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Management of Environmental Quality: An International Journal

The impact of air and rail transportation on environmental pollution in Turkey: a Fourier cointegration analysis

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Received 20 February 2024
Revised 2 May 2024
Accepted 10 June 2024

Abstract

Purpose – This paper aims to investigate the influence of air and rail transportation on pollution in Turkey from 1970 to 2020.

Design/methodology/approach – Fourier Autoregressive Distributive Lags (ADL) and Fourier Fractional ADL cointegration tests (Banerjee *et al.*, 2017; Ilkay *et al.*, 2021) are employed to analyze the relationship be-tween the variables. Cointegration tests that take into account soft transitions under structural changes are implemented. Structural change issues are crucial for this topic since the changes in countries' environmental policies and transportation habits are shaped by the decisions taken in relation to environmental regulations. Finally, for robustness purposes, we tested the estimated equation with a completely different methodology. Thus, a Machine Learning (ML) analysis is conducted, through a Ridge Regression (RR).

Findings – The findings obtained by applying Fourier Autoregressive Distributive Lags (FADL) and Fourier Fractional ADL cointegration tests, which can control for structural changes, reveal the existence of a long-term relationship between the variables. In addition, FMOLS estimates emphasize that economic growth and air transport can lead to increased pollution in the long run, while rail transport reduces it. Moreover, the statistically significant trigonometric terms indicate the existence of a smooth structural change among the variables. Robustness checks are performed through a Machine Learning (ML) analysis, which roughly confirms the previous results.

JEL Classification — Q43, R4, R41

Declarations: All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

Competing interests: The authors declare that they have no competing interests.

Availability of data and materials: Data are available upon reasonable request.

Ethical Approval: Not Applicable.

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Management of Environmental Quality: An International Journal
Emerald Publishing Limited
1477-7835
DOI 10.1108/MEQ-02-2024-0079

Originality/value – To our knowledge, existing research in Turkey focuses mainly on road transport, while the impact of rail and air transport on pollution has not yet been investigated. As such, this study will be a significant addition to the academic literature.

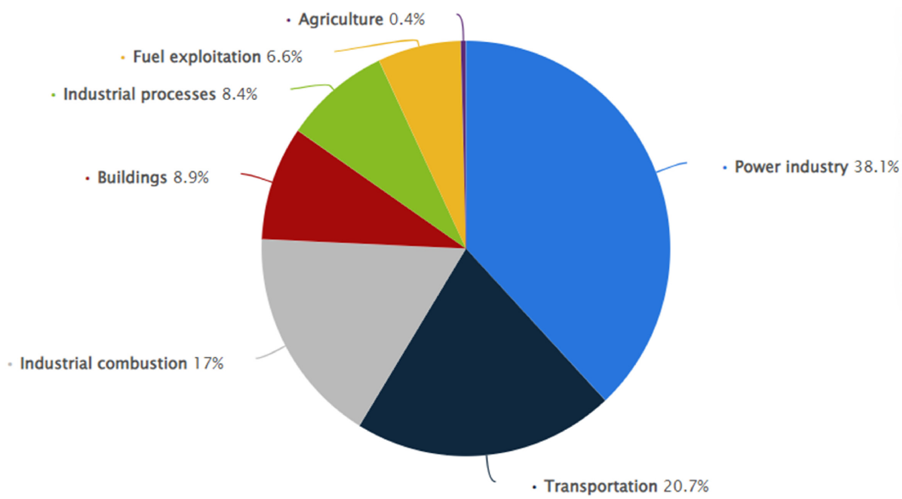
Keywords Air transport, Rail transport, Environmental pollution, Fourier cointegration, Fourier fractional ADL, Ridge regression, Turkey

Paper type Research paper

1. Introduction

In line with the objectives of the 2030 Agenda set out by the United Nations (UN), one of the key Sustainable Development Goals (SDGs) is to cut down on Greenhouse Gas (GHG) emissions, a crucial step in addressing the challenge of climate change, as noted by the International Energy Agency (IEA) in 2018. The aim of SDG-7 is "Clean and Affordable Energy". As part of this goal, it is crucial to increase access to clean energy through international cooperation. This may include promoting the use of renewable energy sources, improving energy efficiency, and developing cleaner fossil fuel technologies (UN, 2021). However, efforts to achieve sustainable low-carbon transportation need to be increased to achieve these goals. 24% of direct carbon dioxide (CO_2) emissions from fuel combustion are attributable to the transportation industry. While road travel is responsible for 75% of the emissions from transport. Most of this rate consists of passenger vehicles. The aviation sector accounts for approximately 11.6% of global transport emissions, while rail and freight transport contribute only 1% of these emissions (Ritchie, 2020). Globally, in 2018, CO_2 emissions from the transportation sector totaled 8 billion tons. Globally, CO_2 emissions from the transport sector amounted to 8 billion tons in 2018. Transport is the source of 24% of CO_2 emissions related to energy use (Our World in Data, 2022). By 2022, the share of the transportation sector in the distribution of global CO_2 emissions by sectors is around 21%, as shown in Figure 1 (STATISTA, 2024).

The transport sector is the second highest polluting sector. However, the transportation industry's critical role in supporting the economic, social, and cultural spheres of a country is also dependent on the efficient use of resources, rapid and effective distribution of goods and



Source(s): STATISTA (2024)

Figure 1. Distribution of carbon dioxide emissions worldwide in 2022, by sector

services, and trade dynamics. The growth of this sector and the development of its networks are key to achieving this progress. The growth of this sector and the development of its networks play a key role in achieving this progress. As the world's population and income levels rise, global demand for transport is expected to increase as more people acquire vehicles. Based on the International Energy Agency (IEA) forecasts, global transportation volume (on a passenger-kilometer basis) will double by 2070. This includes a 60% increase in car ownership and a threefold increase in demand for passenger and freight air travel. However, rapidly expanding transportation systems and diversifying vehicles due to technological developments also cause environmental problems. Energy resources used in transportation systems play a leading role in the increase of environmental problems due to the increase in the number of vehicles (Kelen, 2014). Not only does road transportation contribute significantly to air pollution, but it also releases millions of tons of greenhouse gases, such as CO_2, into the atmosphere annually on a global scale (Ajufo and Bekaroo, 2021).

Despite the significant effect of the Coronavirus 2019 (COVID-19) pandemic on the transport sector, the likelihood of a continued increase in emissions remains. This is due to the growing demand for transport and the limited availability of alternative fuels. With emissions on the rise, the need to move societies towards greener transport is a pressing issue in today's world. Green transport can be defined as "a kind of transportation that, in comparison with existing modes, has a lower detrimental influence on the environment and human health" (Björklund, 2011). Considering the negative effects of fossil fuel use in the transportation sector on the way to achieving SDG-7, the importance of using green energy in the transportation sector is increasing. In addition, it is necessary to adopt technologies and practices that may reduce emissions from the transportation sector and bring them closer to zero. This includes the transition of transportation vehicles, fuels, and infrastructure to renewable energy sources and low-carbon technologies. Achieving zero emissions will be a major milestone in the fight against climate change and for a sustainable future (UN, 2024).

The green transportation system is among the basic needs of the modern world, representing a driving force that improves environmental quality (Sohail *et al.*, 2021). Green transportation – which aims to transform the environment into a more liveable environment by minimizing the possible damage to nature – is also defined as a part of the infrastructure. Green transport does not only address the climate and environmental dimensions but also includes sustainable transport. Sustainability of transportation, on the other hand, is a system that aims to reduce the use of automobiles and, therefore, minimize emissions (Sutcliffe, 2012). Road transport is shown as the mode of transport that makes the largest contribution to emissions among different kinds of transport (Air Transport Action Group, 2019). CO_2 emissions from road transport are directly related to the kind and amount of fuel utilized. Since most trucks use diesel fuel, there's a direct correlation between emissions and the amount of diesel used (Léonardi *et al.*, 2006). Numerous countries are working to develop low-carbon transportation systems, mainly those based on alternative fuels, in an effort to lower the considerable CO_2 emissions associated with road transportation (Chang and Huang, 2022). In addition, many studies emphasize that the widespread use of electric vehicles will contribute to cutting down on energy use and carbon dioxide emissions in the transportation industry (Teixeira and Sodre, 2018).

Green transformation constitutes an important area for the Turkish economy. Emissions from transportation are one of the main emission sources in Turkey. In Turkey, a significant proportion of total energy demand is accounted for by the transport sector, which consumes about 26% of the country's total primary energy (Bıyık and Civelekoğlu, 2018). According to IEA data (2019), Turkey is among the top 20 countries that emit the most carbon. In Turkey, 93% of CO_2 emissions from transportation originate from the road, 4.3% from the airway, 1.5% from the sea, 0.4% from the railway, and 0.7% from the remaining sectors (TURKSTAT, 2021). Total GHG emissions increased by 3.1% compared to the previous year and reached 523.9 million tons (Mt) of CO_2 equivalent (TURKSTAT, 2020). Considering this situation, it is possible to cut down on emissions from transportation by promoting green transportation. Given that Turkey, which makes 40% of its total exports to EU countries, will be directly affected by the carbon regulation mechanism on the verge, it should reduce its carbon emissions to avoid losses in its exports with the EU (Yeldan *et al.*, 2020).

An analysis of the literature reveals that the transportation sector has significant positive effects on economic development. However, since environmental pollution originating from the transportation sector varies according to the transportation measurements and methods of each country, there is no consensus in the literature about the environmental effects of the transportation industry. To our knowledge, existing research in Turkey focuses mainly on road transport, while the impact of rail and air transport on pollution has not yet been investigated. As such, this study will be a significant addition to the academic literature. In addition, cointegration tests were used to investigate the relationship between the variables that take soft transitions into account under structural change. The main reason for addressing structural change is the changes in the environmental policies of countries and the habits of using vehicles in line with the decisions taken regarding environmental regulations. In addition, the examination of the structural change with Fourier functions shows that the case where the fracture softly occurs is taken into account. Particularly considering that the break in macroeconomic variables is soft (Enders and Lee, 2012), the results of this study employing econometric methods will contribute to researchers who will investigate the negative or positive effects of various transportation vehicles on the environment, particularly their contribution to environmental pollution.

The impact of air and rail transportation on environmental pollution in Turkey is significant, albeit with differing magnitudes. Air travel, characterized by jet emissions and airport operations, contributes substantially to air pollution, particularly in urban centers and around major airports like Istanbul and Sabiha Gökçen. The combustion of aviation fuel releases carbon dioxide, nitrogen oxides, and particulate matter, contributing to greenhouse gas emissions and local air quality degradation. Rail transportation, on the other hand, generally has a lower environmental footprint compared to air travel. Trains powered by electricity produce fewer emissions per passenger-kilometer traveled, offering a more sustainable alternative. However, challenges persist, such as outdated infrastructure and insufficient investment in electrification, which limit the expansion and efficiency of rail networks across the country. To mitigate the environmental impact of transportation, Turkey must prioritize investments in rail infrastructure, promote modal shifts from air to rail where feasible, and implement stringent emissions regulations for the aviation sector.

The study covers the period from 1970 to 2020, focusing on carbon dioxide emissions, air and rail transport, and GDP as key variables. The lack of data for the period after 2020 is a limitation of this study. Fourier Autoregressive Distributive Lags (FADL) and Fourier Fractional ADL cointegration tests (Banerjee *et al.*, 2017; Ilkay *et al.*, 2021) are employed to analyze the relationship between the variables. Cointegration tests that consider soft transitions under structural changes are implemented. Structural change issues are crucial for this topic since the changes in countries' environmental policies and transportation habits are shaped by the decisions taken in relation to environmental regulations. In fact, from a statistical point of view, when structural changes are not properly considered, the null hypothesis tends to be rejected even if there is no causal relationship between the variables (Ventosa-Santaulària and Vera-Valdés, 2008; Ender and Lee, 2012; Nazlioglu *et al.*, 2016). Therefore, this paper tests the relationship between the variables through the Fourier ADL and Fourier Fractional ADL cointegration tests. Especially considering that the break in macroeconomic variables is soft (Enders and Lee, 2012), the results here shed new light on the analyzed nexus. Moreover, this research aims to help policymakers develop better strategies for environmental protection by providing insights into the transport sector and its impacts on the environment. Finally, for robustness purposes, we tested the estimated equation with a completely different methodology. Thus, a Machine Learning (ML) analysis is conducted, through a Ridge Regression (RR). In general, these results confirm the estimates from the time-series econometric method.

The study's plan is structured as follows next the introduction. The literature review is presented in Section 2, and the methodology is explained in Section 3. The dataset employed is described in Section 4, and the analysis and discussion of the empirical results are presented in Section 5. Section 6 concludes with policy recommendations.

2. Review of the literature

Because of the increase in economic growth and the process of urbanization, the number of private vehicles in a country can increase, with an important effect on CO_2 emissions. The transport sector plays a significant part in emissions. The effects of vehicles on air pollution have been the subject of numerous past research (Jang and Lee, 2005; Jayaratne *et al.*, 2009; Jahirul *et al.*, 2010; Qian and Li, 2014; Guo *et al.*, 2014; Huang *et al.*, 2016; Wang *et al.*, 2016; Helgesen *et al.*, 2018; Liu and Lin, 2018; Chai *et al.*, 2020). As a result of the increasing severity of air pollution caused by global transportation activities, many researchers inspected the relationship between the transportation sector and CO_2 emissions. In this vein, several studies showed that environmental quality is negatively impacted by economic growth (Steenhof *et al.*, 2006; Timilsina and Shrestha, 2009; Chandran and Tang, 2013; Zhang and Nian, 2013; Saboori *et al.*, 2014; Shahbaz *et al.*, 2015; Saidi and Hammami, 2016; Çetin *et al.*, 2018, 2022; Işık *et al.*, 2020; Hossain *et al.*, 2021; Ahmed *et al.*, 2020; Mangones *et al.*, 2020; Sohail *et al.*, 2021). Thus, it can be thought that the environmental quality can deteriorate, and pollution can increase with the development of both airway and road transportation in the transportation sector. However, this may differ from country to country and from region to region. We can understand this from the results of the studies discussed. In some of the countries discussed, while the airway increases pollution, in some it is revealed that the railway increases it, and in some, a significant effect cannot be determined.

Steenhof *et al.* (2006) found that the increase in GHG emissions from transport activity from 1990 to 2003 was due to increased transport activity. Timilsina and Shrestha (2009) examined the possible contributions that increase CO_2 emissions in the transportation sector in Asian countries. They concluded that GDP per capita, population growth, and differences in transport energy intensity were the key factors that direct transport industry CO_2 emissions growth in the countries involved. Chandran and Tang (2013) analyzed energy use in the transport sector and examined the effect of foreign direct investment on CO_2 emissions, dealing with cointegration and Granger causality techniques. The findings showed that CO_2 emissions and their drivers were cointegrated in Indonesia, Malaysia, and Thailand. The study findings show that the long-term resilience estimate shows that income and energy consumption in transportation significantly affect CO_2 emissions, whereas foreign direct investment does not. Zhang and Nian (2013) used regional panel data and the STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) model for the period of 1995–2010 on CO_2 emissions in the transportation sector in various regions of China. The results revealed that CO_2 emissions increase in the transportation sector, but this result varies according to the region. Hao *et al.* (2015), in their study, analyzing how China's freight transport industry affects emissions, found that the transport sector accounts for approximately 80% of national emissions. It was also concluded that emissions associated with these sectors have the potential to increase 2.4 times by 2050. Çetin *et al.* (2018) explored how CO_2 emissions and urbanization are related specifically in the context of Turkey. Analyzing data from Turkey from 1960 to 2014, they found that while economic growth and energy consumption were the main drivers of CO_2 emissions in the short term, urbanization played a more significant role in the long term. Çetin *et al.* (2022) conducted a study on the mechanisms underlying the degradation of the environment in 18 upper-middle-income countries with the world's highest growth rates, covering the period from 1990 to 2018. The results show that economic growth, urbanization, and trade openness exert an adverse impact on environmental quality.

Neves *et al.* (2017) focused on the relationship between CO_2 emissions, economic growth, and transportation energy use in 15 OECD countries. According to the results of the Autoregressive Distributive Lag (ADL) model, transportation increases CO_2 emissions and economic growth. Saboori *et al.* (2014) investigated whether road transport sector economic growth in OECD countries has a positive relationship with energy consumption and CO_2 emissions over the long run. Using 1960–2008 data and the Fully Modified Ordinary Least Squares (FMOLS) cointegration approach, this study showed a positive, significant, and a long-term bidirectional relationship between CO_2 emissions and highways. Saidi and Hammami (2016) examined the impact of different categories of investment in public infrastructures on economic growth and private investment in Tunisia during the 1975–2014 period. The results showed that in both cases investment in public infrastructures positively and strongly impacts growth and private investment. Hossain *et al.* (2021) examined how CO_2 emissions from energy consumption and the transportation sector are related in Bangladesh between 1990 and 2017. The result revealed a growth of 106.94% in total CO_2 emissions in Bangladesh's transportation sector. Liu *et al.* (2013) found that China's road-sourced CO_2 emissions increased about 20 times in 2008 compared to their 1978 level. A study by Shahbaz *et al.* (2015) investigated the causal relationship between fuel prices, value added in the transport sector, energy use in road transport, and CO_2 emissions in Tunisia over the period 1980–2012. They concluded that energy consumption, fuel prices, and road infrastructure widen CO_2 emissions. Ahmed *et al.* (2020) estimated traffic characteristics and air pollutant emissions for cars and trucks in Kyoto, Japan. The study used a vehicle emissions model called COPERT to calculate emissions from road transport. The results showed that pollutant emissions reached higher levels during the lower cruising speed phase. Achour and Belloumi (2016) conclude that transport density has a positive effect on CO_2 emissions in Tunisia.

Sohail *et al.* (2021), using 1991–2019 data, examined the unsymmetrical impact of air-rail transportation on pollution in Pakistan's environment. The findings reveal that positive shock in air passengers and transported rail passengers' increases carbon emissions. It is also shown that an increase in the number of passengers transported causes an increase in air pollution in Pakistan in the long-run and the same results are valid for rail pollution. It was also found that a positive shock to rail transport increases pollution, while a negative shock reduces pollution in the short run.

Abdullah *et al.* (2013) investigated the casualty between transport-added value, energy consumption related to road transport, road infrastructure, fuel price, and CO_2 emissions resulting from the transport sector in Tunisia for the 1980–2010 years by using the Johansen cointegration technique. The findings of the study showed a long-term mutual causal relationship between the variables.

Danish *et al.* (2018) investigated the correlation between energy use for transport, economic growth, and CO_2 emissions from the transport sector. They applied ADL and Vector Error Correction Model (VECM) in Pakistan for the period between 1990 and 2015. The empirical findings show that energy use for transportation has a strong and important impact on CO_2 emissions. Moreover, Foreign Direct Investments (FDIs) exert a significant impact on emissions, as well.

In the context of Turkey, there are only a few studies that examine the connection between transportation and the environment. These studies also generally focus on measuring emissions from transportation and green supply chain strategies. Magazzino (2016a) examined the relationship between economic growth, CO_2 emissions, and energy consumption in the South Caucasus region and Turkey during 1992–2013, using a VAR model. The results showed that there was an adverse and statistically significant response of CO_2 emissions to energy consumption. This trend was evident in both the estimated coefficients and the impulse responses. Soylu (2007) calculated the GHG emissions from road transportation in Turkey in 2004 using the COPERT III program. Yasar (2022) examined the connection between CO_2 emissions, economic growth, air cargo transportation, Information and Communication Technologies (ICTs), and population in Turkey between 1995 and 2018 by using the ADL model. The results showed that, over time, air transport has a positive and significant impact on emissions. Magazzino (2016b) provided empirical evidence in favor of the "neutrality hypothesis" for Turkey. Isik *et al.* (2020) evaluated the factors impacting CO_2 emissions in the transportation sector between 2000 and 2017 by using the Logarithmic Average Divisia Index (LMDI) method. The findings show that the CO_2 emissions from the transportation sector widened due to economic growth. Dundar (2021) calculated GHG emissions from highway transportation in Turkish metropolitan cities for the years 2010 and 2019 using the Tier 1 method developed by The Intergovernmental Panel on Climate Change (IPCC). The results showed that the total amount of emissions in 30 metropolitan cities increased by 61.90% over the analyzed time period. Eweade *et al.* (2023) examined the relationship between energy consumption and environmental footprint in transportation for the period between 1990 and 2020 in the United Kingdom. The results show that the use of electricity in transportation reduces the environmental impact. Similarly, Shabir *et al.* (2022) emphasized that energy consumption in transportation improves the environment. Wenlong *et al.* (2023) found that the environmental impact of transportation in the US is negative. Dai *et al.* (2023) revealed that green energy consumption in transportation in the US for the period 1970–2019 improves environmental quality, while the use of fossil fuels in this sector contributes to environmental degradation by increasing CO_2. Wang *et al.* (2023) examined the impact of infrastructure investment in transportation systems on environmental degradation in China, Turkey, India, and Japan for the period 1995–2020. Using the Dynamic Ordinary Least Squares (DOLS) method, the study found that road infrastructure investment has a significant positive impact on environmental degradation, while rail infrastructure investment has a significant negative impact on environmental degradation in these countries. Similarly, air infrastructure investment has a significant impact on pollution. Jahangar *et al.* (2024) examined the impact of air transport on the ecological footprint in the G7 countries for the period 1994–2020. The results of the Method of Moments Quantile Regression (MMQR) approach show that air transport accelerates emissions.

This study makes a crucial contribution to the literature by highlighting that transport activity is an important source of carbon dioxide emissions, which is essential for economic development. In contrast to other studies in the literature, this study analyses separately airline and railway transport. Moreover, while the majority of the studies conducted in Turkey focused on road transport, the impact of train and air passengers on CO_2 emissions received little attention. Consequently, by including it in the suggested model, this study aims to fill this gap.

3. Methodology

3.1 Standard unit root tests

Traditional unit root tests such as Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) do not take structural changes into account. Structural changes and their effects were analyzed by Perron (1989), who showed that in the presence of structural change, the results obtained by using a traditional unit root test would change. However, in this study, the structural change was determined externally. Over the years, various unit root tests with linear and nonlinear structural breaks were developed to allow the structural change to be determined internally (Zivot and Andrews, 2002; Lee and Strazicich, 2003; Kapetanios *et al.*, 2003). These tests assume that breaks occur rapidly or that these circumstances lead to unexpected movements in the variables' mean and/or slope. Although shocks can have an impact, this is slower (smoother), in particularly for macroeconomic variables (Enders and Lee, 2004, 2012). This smooth impact is investigated with Fourier approximations involving trigonometric terms. Fourier's approach addresses multiple unknown structural problems. In addition to working well in gradual breaks, it can also detect sudden breaks in data. Traditional tests with dummy variables ask for the estimation of sudden break dates. However, Fourier's approach works well in the presence of unknown breaks without the need to predict break dates (Banerjee *et al.*, 2017). In addition, Omay (2015) found that nonlinearity in both deterministic and stochastic components is covered by a Fourier-type test at the same time.

In this regard, Enders and Lee (2012) applied the following Fourier's expansion to the ADF unit root test.

$$a(t) = a_0 + \sum_{k=1}^{n} a_k sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} \beta_k cos\left(\frac{2\pi kt}{T}\right), n \leq \frac{T}{2} \quad (1)$$

In this equation, T stands for sample volume; t refers to the trend, and k takes a value between 1 and 5, which minimizes the sum of residual squares. If $a_1 = \beta_1 = \ldots = a_n = \beta_n = 0$, then the process is linear, and traditional unit root tests should be used. However, if this is not the case, there is a break or a nonlinear slope and at least one Fourier's frequency should be present in the data generation process. The existence of a unit root can be tested with the following equation in the Fourier ADF unit root statistics built up by Enders and Lee (2012).

$$\Delta y_t = \rho y_{t-1} + c_1 + c_2 t + c_3 sin\left(\frac{2\pi kt}{T}\right) + c_3 cos\left(\frac{2\pi kt}{T}\right) + e_t \quad (2)$$

While the null hypothesis of the test states the existence of a unit root, the alternative hypothesis suggests that a unit root does not exist.

3.2 Fractional Fourier ADF unit root test

Inferences can be made about the effect of structural changes based on the shape of k. Since the first and end values of the Fourier terms are the same when k is not a fraction, using the integer values of k makes the breaks temporary (Christopoulos and Leon-Ledesma, 2010). On the opposite, when k takes a fractional value, it is concluded that the structural change is permanent. Omay (2015) developed the fractional FADF unit root test, which allows the frequency number to be estimated between 0.1 and 2. Bozoklu *et al.* (2020), on the other hand, expanded the frequency range to 0–5. Therefore, it is possible to comment on whether or not the structural change is temporary. In this instance, the existence of a unit root can be determined by the following equation.

$$\Delta y_t = \rho y_{t-1} + c_1 + c_2 t + c_3 sin\left(\frac{2\pi k^{fr} t}{T}\right) + c_3 cos\left(\frac{2\pi k^{fr} t}{T}\right) + e_t \quad (3)$$

The critical values of test statistics take place in Bozoklu *et al.* (2020). The asymptotic properties of this test have the same properties as those of Enders and Lee (2012). Similar to the FADF unit root test, the critical values for assessing the null hypothesis of the presence of a unit root rely on the frequency value and the sample size. It is worth noting that the asymptotic distribution is independent of the coefficients of the Fourier's function and any deterministic terms.

3.3 Fourier ADL cointegration test

Cointegration tests are tested to identify the long-run relationship between variables. However, standard cointegration tests do not take structural breaks into account (Engle and Granger, 1991; Johansen, 1992). Similar to unit root tests, neglecting structural breaks in a model can cause misspecification, with potentially misleading results. In fact, ignoring structural changes will lead to wrong decision-making in the null hypothesis (Nazlioglu *et al.*, 2016). In the more recent cointegration tests, the quantity and type of structural changes are predetermined (Gregory and Hansen, 1996; Hatemi-J, 2008). These tests produce results under the assumption that structural changes happen suddenly. However, structural breaks come in numerous and different forms in the macroeconomic framework. As Enders and Lee (2012) noted, the structural change in macroeconomic variables takes place slowly (smoothly). Therefore, in this study, the new ADL cointegration test is used under nonlinear breaks determined by Banerjee *et al.* (2017) Fourier's functions. The Fourier ADL test uses full information Maximum Likelihood (ML) estimation and checks for the unknown multiple breaks in the cointegration test in a single-equation ADL model. The flexibility of the Fourier ADF cointegration test provides ease of estimation. Thus, it allows the detection of various structural breaks. Simulation experiments show that it has good size and high power.

Considering Enders and Lee (2012), deterministic terms using Fourier's approach are defined as follows:

$$d(t) = \gamma_0 + \sum_{k=1}^{q} \gamma_{1,k} sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{q} \gamma_{2,k} cos\left(\frac{2\pi kt}{T}\right), q \leq T \Big/ 2 \tag{4}$$

where γ_0 refers to deterministic terms such as constant and trend; k refers to the number of frequencies; and T refers to the number of observations. The ADL equation proposed by Banerjee *et al.* (2017) can be re-estimated by adding Fourier terms as follows:

$$\Delta y_{1t} = d(t) + \delta_1 y_{1,t-1} + \gamma' y_{2,t-1} + \varphi' \Delta y_{2t} + \epsilon_t \tag{5}$$

γ, φ and y_{2t} in the equation include n*1 sized parameters and explanatory variables. While the null hypothesis of the test suggests that the cointegration relationship does not exist, the alternative hypothesis considers the existence of a long-run relationship.

3.4 Fractional Fourier ADL cointegration test

The structure of the frequency number supplies information on the permanence of the structural change. In Fourier's cointegration test, k is determined as an integer value between 1 and 5. Ilkay *et al.* (2021) showed that these values indicate temporary structural change and performed the Fractional Fourier ADL cointegration test with the permanent break suggested by Christopoulos and Leó n-Ledesma (2010). In this way, the frequency number could take fractional values between 0.1 and 5. The null hypothesis is the same as the Fourier ADL cointegration test. The test statistic is calculated as follows:

$$t_{ADL} = \frac{\widehat{\delta}_1}{se(\widehat{\delta}_1)} \tag{6}$$

This test's main benefit over traditional cointegration tests, which incorporate structural breaks through dummy variables, is its ability to understand both gradual and abrupt breaks without requiring the form, location, or quantity of these breaks to be predetermined. By performing 100,000 Monte Carlo (MC) simulations, the critical values needed for the Fourier ADL cointegration test were found utilizing fractional frequencies.

3.5 FMOLS estimator

The Fully Modified Ordinary Least Squares (FMOLS) estimator is used to estimate the long-term coefficients of the model with a long-term relationship. The FMOLS coefficient estimator corrects the autocorrelation problems. In addition, it eliminates the effect of deviation in long-term relationship equations by using kernel estimators (Phillips and Hansen, 1990).

3.6 Ridge Regression

The Ridge estimator is the Ordinary Least Squares (OLS) estimator with an L2 penalty term attached:

$$J = \frac{1}{2m} \sum_{i=1}^{m} \left(y_i - \beta_0 - \sum_{j=1}^{p} x_{ij}\beta_j \right)^2 + \lambda \sum_{j=1}^{p} \beta_j^2 \qquad (7)$$

where the coefficients' sizes are shrunk by the penalty, but they are not made zero. More shrinkage occurs when the cost function is optimized with a bigger lambda.

The analytic solution of the previous equation is:

$$\beta = (X'X + \lambda I)^{-1} (X'Y). \qquad (8)$$

4. Data

This study seeks the effect of transportation types on environmental pollution in Turkey over the sample period 1970–2020. The railway transport data series starts in 1970, while the carbon dioxide emissions series was released in 2020, constraining our dataset. Railways and airways are considered transportation activities. The literature points out that road transportation causes environmental pollution. However, other transportation channels are defined as green transportation that causes less damage to the environment, and there is a lack of consensus on the effects on environmental pollution. On the other hand, considering Shouket *et al.* (2019), the economic growth level of the country is added as a control variable in this study. Table 1 shows the main information on the variables used in the empirical analysis along with their sources.

5. Results and discussion

The descriptive statistics for the selected variables are displayed in Table 2. *LCO_2* and *LRAIL* series are left-skewed, while *LGDP* and *LAIR* variables are skewed to the right. At the same time, Kurtosis statistics show that all variables have platykurtic distributions. Finally, the Jarque-Bera (JB) normality test results show that all series follow a normal (Gaussian) distribution.

Variable	Explanation	Source
LCO_2	CO_2 emissions (kt)	World Bank, https://databank.worldbank.org/source/world-development-indicators
LGDP	GDP (constant 2010 US$)	
LAIR	Air transport (number of carried passengers)	
LRAIL	Rail transport (number of carried passengers)	https://www.tcdd.gov.tr/kurumsal/istatistikler

Table 1.
Description of the dataset

Statistics	LCO_2	LGDP	LRAIL	LAIR
Mean	11.973	26.568	18.567	15.979
Median	12.033	26.547	18.582	15.863
Maximum	12.938	27.647	19.321	18.566
Minimum	10.661	25.480	18.107	13.851
Std. Dev	0.647	0.636	0.268	1.422
Skewness	−0.245	0.093	0.237	0.457
Kurtosis	1.941	1.889	3.064	1.944
Jarque-Bera	2.894	2.698	0.486	4.150

Source(s): Authors' elaborations in EViews

Table 2. Descriptive statistics

To investigate the long-term relationship of transport on carbon dioxide emissions, the unit root process of the variables should be determined first. The period covered in the study includes many economic and political crises. Here, the unit root process was determined using the Fourier ADF and Fractional Fourier ADF unit root tests. The frequency number and lag length of the Fourier ADF unit root test are 5 and 3, respectively (see Table 3). The findings show the minimum frequency value and the optimal delay length of the residual sum of squares. *F* statistics confirm that trigonometric terms are significant in the unit root process; hence the Fourier ADF unit root test can be applied. Based on the findings, the variables are first-difference stationary, or I(1). Moreover, in Figure 2 we show the graphical Fourier's analysis.

For robustness purposes, the Fractional Fourier ADF test is also performed. The results obtained are given in Table 4. As in the Fourier ADF test, the variables are I(1). At the same time, *F* statistics show that trigonometric terms except for *LGDP* are significant in the unit root process and the Fractional Fourier ADF test can be applied. Since the trigonometric terms of the Fractional FADF unit root test of *LGDP* are insignificant, the variable was tested with the traditional ADF unit root test. The findings show that the variable is an I(1) process.

In what follows, cointegration tests were used to examine the long-term relationship between transportation vehicles and pollution. When the Fourier's functions of the variables are examined, it is determined that they contain structural breaks in different forms. The results of the cointegration test are shown in Table 5.

The results of the cointegration tests show that the variables have a cointegration relationship. In this case, we can state that carbon dioxide emissions are affected by rail transport, air transport, and economic growth over a long-time horizon.

Since a cointegration relationship has been established, the FMOLS estimator is applied to estimate the coefficients. The results obtained from the FMOLS coefficient estimator are shown in Table 6.

Variable	k	p	F	Test statistics
LCO_2	1	1	34.011	−0.786
LGDP	1	1	33.287	−0.731
LAIR	1	1	43.886	−2.042
LRAIL	2	0	22.125	−2.069

Note(s): The test statistic has been compared with the Critical Values tabulated in Christopoulos and Leon-Ledesma (2010). The significance of the trigonometric terms was tested by considering the Critical Values in Enders and Lee (2012)
Source(s): Authors' elaborations in Rats

Table 3. FADF unit root test results

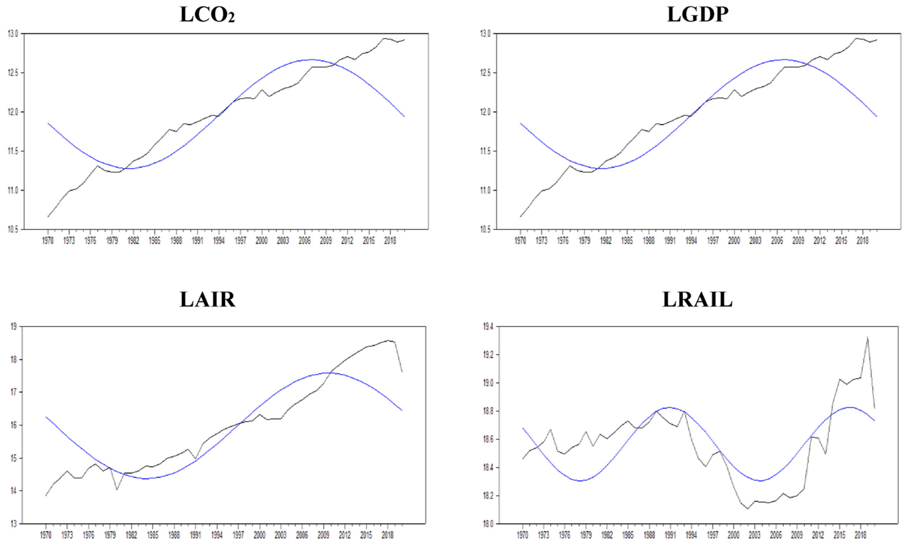


Figure 2.
Fourier's analysis

Source(s): Authors' elaborations in Rats

Table 4.
Fractional FADF unit root test results

Variable	k	F	Test statistics
LCO_2	0.10	7.725	−3.079
LGDP	0.10	6.465	−3.496
LAIR	1.50	6.607	−2.564
LRAIL	0.460	7.639	−2.981

Note(s): The test statistic has been compared with the Critical Values tabulated in Bozoklu *et al.* (2020). The significance of the trigonometric terms was tested by considering the Critical Values in Enders and Lee (2012)
Source(s): Authors' elaborations in Rats

Table 5.
Cointegration test results

Test	Statistics	k	Min. AIC
Fourier ADL Cointegration	−4.827**	5.0	−3.285
Fractional Fourier ADL Cointegration	−4.047**	4.9	−3.332

Note(s): **p < 0.05. The test statistics for Fourier ADL cointegration and Fractional Fourier ADL cointegration tests were compared with Critical Values tabulated in Banerjee *et al.* (2017) and Ilkay *et al.* (2021), respectively
Source(s): Authors' elaborations in Rats

According to the estimates in Table 6, we see that air passenger transportation has a positive and significant impact on CO_2 emissions with an increasing trend. At the same time, economic growth is also a crucial part of increasing CO_2 emissions. While economic growth and air transportation have a positive effect on CO_2 emissions and increase pollution, railway transportation appears to reduce air pollution. Our results are in line with the studies of Shouket *et al.* (2019), Sohail *et al.* (2021), Habib *et al.* (2022), and Hassan and Nosheen (2017).

However, it differs in that the railway reduces CO_2. A higher level of national income generally means an increased demand for energy. If this energy is not from renewable sources, it is usually produced by burning fossil fuels such as coal, oil, and natural gas, which increases CO_2 emissions. Air transportation is one of the fastest transportation methods, especially for long-distance travel. However, it is important to note that airplanes consume significant amounts of fossil fuel, which in turn results in significant CO_2 emissions and other GHG into the atmosphere. Aircraft engines produce CO_2 emissions from carbon-based fuels during the combustion process. These emissions are a factor leading to global warming. The growth of the transportation sector and the rise in air travel have been instrumental in the increase of CO_2 emissions.

Furthermore, trigonometric terms appear to be statistically significant. Trigonometric terms are based on the assumption that structural change occurs smoothly. The fact that these terms are significant in the long-run indicates the existence of a smooth structural change between the variables. This situation reveals the necessity of including trigonometric terms in the analysis without ignoring the structural change.

For robustness checks, we performed an ML test through an RR. The findings for the analytic solution are shown in Table 7.

Out of the list of lambda values used in the cross-validation procedure, the value of 0.0300 is chosen as having the lowest Mean Absolute Error (MAE). As for FMOLS estimates, all the estimated coefficients for the three independent variables have a negative sign, indicating that each regressor contributes to environmental protection reducing carbon emissions. It is worth noticing the high R-squared values for each estimate. For more diagnostic tools, see Figure A in the Appendix, which reports the actual versus fitted residual graph.

Variable	Coefficients
LGDP	0.922^{***} (0.000)
LRAIL	-0.1802^{***} (0.001)
LAIR	0.0801^{**} (0.035)
Constant	-10.467^{***} (0.000)
Sine	0.094^{***} (0.008)
Cosine	-0.025^{***} (0.000)

Note(s): Robust Standard Errors in parentheses. $^{**}p < 0.05$, $^{*}p < 0.10$
Source(s): Authors' elaborations in EViews

Table 6. FMOLS estimates

	Minimum	(+1 SE)	(+2 SE)
Lambda	0.0300	0.1212	0.1930
Variable		Coefficients	
LGDP	−0.1573	−0.1294	−0.1102
LRAIL	−0.0779	−0.0849	−0.0897
LAIR	−1.3730	−1.3088	−1.2646
Constant	−20.5385	−19.1500	−18.1924
L1 Norm	22.1467	20.6732	19.6568
R-squared	0.9915	0.9912	0.9908

Note(s): Regressor transformation: Standardization by sample. Cross-validation method: K-Fold. Selection measure: Mean Absolute Error (MAE). Random generator: Knuth. Weights type: Inverse Standard Deviation
Source(s): Authors' elaborations in EViews

Table 7. Ridge Regression estimates

Observing the progression of the coefficients as a function of the regularization parameter lambda, it can be seen that as the value of lambda increases, the absolute magnitude of each coefficient decreases, in line with the expected behavior of a penalized regression. Consequently, as lambda increases, the complexity of the model decreases.

To better evaluate these results, after having selected the K-Fold as a cross-validation method, Figure 3 shows the Training/Test Error graph, which displays the evolution of the errors produced by cross-validation against the lambda values.

From Figure 3 it can be seen the lambda path on the horizontal axis and the error measure means of the training and test sets on the vertical one. The training error is consistently smaller than the test error over the whole spectrum, but the two sets of data are close, as expected. The same conclusions can be derived by looking at the Training/Test Error set table.

6. Conclusions and policy recommendations

Climate change, exacerbated by global warming, has become the most important environmental challenge in recent years, and it is especially intensified because of GHG emissions arising from freight transportation. In Turkey, one of the top 20 countries with the highest carbon emissions, 93% of CO_2 emissions originate from road transportation, while 4.3% from air travel, according to the IEA (2019). The fact that 92% of the vehicles used in the transportation sector are powered by oil causes noise and heavy metal pollution locally, and an increase in emissions that generates climate change globally. The increase in the number of private vehicles is another factor that aggravates environmental pollution. The preference for motor vehicles for road transport necessitates infrastructure services such as highways and bridges. This leads to environmental problems. However, the use of other vehicles is also becoming widespread besides the highways. The major contribution of this study, therefore, is the examination of how air and rail transportation affect CO_2 emissions in the long-term.

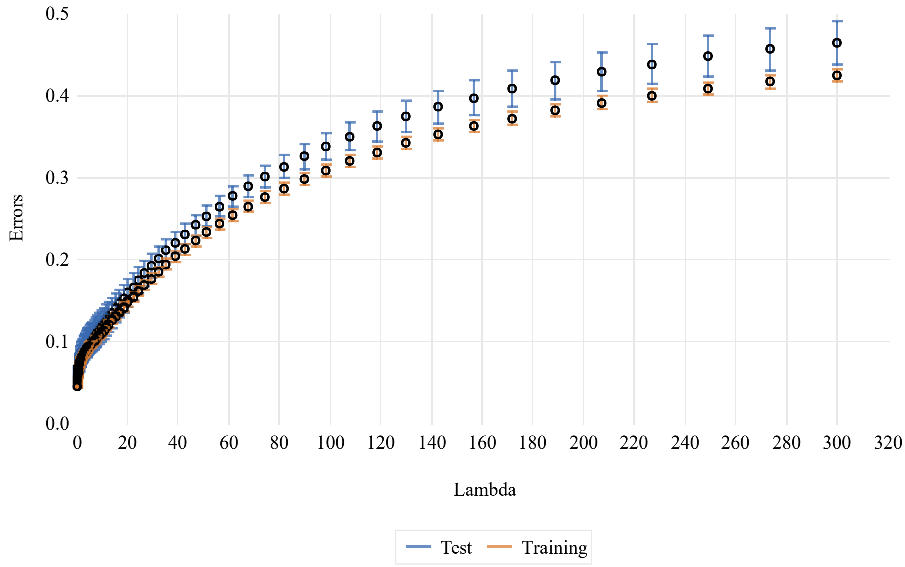


Figure 3.
Training/test evolution errors

Source(s): Authors' elaborations in EViews

The effects of airway and rail transport on CO_2 emissions in Turkey between 1970 and 2020 are examined. International environmental agreements and regulations were realized in the period under consideration. For this reason, the research of the relationships between the variables through unit root and cointegration tests that allow for structural changes becomes relevant.

The findings of this study show that air transportation, the second most preferred mode of transportation in the country, has a positive impact on CO_2 emissions but it has a negative effect on railway transportation emissions. The results of our study are consistent with the previous research conducted by Hassan and Nosheen (2017), Shouket *et al.* (2019), Sohail *et al.* (2021), and Habib *et al.* (2022), Wang *et al.* (2023). According to Wang *et al.* (2023), modern electric rail systems are expected to be less polluting. Increasing investment in railways is important for moving Turkey's transport sector in a more sustainable and environmentally friendly direction. Increased investment in railways can reduce dependence on road transport and promote the integration of different transport modes. This can increase energy efficiency and reduce carbon emissions, while reducing negative impacts on the environment. In addition, rail can help us achieve SDGs by providing a more economical and environmentally friendly option for high-volume, long-distance transport. It is, therefore, important to prioritize the use of sustainable energy technologies in the transport sector to ensure long-term environmental sustainability. The use of these forms of energy can support economic progress while reducing the environmental impact of transport activities.

Turkey's growing tourism sector attracts large numbers of domestic and foreign visitors throughout the year, leading to significant increases in air traffic, especially during the tourist season. This should be considered as an important factor in the increase of CO_2 emissions. Our study analyses the dimensions and impacts of this increase in detail and emphasizes the importance of reshaping air transport policies in Turkey and similar developing countries in line with sustainability and environmental protection objectives. Turkey's policies and practices for sustainability in the transport sector can serve as examples for other countries in similar situations to consider. Therefore, given the rapidly increasing trend of transportation emissions in developing countries, they can reduce transportation emissions by using renewable energy sources for public transportation and logistics. The use of electric buses and trains, solar-powered bus stops, and train stations are some steps in this direction. At the same time, these countries can take advantage of international cooperation and technology transfer opportunities to increase their access to clean transportation technologies. The conclusion that air transport contributes to CO_2 emissions and that rail transport reduces CO_2 emissions may influence public transport preferences. These findings may increase society's environmental awareness and lead them to choose more environmentally friendly transportation options. Especially for people living in large cities, choosing green transportation options can improve air quality and living conditions. At the same time, these findings can contribute to the development of inclusive transportation policies at both local and international levels. In fact, a holistic approach that considers a variety of factors such as environmental sustainability, economic impact, public health, and quality of life may promote more effective policymaking.

In this context, supporting and promoting more environmentally friendly transport alternatives such as rail transport can play a critical role in offsetting the environmental impacts of air transport. Moreover, the development of technological innovations to reduce carbon emissions in the aviation sector and practices that increase fuel efficiency can contribute to reducing the environmental footprint in this area.

The transport sector plays a crucial role in the fight against climate change as it is responsible for a large proportion of global carbon emissions. In light of our findings, measures and various policy recommendations that can be taken to reduce emissions in the transport sector can be highlighted as follows. Increasing the fuel efficiency of vehicles can significantly reduce carbon emissions. It may be useful to focus on the development and integration of innovations such as sustainable aviation fuels derived from renewable energy sources and electric aircraft technologies. For example, promoting the use of electric vehicles can significantly reduce carbon emissions, especially as the share of renewable sources in electricity generation increases. The development of strong, efficient, and accessible public transport systems can reduce the use of private cars and thus lower emissions. The development and integration of these innovations are important for both environmental sustainability and long-term economic efficiency. As part of this process, the development and integration of sustainable aviation fuels and electric aircraft technologies derived from renewable energy sources is critical to the transformation of the industry. Unlike conventional fossil fuels, sustainable aviation fuels are derived from renewable energy sources, which promote the sustainable use of resources. Sustainable aviation fuels, which can be produced without harming ecosystems, also minimize environmental impact by preserving biodiversity. The use of environmentally friendly methods in freight transport can also reduce CO_2 emissions. Therefore, the government should promote green freight transport and the use of sustainable aviation fuels to reduce CO_2 emissions by adopting environmentally friendly regulatory policies. With the widespread adoption of sustainable aviation fuels and electric aircraft technologies, the aviation industry will have taken an important step towards a low-carbon future. This will require coordinated efforts by policymakers, industry leaders, and consumers. Government incentives, investment in Research and Development (R&D), and public support can accelerate the adoption of these innovations. Moreover, this procedure will boost economic development in addition to reducing pollution (Magazzino *et al.*, 2023).

This study has some limitations due to data constraints. For a more comprehensive analysis in future studies, it may be suggested to examine the same topic at a sub-national level. This might allow the evaluation of the differences between different regions, also contributing to a better understanding of the interregional strategies. In addition, the use of ecological footprint instead of CO_2 emissions as a proxy for environmental pollution may improve the robustness of the findings.

Abbreviations

ADF:	Augmented Dickey-Fuller
ADL:	Autoregressive Distributive Lag
COPERT:	Computer Program
DOLS:	Dynamic Ordinary Least Squares
FADL:	Fourier Autoregressive Distributive Lags
FDIs:	Foreign Direct Investments
FMOLS:	Fully Modified Ordinary Least Squares
GDP:	Gross Domestic Product
GHG:	Greenhouse Gas
ICTs:	Information and Communication Technologies
IPCC:	The Intergovernmental Panel on Climate Change
JB:	Jarque-Bera
LMDI:	Logarithmic Average Divisia Index
MAE:	Mean Absolute Error
MC:	Monte Carlo
ML:	Machine Learning
ML:	Maximum Likelihood
MMQR:	Method of Moments Quantile Regression

OLS:	Ordinary Least Squares
PP:	Phillips-Perron
R&D:	Research and Development
RR:	Ridge Regression
SDGs:	Sustainable Development Goals
STIRPAT:	Stochastic Impacts by Regression on Population, Affluence and Technology
VAR:	Vector Auto-Regression
VECM:	Vector Error Correction Model

References

Abdallah, B.K., Belloumi, M. and De Wolf, D. (2013), "Indicators for sustainable energy development: a multivariate Cointegration and causality analysis from Tunisian road transport sector", *Renewable and Sustainable Energy Reviews*, Vol. 25, pp. 34-43.

Achour, H. and Belloumi, M. (2016), "Decomposing the influencing factors of energy consumption in Tunisian transportation sector using the LMDI method", *Transport Policy*, Vol. 52, pp. 64-71.

Ahmed, Z., Ali, S., Saud, S. and Shahzad, S.J.H. (2020), "Transport CO_2 emissions, drivers, and mitigation: an empirical investigation in India", *Air Quality, Atmosphere and Health*, Vol. 13, pp. 1367-1374.

Air Transport Action Group (2019), available at: https://web.shgm.gov.tr/documents/sivilhavacilik/files/kurumsal/faaliyet/2019.pdf

Ajufo, C.A.M. and Bekaroo, G. (2021), "An automated personal carbon footprint calculator for estimating carbon emissions from transportation use", *International Conference on Artificial Intelligence and its Applications*, pp. 1-7.

Banerjee, P., Arčabić, V. and Lee, H. (2017), "Fourier ADL cointegration test to approximate smooth breaks with new evidence from crude oil market", *Economic Modelling*, Vol. 67, pp. 114-124.

Bıyık, Y. and Civelekoğlu, G. (2018), "Investigation of carbon footprint change originated from transportation sector", *Bilge International Journal of Science and Technology Research*, Vol. 2 No. 2, pp. 157-166.

Björklund, M. (2011), "Influence from the business environment on environmental purchasing - drivers and hinders of purchasing green transportation services", *Journal of Purchasing and Supply Management*, Vol. 17 No. 1, pp. 11-22.

Bozoklu, S., Yilanci, V. and Gorus, M.S. (2020), "Persistence in per capita energy consumption: a fractional integration approach with a Fourier function", *Energy Economics*, Vol. 91, 104926.

Cetin, M., Ecevit, E. and Yücel, A.G. (2018), "Structural breaks, urbanization and CO_2 emissions: evidence from Turkey", *Journal of Applied Economics and Business Research*, Vol. 8 No. 2, pp. 122-139.

Cetin, M., Aslan, A. and Sarıgül, S.S. (2022), "Analysis of the dynamics of environmental degradation for 18 upper middle-income countries: the role of financial development", *Environmental Science and Pollution Research*, Vol. 29, pp. 64647-64664.

Chai, J., Lu, Q., Wang, S. and Keung, K. (2020), "Analysis of road transportation energy consumption demand in China", *Transportation Research Part D: Transport and Environment*, Vol. 48, pp. 112-124.

Chandran, V.G.R. and Tang, C.F. (2013), "The impacts of transport energy consumption, foreign direct investment and income on CO_2 emissions in ASEAN-5 economies", *Renewable and Sustainable Energy Reviews*, Vol. 24, pp. 445-453.

Chang, C.C. and Huang, P.C. (2022), "Carbon footprint of different fuels used in public transportation in Taiwan: a life cycle assessment", *Environment, Development and Sustainability*, Vol. 24 No. 4, pp. 5811-5825.

Christopoulos, D.K. and León-Ledesma, M.A. (2010), "Smooth breaks and non-linear mean reversion: post-Bretton Woods real exchange rates", *Journal of International Money and Finance*, Vol. 29 No. 6, pp. 1076-1093.

Dai, J., Alvarado, R., Ali, S., Ahmed, Z. and Meo, M.S. (2023), "Transport infrastructure, economic growth, and transport CO_2 emissions nexus: does green energy consumption in the transport sector matter?", *Environmental Science and Pollution Research*, Vol. 30 No. 14, pp. 40094-40106.

Danish, Balouch, M.A. and Suad, S. (2018), "Modeling the impact of transport energy consumption on CO_2 emission in Pakistan: evidence from ARDL approach", *Environmental Science and Pollution Research*, Vol. 25, pp. 9461-9473.

Dundar, A.O. (2021), "Comparative analysis of the greenhouse gas emissions from road transport in the metropolitan cities of Turkey", *Journal of Natural Hazards and Environment*, Vol. 7 No. 2, pp. 318-337.

Enders, W. and Lee, J. (2004), "Testing for a unit root with a nonlinear Fourier function", *Econometric Society 2004 Far Eastern Meetings*, Vol. 457, pp. 1-47.

Enders, W. and Lee, J. (2012), "The flexible Fourier form and Dickey–Fuller type unit root tests", *Economics Letters*, Vol. 117 No. 1, pp. 196-199.

Engle, R. and Granger, C. (1991), "Cointegration and error correction: representation, estimation, and testing", in Engle and Granger (Eds), *Long run economic readings in cointegration*, Oxford University Press, New York, pp. 81-113.

Eweade, B.S., Güngör, H. and Karlilar, S. (2023), "The determinants of ecological footprint in the UK: the role of transportation activities, renewable energy, trade openness, and globalization", *Environmental Science and Pollution Research*, Vol. 30 No. 58, pp. 122153-122164.

Gregory, A.W. and Hansen, B.E. (1996), "Practitioners corner: tests for cointegration in models with regime and trend shifts", *Oxford Bulletin of Economics and Statistics*, Vol. 58 No. 3, pp. 555-560.

Guo, B., Geng, Y., Franke, B., Hao, H., Liu, Y. and Chiu, A. (2014), "Uncovering China's transport CO_2 emission patterns at the regional level", *Energy Policy*, Vol. 74, pp. 134-146.

Habib, Y., Xia, E., Hashmi, S.H. and Yousaf, A.U. (2022), "Testing the heterogeneous effect of air transport intensity on CO_2 emissions in G20 countries: an advanced empirical analysis", *Environmental Science and Pollution Research*, Vol. 29, pp. 44020-44041.

Hao, H., Geng, Y., Li, W. and Guo, B. (2015), "Energy consumption and GHG emissions from China's freight transport sector: scenarios through 2050", *Energy Policy*, Vol. 85, pp. 94-101.

Hassan, S.A. and Nosheen, M. (2017), "The impact of air transportation on carbon dioxide, methane, and nitrous oxide emissions in Pakistan: evidence from ARDL modelling approach", *International Journal of Innovation and Economic Development*, Vol. 3 No. 6, pp. 7-32.

Hatemi-J, A. (2008), "Tests for cointegration with two unknown regime shifts with an application to financial market integration", *Empirical Economics*, Vol. 35 No. 3, pp. 497-505.

Helgesen, P.I., Lind, A., Ivanova, O. and Tomasgard, A. (2018), "Using a hybrid hard-linked model to analyze reduced climate gas emissions from transport", *Energy*, Vol. 156, pp. 196-212.

Hossain, M.A., Chen, S. and Khan, A.G. (2021), "Decomposition study of energy-related CO_2 emissions from Bangladesh's transport sector development", *Environmental Science and Pollution Research*, Vol. 28, pp. 4676-4690.

Huang, X., Wang, Y., Xing, Z. and Du, K. (2016), "Emission factors of air pollutants from CNG-gasoline bi-fuel vehicles: Part II. CO, HC and NOx", *Science of The Total Environment*, Vol. 565, pp. 698-705.

IEA (2019), available at: https://www.iea.org/reports/global-energy-review-2019

Ilkay, S.C., Yilanci, V., Ulucak, R. and Jones, K. (2021), "Technology spillovers and sustainable environment: evidence from time-series analyses with Fourier extension", *Journal of Environmental Management*, Vol. 294, 113033.

Isik, M., Sarica, K. and Ari, I. (2020), "Driving forces of Turkey's transportation sector CO_2 emissions: an LMDI approach", *Transport Policy*, Vol. 97, pp. 210-219.

Işık, M., Sarica, K. and Ari, I. (2020), "Driving forces of Turkey's transportation sector CO2 emissions: an LMDI approach", *Transport Policy*, Vol. 97, pp. 210-219.

Jahanger, A., Ozturk, I., Onwe, J.C., Ogwu, S.O., Hossain, M.R. and Abdallah, A.A. (2024), "Do pro-environmental interventions matter in restoring environmental sustainability? Unveiling the role of environmental tax, green innovation and air transport in G-7 nations", *Gondwana Research*, Vol. 127, pp. 165-181.

Jahirul, M.I., Masjuki, H.H., Saidur, R., Kalam, M.A., Jayed, M.H. and Wazed, M.A. (2010), "Comparative engine performance and emission analysis of CNG and gasoline in a retrofitted car engine", *Applied Thermal Engineering*, Vol. 30, pp. 2219-2226.

Jang, C. and Lee, J. (2005), "Experimental investigation of the effects of various factors on the emission characteristics of low-emission natural gas vehicles", *Proceedings of the Institution of Mechanical Engineers, Part D*, Vol. 219, pp. 825-831.

Jayaratne, E., Ristovski, Z., Meyer, N. and Morawska, L. (2009), "Particle and gaseous emissions from compressed natural gas and ultralow sulphur diesel-fuelled buses at four steady engine loads", *Science of The Total Environment*, Vol. 407, pp. 2845-2852.

Johansen, S. (1992), "Cointegration in partial systems and the efficiency of single-equation analysis", *Journal of Econometrics*, Vol. 52 No. 3, pp. 389-402.

Kapetanios, G., Shin, Y. and Snell, A. (2003), "Testing for a unit root in the nonlinear STAR framework", *Journal of Econometrics*, Vol. 112 No. 2, pp. 359-379.

Kelen, F. (2014), "Effects of motor vehicle emissions on human health and environment", *Journal of The Institute of Natural and Applied Sciences*, Vol. 19 Nos 1-2, pp. 80-87.

Lee, J. and Strazicich, M.C. (2003), "Minimum Lagrange multiplier unit root test with two structural breaks", *Review of Economics and Statistics*, Vol. 85 No. 4, pp. 1082-1089.

Leonardi, J., Kveiborg, O., Baumgartner, M. and Krusch, O. (2006), "Decoupling GDP and performance growth from energy use in German road freight traffic", Copenhagen DTF Working Paper, 0705.

Liu, W. and Lin, B. (2018), "Analysis of energy efficiency and its influencing factors in China's transport sector", *Journal of Cleaner Production*, Vol. 170, pp. 674-682.

Liu, Y., Wang, Y. and Huo, H. (2013), "Temporal and spatial variations in on-road energy use and CO_2 emissions in China 1978-2008", *Energy Policy*, Vol. 61, pp. 544-550.

Magazzino, C. (2016a), "Economic growth, CO_2 emissions and energy use in the South Caucasus and Turkey: a PVAR analyses", *International Energy Journal*, Vol. 16 No. 4, pp. 153-162.

Magazzino, C. (2016b), "The relationship among real GDP, CO_2 emissions, and energy use in South Caucasus and Turkey", *International Journal of Energy Economics and Policy*, Vol. 6 No. 4, pp. 672-683.

Magazzino, C., Mele, M., Drago, C., Kuşkaya, S., Pozzi, C. and Monarca, U. (2023), "The trilemma among CO_2 emissions, energy use, and economic growth in Russia", *Scientific Reports*, Vol. 13, 10225.

Mangones, S.C., Jaramillo, P., Rojas, N.Y. and Fischbeck, P. (2020), "Air pollution emission effects of changes in transport supply: the case of Bogotá, Colombia", *Environmental Science and Pollution Research*, Vol. 27, pp. 35971-35978.

Nazlioglu, S., Gormus, N.A. and Soytas, U. (2016), "Oil prices and real estate investment trusts (REITs): gradual-shift causality and volatility transmission analysis", *Energy Economics*, Vol. 60, pp. 168-175.

Neves, S.A., Marques, A.C. and Fuinhas, J.A. (2017), "Is energy consumption in the transport sector hampering both economic growth and the reduction of CO_2 emissions? A disaggregated energy consumption analysis", *Transport Policy*, Vol. 59, pp. 64-70.

Omay, T. (2015), "Fractional frequency flexible Fourier form to approximate smooth breaks in unit root testing", *Economics Letters*, Vol. 134, pp. 123-126.

Our World in Data (2022), “Cars, planes, trains: where do CO_2 emissions from transport come from?”, available at: https://ourworldindata.org/co2-emissions-from-transport

Perron, P. (1989), “The great crash, the oil price shock, and the unit root hypothesis”, *Econometrica*, Vol. 57 No. 6, pp. 1361-1401.

Phillips, P. and Hansen, B. (1990), “Statistical inference in instrumental variables regression with I(1) processes”, *Review of Economic Studies*, Vol. 57, pp. 99-125.

Qian, F. and Li, T.Z. (2014), “Emission characteristics of CNG/gasoline dual-fuel taxi”, *Applied Mechanics and Materials*, Vols *505–506*, pp. 365-369.

Ritchie, H. (2020), “Cars, planes, trains: where do CO_2 emissions from transport come from?”, available at: https://ourworldindata.org/co2-emissions-from-transport

Saboori, B., Sapri, M. and Bin, B.M. (2014), “Economic growth, energy consumption and CO_2 emissions in OECD (Organization for Economic Co-operation and Development)’s transport sector: a fully modified bi-directional relationship approach”, *Energy*, Vol. 66, pp. 150-161.

Saidi, S. and Hammami, S. (2016), “The place of transport infrastructures among the economic factors of foreign direct investment attractiveness in the meda-10 region”, *American Journal of Economics and Business Administration*, Vol. 8 No. 1, pp. 23-34.

Shabir, M., Gill, A.R. and Ali, M. (2022), “The impact of transport energy consumption and foreign direct investment on CO_2 emissions in ASEAN countries”, *Frontiers in Energy Research*, Vol. 10.

Shahbaz, M., Khraief, N. and Jemaa, M.M.B. (2015), “On the causal nexus of road transport CO_2 emissions and macroeconomic variables in Tunisia: evidence from combined cointegration tests”, *Renewable and Sustainable Energy Reviews*, Vol. 51, pp. 89-100.

Shouket, B., Zaman, K., Nassani, A.A., Aldakhil, A.M. and Abro, M.M.Q. (2019), “Management of green transportation: an evidence-based approach”, *Environmental Science and Pollution Research*, Vol. 26 No. 12, pp. 12574-12589.

Sohail, M.T., Ullah, S., Majeed, M.T. and Usman, A. (2021), “Pakistan management of green transportation and environmental pollution: a nonlinear ARDL analysis”, *Environmental Science and Pollution Research*, Vol. 28, pp. 29046-29055.

Soylu, S. (2007), “Estimation of Turkish road transport emissions”, *Energy Policy*, Vol. 35 No. 8, pp. 4088-4094.

STATISTA (2024), available at: https://www.statista.com/statistics/1129656/global-share-of-co2-emissions-from-fossil-fuel-and-cement/

Steenhof, P., Woudsma, C. and Sparling, E. (2006), “Greenhouse gas emissions and the surface transport of freight in Canada”, *Transportation Research*, Vol. 11 No. D, 5, pp. 369-376.

Sutcliffe, E.B. (2012), *The role of rail systems in urban transportation*, Heinrich Böll Stiftung Association Turkey Representation, pp. 23-31.

Teixeira, A.C.R. and Sodre, J.R. (2018), “Impacts of replacement of engine powered vehicles by electric vehicles on energy consumption and CO_2 emissions”, *Transportation Research Part D: Transport and Environment*, Vol. 59, pp. 375-384.

Timilsina, G.R. and Shrestha, A. (2009), “Transport sector CO2 emissions growth in Asia: underlying factors and policy options”, *Energy Policy*, Vol. 37 No. 11, pp. 4523-4539.

TURKSTAT (2020), Turkish Statistical Institute, available at: https://data.tuik.gov.tr/Bulten/Index?p=Sera-Gazi-Emisyon-Istatistikleri-1990-2020-45862

TURKSTAT (2021), Turkish Statistical Institute, available at: https://data.tuik.gov.tr/Bulten/Index?p=Sera-Gazi-Emisyon-Istatistikleri-1990-2021-49672

UN (2021), “Department of economic and social affairs”, available at: https://sdgs.un.org/goals/goal7

UN (2024), “Transforming our world: the 2030 Agenda for sustainable development”, available at: https://sdgs.un.org/2030agenda

Wang, Y., Xing, Z., Zhao, S., Zheng, M., Mu, C. and Du, K. (2016), "Are emissions of black carbon from gasoline vehicles overestimated? Real-time, in situ measurement of black carbon emission factors", *Science of The Total Environment*, Vol. 547, pp. 422-428.

Ventosa-Santaulària, D. and Vera-Valdés, J.E. (2008), "Granger-causality in the presence of structural breaks", *Economics Bulletin*, Vol. 3 No. 61, pp. 1-14.

Wang, W., Ali, A., Wang, H., Feng, Y. and Dai, S. (2023), "EKC hypothesis testing and environmental impacts of transportation infrastructure investments in China, Turkey, India, and Japan", *Environmental Science and Pollution Research*, Vol. 30 No. 34, pp. 81600-81615.

Wenlong, Z., Nawaz, M.A., Sibghatullah, A., Ullah, S.E., Chupradit, S. and Minh Hieu, V. (2023), "Impact of coal rents, transportation, electricity consumption, and economic globalization on ecological footprint in the USA", *Environmental Science and Pollution Research*, Vol. 30 No. 15, pp. 43040-44305.

Yaşar, E. (2022), "The effect of air transportation, information communication technology, economic growth and population on CO_2 emissions: the case of Turkey", *Journal of Economics, Business and Finance Studies*, Vol. 4 No. 3, pp. 172-193.

Yeldan, E., Acar, S. and Asici, A.A. (2020), *New climate regime through the lens of economic indicators*, TUSIAD.

Zhang, C. and Nian, J. (2013), "Panel estimation for transport sector CO2 emissions and its affecting factors: a regional analysis in China", *Energy Policy*, Vol. 63, pp. 918-926.

Zivot, E. and Andrews, D.W.K. (2002), "Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis", *Journal of Business and Economic Statistics*, Vol. 20 No. 1, pp. 25-44.

Further reading

Bal, H., Akar, P.G. and Manga, M. (2017), "An empirical analysis on the elasticity of air transportation demand: sample of Turkey", *International Conference on Eurasian Economies*.

International Energy Agency (IEA) (2018), *World Energy Outlook*, IEA, Paris.

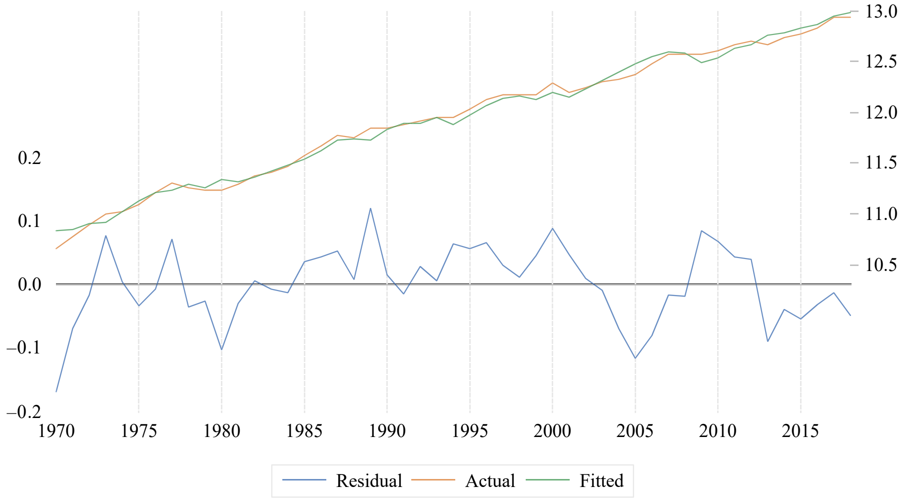
International Energy Agency (IEA) (2020), *Energy Technology Perspectives 2020*, IEA, Paris.

Lin, B. and Du, Z. (2015), "How China's urbanization impacts transport energy consumption in the face of income disparity", *Renewable and Sustainable Energy Reviews*, Vol. 52, pp. 1693-1701.

Republic of Türkiye Ministry of Transport and Infrastructure (2021),

(The Appendix follows overleaf)

Appendix



Source(s): Authors' elaborations in EViews

Figure A1.
Actual vs Fitted Residual graph

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