0.4503	F/t stats.	0.7706	F/t stats.	2.6074
Prob	0.316	Prob	0.945	Prob	0.469	Prob	0.271

The results of the diagnostic test, as presented in the table, indicate the absence of autocorrelation and a changing variance problem in the model. The series is found to be normally distributed. The Ramsey-Reset result confirms the absence of specification error in the model, thereby supporting the validity and reliability of the model constructed within the scope of the study.

5. Conclusion

Humanity's need for development has brought new technologies and new forms of production. New forms of production and the transition to a consumer society led to the excessive spread of industrialization and the development of urbanization activities in the regions where factories were established. In this sense, the Industrial Revolution can be characterized as the basis for creating excessive pressure on natural resources to increase production based on human consumption needs. The pressure created on natural resources due to human activities can be defined as an ecological footprint. The carbon footprint represents a significant and pivotal element of the conceptual framework of the ecological footprint. In this respect, reducing the ecological footprint is directly related to reducing carbon footprint creation. Carbon footprint is one of the main subjects that needs to be studied to accomplish the goals within the understanding of a sustainable environment and development.

Understanding the different degrees of economic development of countries and the various effects of industrialization and urbanization on carbon footprint will help each country find its solutions. The carbon footprint differences between countries are directly affected by energy use and the quality of the resources used in industrialization and urbanization, which are the main elements that expand carbon emissions. Although urbanization creates a footprint by increasing carbon emissions at a particular stage, it is seen that countries can reduce their carbon footprint with the arrangements made in the energy structure after a specific stage of urbanization and industrialization. In this sense, adjusting the energy structure in line with the requirements created by the urbanization and industrialization process and implementing technical innovation in industrialization will provide an essential breakthrough for Türkiye, as in other developing countries, to achieve a reduction in its carbon footprint.

Urbanization and industrialization are considered an inevitable phase in today's societies. In this context, various strategies should be developed to reduce the carbon footprint created through industrialization and urbanization. It is recommended that sustainable and green urbanization be encouraged, as it has the potential to stimulate economic growth while simultaneously reducing environmental degradation. Regulations on urban infrastructures should be supported by strategically optimizing the industrial structure. One of the viable strategies for reducing the carbon footprint is to enhance energy efficiency and the proportion of renewable energy in the total energy use mix by pursuing technological innovations in energy utilization.

Aging, in addition to urbanization and industrialization, is another phase that societies cannot avoid, and it is estimated that Türkiye will soon be among the elderly countries. In this respect, it is necessary to discuss the issue of aging and carbon footprint. The elderly population is a group with high energy savings rates and lower carbon consumption habits, considering cultural reasons and savings-oriented lifestyles. For this reason, the understanding and awareness of environmental protection should be promoted among the young population, first and foremost through education. A comprehensive educational program has the potential to facilitate a conscious shift amongst younger demographics towards more environmentally conscious consumption patterns.

The relationship between aging and carbon footprint is not just a statement of fact but can also be used as an active policy tool. This research suggests that older adults should be considered a valuable resource for promoting sustainable lifestyles, as well as a target group. In this context, it is recommended that several regulations be introduced to encourage older adults to implement sustainable living strategies in Türkiye. Sustainable housing projects and tax incentives that promote reduced carbon emissions could increase environmental awareness among both the elderly and younger populations. Low-carbon urban planning, especially when implemented in an age-friendly manner, can lead to structural carbon reductions, in addition to the elderly population's already low carbon emissions. Programs that enable the elderly to influence the consumption habits of younger generations can facilitate intergenerational interaction, allowing the elderly to become active participants rather than passive observers. Their active involvement in carbon reduction efforts can raise awareness and encourage the development of new behavioral patterns. Consequently, this approach can help pass on an environmentally conscious lifestyle to younger generations. Incentives for an environmentally friendly lifestyle, such as tax breaks and additional payments, can lead to sustainable carbon reduction across generations. In short, considering demographic change in carbon emission reduction targets can transform the positive effects of aging into a long-term advantage for the broader population.

In future studies, the elderly population that continues to enter the labor market as a result of aging can be added as a separate variable. In addition, environmental degradation can be investigated at the regional level.

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