



How do logistics and financial indicators contribute to carbon emissions in Türkiye?

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Abstract

Increasing carbon emissions (CO₂) due to factors such as energy consumption (enco), industrialization, increase in world population, and decrease in green areas with the industrial revolution is one of the main causes of both climate change and global warming. In this context, due to the increasing commercial activities in Türkiye, the rapid growth of energy consumption and greenhouse gas (GHG) emissions in the logistics sector alert the government. However, there is a lack of standard measures for evaluating GHG emissions generated from freight transport operations. To improve this situation, Türkiye's policymakers need to evaluate GHG emissions for energy saving and pollution reduction. This background leads us to examine the GHG emission trajectories and features of Türkiye's freight transport patterns in the last three decades. In this context, it is aimed to determine the impacts of financial development (findev), GDP per capita, energy consumption, and amount of freight carried by rail and road on CO₂ emissions within the framework of 1990–2021 time-series data for Türkiye. By doing so, the ARDL bound testing cointegration test is employed and observes that independent variables have similar and different effects on CO₂ emissions. Energy consumption, findev, and per capita income variables have a positive effect on CO₂ emissions in Türkiye. According to these results, it is seen that the environmental Kuznets curve (EKC) is valid in Türkiye. However, the effect of rail and road freight transport (FT) on CO₂ emissions is negative. The unexpected finding is related to road FT. The amount of freight transported by road has a decreasing effect on CO₂ emissions in Türkiye. This paradoxical situation in Türkiye may be due to the developments in the transportation infrastructure, which has enabled the convergence of space and time in recent years, young and modern vehicle fleets, and the efficiency provided through logistics companies. The findings will assist in formulating specific and effective policies for Türkiye's transport sector.

Keywords Carbon emissions · Logistics sector · Freight transport · Financial development · Energy consumption · ARDL bounds test

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Introduction

In the current century, sustainable economic development and protection and improvement of environmental quality (*EQ*) are among the most serious problems facing the

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world. In the modern age, development efforts have turned towards eco-friendly economic growth (*EG*) rather than just growth. Accordingly, developed and developing countries are performing vigorous efforts to cope with the high carbon emissions issue. The increasing global warming issue has been the focus of local and global discussions in recent years (Usman et al. 2020; Shahbaz et al. 2013; Ahmad et al. 2018). Increasing the levels of greenhouse gases (*GHGs*) in the atmosphere in terms of EQ has become the leading modern dilemma for all levels of economies. *GHGs* are also in charge of the ozone layer's depletion and increases in the global temperature average. Environmental degradation (*ED*) is responsible for a variety of human diseases like stroke, lung cancer, respiratory and heart disease, increased mortality, natural resources deterioration, and infrastructure damage in farmlands (Shahbaz et al. 2013).

The theoretical background of the relationship between environmental degradation and economic growth is discussed in the context of the environmental Kuznets curve (*EKC*) hypothesis. The *EKC* hypothesis was developed to describe the existing relationship between a country's economic development and environmental degradation. In this context, it implies an inverted U-shaped relationship between economic development and environmental degradation. In this hypothesis, environmental degradation increases in the early stages of economic development, because a healthy environment is ignored at the expense of economic development (Can et al. 2020). This continues until a threshold level (turning point) is reached in per capita income, and this level turns into decrease as income increases (Uchiyama 2016). At this level, environmental concerns shift to environmental conservation and protection, with more attention paid to promoting environmental protection (Adedoyin et al. 2021). Within the scope of the *EKC* hypothesis, studies are carried out between environmental degradation and various social and economic variables and activities. *EG*, energy demand (production and consumption), financial development, transport infrastructure and activities, trade openness, and environmental sustainability, as well as causality effects, are examined (Sadiq et al. 2023; Khan et al. 2022; Shabir et al. 2022; Shahbaz et al. 2022; Adedoyin et al. 2021; Munir et al. 2020; Go et al. 2020; Alshehry and Belloumi 2017; Kharbach and Chfadi 2017; Öztürk and Öz 2016; Abid 2016; Pilatowska et al. 2014). The changes in national income are one of the factors that are thought to have an impact on CO_2 . The World Bank (2021) has argued that *EG* is well for individuals, the public, and the environment. Such a situation of "win-win" is based on the prospect that the instant benefit of *EG* is an increase in income per capita. This can contribute to poverty reduction and environmental cleanup. Some scientists such as Tamazian et al. (2009), Tamazian and Rao (2010), and Beckerman (1992) have even argued that *EG* is compulsory to cure ecological diseases. On the

contrary, some studies have argued that *EG* requires more manufacturing and consumption activities to meet human desires. However, this causes more waste, more environmental pollution (*EPol*), and more pressure on the resources of the environment (Tamazian et al. 2009; Rothman 1998).

Another factor that can affect CO_2 is the level of *findev*. In this framework, a healthy, efficient, and improved financial sector also plays a crucial role in sustainable economic development and can improve EQ as well as deteriorate (Usman et al. 2020). This situation, by removing investment barriers and facilitating access to financial resources, facilitates access to loans when considered from the consumer perspective; making refrigerators, cars, washing machines, even automobiles, and houses makes consumption of expensive products (big/large tickets) easier (Sadorsky 2010). In addition, using technology in manufacturing to expand the scale of manufacturing can cause high *EPol* as financial institutions give more frequent loans to big-size firms or heavy manufacturing companies (Cole et al. 2005; Brännlund et al. 2007; Ahmad et al. 2018). In other words, benefiting from *findev* has a cost, which is an increase in CO_2 due to increased energy consumption (*enco*) (Ahmad et al. 2018, Shoaib et al. 2020, Baloch et al. 2019, Ang and McKibbin 2007, Sadorsky 2010, 2011, Shahbaz and Lean 2012, Coban and Topcu 2013). Therefore, an increase in *findev* facilitates access to financial resources in terms of quality and quantity; as a result, consumption and investment expenditures increase at individual and institutional levels.

Another factor associated with CO_2 emissions is *enco*. The increasing use of traditional energy sources seriously threatens EQ. Increasing business activities, increasing urban population, and improved *findev* can lead to boosts in *enco* and air pollution. Existing studies show that there is a dynamic connection between the environment, economic activities, and resource usage. Although the use of resources (especially energy resources) provides immediate economic benefits, it is argued that its adverse impact on the environment can be seen in the long term. Besides that, it has been proven that there are significant environmental damages caused by ineffective *enco*. In contrast, economic incentives and constraints imposed on *enco* can provide significant environmental benefits and must be accounted for as a substantial part of a country's financial system (Kolstad and Krautkraemer 1993).

The logistics sector, which is thought to affect CO_2 , is represented by the amount of freight transported by rail and road. Transportation is one of the most significant components of logistics (Tseng et al. 2005). The transport sector consumes 25% of the world's energy and is the third largest source of global CO_2 emissions after electricity and industry (IEA 2018, 2021). It also reflects the general economic activity through personal transportation preferences based on income levels and cultural influences, as well as physical

movements resulting from transactions related to services and goods (Geng et al. 2013). However, due to the widespread usage of fossil fuels, FT and transportation infrastructure cause ED (Afaq et al. 2021), especially due to fuel/enco (Isik et al. 2020; Pradhan 2010; Saidi and Hammami 2017; Benali and Feki 2020; Rasool et al. 2019). On the other hand, it is seen that CO₂ emissions density, energy density, energy structure, and transportation type density of transportation services reduce ED (Hossain et al. 2021; Isik et al. 2020; Kumbaroğlu 2011).

Determining the factors that cause environmental problems (environmental pollution, environmental degradation, destruction of the environment, etc.) and then making suggestions for these problems are an important topic of discussion in the world. In this context, the potential impacts on CO₂ emissions are explored in the present article from a multidisciplinary perspective through a dataset consisting of financial, economic, and logistics-based variables. In the literature on the subject, the number of studies dealing with the effects of transportation infrastructure is negligible. This deficiency is one of the main motivation sources in our study. In this direction, the aim of the study can be expressed as modeling the effect of financial, economic, and logistic factors on CO₂. According to the results, enco, findev level, and per capita income variables have a positive effect on CO₂ in Türkiye. The impact of rail and road FT on CO₂ is negative. In other words, we found empirical evidence that the amount of freight transported by rail and road in Türkiye has a reducing effect on CO₂ emissions.

In doing so, the study contributes to the literature from the following three points. Accordingly, (i) economic resources, economic and financial policies applied, balances of foreign trade, and political-economic preferences may differ in any country. Therefore, the issue has been approached from the perspective of Türkiye, due to the different dynamics and different processes. In this context, it can be thought that diversity can be provided to existing literature via ARDL cointegration and regression methods to examine the effect of financial, economic, and logistics indicators on the quantity of CO₂ in this country. (ii) The subjects that can be taken as references on the related problem by country comparison are presented as examples. In this context, Türkiye can take developed countries as an example in terms of CO₂ reduction in per capita income and financial institutions (findev). On the other hand, underdeveloped, developing and even some developed countries can take Türkiye's transportation policies and preferences as role models in road and rail freight transportation. (iii) The most interesting result obtained from the study is CO₂-reducing effect of road transport in Türkiye, which is a serious expansion, a different dimension, and contributes to the existing literature due to its reasons.

The study consists of five sections, after the “Introduction,” the “Literature review” section presents a relevant

literature review. The econometric methodology is explained in the “Econometric methodology” section. Empirical results and discussions are presented in the “Empirical analysis and findings” section. Policy implications are given in “Conclusion and policy recommendation” section.

Literature review

There is a mature literature in the context of individual and country groups on the effects of financial and economic factors on carbon emissions, for example, in a multi-country context (Yan et al. 2023; Lv and Li 2021; Usman et al. 2020; Ghazali and Ali 2019; Saud et al. 2018; Saidi and Mbarek 2017; Saidi and Hammami 2017), in the context of Turkey (Benli 2020; Isik et al. 2020; Mert and Caglar 2020; Öztürk and Öz 2016), in the context of China (Liu et al. 2023; Chen et al. 2021; Zeng and Wei 2021; Umar et al. 2020a; Wang et al. 2020; Ahmad et al. 2018; Zhang and Nian 2013), in the context of European Union countries (Shahbaz et al. 2022; Adedoyin et al. 2021; Guven et al. 2020; Andrés and Padilla 2018; Pilatowska et al. 2014), in the context of Pakistan (Khan et al. 2020b; Danish et al. 2018), in the context of OECD countries (Saboori et al. 2014, in the context of the BRICS countries (Zhang et al. 2022), in the context of Asian countries (Sadiq et al. 2023; Shabir et al. 2022; Khan et al. 2022; Munir et al. 2020; Shafique et al. 2020; Go et al. 2020; Lin and Omoju 2017; Timilsina and Shrestha 2009), in the context of India (Bekun 2022, Irfan et al. 2023, Ahmed et al. 2020), in the context of the G-8 and D-8 countries (Shoib et al. 2020), in the context of Arabian countries (Salahuddin et al. 2018; Alshehry and Belloumi 2017), in the context of African countries (Khobai and Le Roux 2017, Belaid and Youssef 2017, Kharbach and Chfadi 2017), providing empirical evidence for the role of financial and economic variables on carbon emissions. This study, on the other hand, contributes empirically to research the role of logistics-based variables, as well as economic and financial indicators.

This section summarizes the extant empirical findings concerning the influences of findev, energy use, economic growth, logistics (in terms of transportation), and other macroeconomic variables on the CO₂ emission figures of nations.

Financial development and CO₂ emissions nexus

It is often argued that if a country can improve credit availability for its private sector, the financial sector can be assumed to improve over time (Yan et al. 2023; Xue et al. 2022). Accordingly, previous research has examined how findev or change in DYY affects CO₂ emissions (Yan et al. 2023; Lv and Li 2021; Usman et al. 2020; Saud et al. 2018; Salahuddin et al. 2018; Ahmad et al. 2018; Saidi and Mbarek

2017; Abid 2016; Benli 2020; Öztürk and Öz 2016). The financial sector is considered a “double-edged sword,” as it is recognized that findev, especially in the context of developing countries, can both increase and prevent atmospheric CO₂ emissions (Yan et al. 2023). Therefore, the empirical findings obtained from previous studies on the subject are inconclusive. In this section, studies on the relationship between findev indicators and the environment are included. For example, Lv and Li (2021) implement a spatial econometric model to measure the impact of EG on CO₂ with a sample of 97 nations from 2000–2014 and find a spatial correlation between CO₂ emissions. It is suggested in their empirical findings that findev hugely impacts the reduction of CO₂, and being adjacent to similarly developed countries can enhance a country’s environmental effort. Usman et al. (2020) explore the long-term relationship between ED and findev, enco, and tourism in twenty economies with the highest ecological footprint (providing the highest emissions). They apply the Westerlund cointegration test, PMG, and FMOLS (panel cointegration regression) approach using data from 1995 to 2017. It is revealed that a significant increase in pollution comes from findev and power consumption, while the tourism sector enhances environmental health. The finding calls for the implementation of policies working in conjunction to monitor and minimize ED while promoting EG and development.

Shoaib et al. (2020) implement principal component analysis to develop financial development index from five sub-components to study the causality correlation between it and CO₂ emissions in G-8 and D-8 countries from 1999 to 2013. They further apply PMG-panel ARDL approaches and find that financial growth significantly contributes to CO₂ in the long run. They also note that while enco and trade openness have a positive effect, GDP causes CO₂ emissions to drop significantly. Moreover, Saud et al. (2018) for 59 Belt and Road Initiative nations through panel data analysis and Salahuddin et al. (2018) for Kuwait through the ARDL bounds testing approach examine the effect of findev and EG, FDI, power consumption, and freedom of trade on CO₂. According to the results of Saud et al. (2018), it is found that findev, FDI, and an increase in openness to trade increase EQ. However, EG and increasing in electricity consumption decrease EQ. According to the result of Salahuddin et al. (2018), it is found that the variables and EG, power consumption, and FDI have a cointegration that vitalized CO₂ in the short run and long run. The Granger causality explained that these factors strongly caused CO₂ from Granger. Ahmad et al. (2018) investigate the influence of findev on CO₂ in China. They apply ARDL and NARDL models as data belonging to the period of 1980–2014. Their findings confirm the asymmetrical relationship of positive and negative impacts of findev on CO₂. This further affirms the positive correlation between these factors of interest.

Moreover, they find that the positive component of findev has a greater impact on CO₂ in the long run than negative findev shocks. A similar study was done by Saidi and Mbarek (2017) in 19 emerging economies, and Abid (2016) between 1996 and 2011 explored the relationship between findev and CO₂ through the generalized method of moments (GMM). Saidi and Mbarek (2017)’s results indicate a positive correlation between findev and CO₂. According to Abid (2016)’s results, findev does not have a significant effect on ED, so there is no evidence for EKC.

Economic growth and CO₂ emissions nexus

The relationship between economic growth and environmental quality has been investigated for many years over CO₂ emissions. Scientific evidence on the origins or effects of economic expansion on CO₂ is unclear, using different variables in these studies (Liu et al. 2023). This section summarizes the current empirical findings on the effects of economic development and different macroeconomic variables on countries’ CO₂ emissions. For example, Khan et al. (2022) analyze the relationship between globalization, energy consumption, and EG among selected South Asian countries. In the study, in which the EKC hypothesis is tested, the data for the period 1972–2017 are analyzed with the completely modified ordinary least squares (FMOLS) method. According to the results, it was found that the EKC hypothesis was valid by determining the causality between EG and carbon emissions. In addition, bidirectional causality was found between EG and energy use. Moreover, Adedoyin et al. (2021) try to explain the economic complexity index (ECI), BREXIT, and other crisis events in the link of growth-energy-emissions in 26 EU member states in line with the EKC model. The one-step system generalized method of moments is used in the analysis of the data for the period 1995–2018. The results reveal that real GDP per capita, energy consumption, tourist activities, and ECI are statistically significant determinants of CO₂ emissions in some regions.

Shahbaz et al. (2022) investigate the effects of GDP, domestic bank loans to the private sector, and military spending on carbon emissions in Visegrád group countries. The panel quantile regression method is used in the analysis of the data for the period 1990–2019. According to the results obtained, it is seen that GDP has a reducing effect on carbon emissions. Furthermore, Khan et al. (2020b) analyze the relationship between energy consumption, EG, and CO₂ emissions in Pakistan with the ARDL method of annual time series data from 1965 to 2015. The results show that energy consumption and EG increase CO₂ emissions in Pakistan. Munir et al. (2020) examined the link between energy use, CO₂ emissions, and economic development in five main ASEAN-5 countries between 1980 and 2016. In the analysis

of the data, Granger used a non-causal panel test. EG and enco have been shown to have a unidirectional causal relationship only in Singapore and Thailand, Indonesia, and Malaysia. EG in the Philippines has been correlated bidirectionally with an increase in energy use. A unidirectional Granger causality relationship was established between EG and carbon emissions in Thailand, Indonesia, and Malaysia. They confirmed the validity of the EKC hypothesis for ASEAN-5 economies. Another study was done by Ghazali and Ali (2019) examined the factors affecting carbon dioxide emissions using panel data from ten newly industrialized countries (NIC) (Brazil, India, China, South Africa, Mexico, Indonesia, Philippines, Malaysia, Thailand, and Turkiye) for the period 1991–2013. The data was analyzed through the extended STIRPAT and group mean dynamic co-associated estimator (DCCE) regression. The results reveal that population, GDP per capita, CO emissions intensity, and energy intensity are the main drivers of CO₂ emissions for NICs. In addition, the energy mix and trade openness have a marginal contribution to CO₂ emissions. In addition, it shows that the main factors that can reduce CO₂ emissions are energy intensity, urban employment level, and labor productivity.

Khobai and Le Roux (2017) explore the relationship between energy consumption, carbon dioxide (CO₂) emissions, EG, trade openness, and urbanization in South Africa. Johansen cointegration and Vector error correction model (VECM) was used in the analysis of data for the period 1971–2013. The results show that there is a long-term relationship between enco, CO₂ emissions, EG, trade openness, and urbanization, and there is a bidirectional causality between enco and EG in the long run. Besides, CO₂ emissions found a unidirectional causality flowing from EG, trade openness, and urbanization to enco, and from enco, CO₂ emissions, trade openness, and urbanization to EG. In another study, Sadiq et al. (2023) examined the link between energy use and growth-based CO₂ emissions in selected South Asian countries such as Bangladesh, India, Pakistan, Nepal, and Sir Lanka from 1972 to 2019 under the EKC hypothesis. Pedroni cointegration and FMOLS tests were used in the analysis of the data. The results show that GDP growth, non-renewable energy, and globalization index significantly increase CO₂ emissions in South Asian regions.

Energy consumption and CO₂ emissions nexus

This section summarizes the current empirical findings on the effects of energy consumption and different macroeconomic variables on countries' CO₂ emissions. For example, Guven et al. (2020) analyze the impact of enco, economic structure, and production output of Eastern European countries on CO₂. They apply structural time series model to annual data from 1990 to 2017. According to the findings, it has been determined that all variables have considerable

effects on CO₂. Their results show that the primary energy source has the strongest impact on CO₂. Moreover, the long-term effect of EG on CO₂ is negative for Romania, Poland, Belarus, and Hungary. However, it is positive for Serbia, Ukraine, and Russia. Benli (2020) examines the connection among enco, EG, CO₂, and some other economic variables in Turkiye. The results reveal that CO₂ and enco follow EG. Öztürk and Öz (2016) investigate the correlation among power consumption, income, FDI inflows, and CO₂ using the Maki cointegration and the Granger causality test. They note the existence of a long-term link between series. Their results also show that the EKC hypothesis is supported in Turkiye. The causality test also reveals that enco causes EG. Pilatowska et al. (2014) investigate the connection between per capita GHG emissions and real GDP per capita and enco per capita for Poland. The nonlinear threshold integration and error correction methodology are applied using quarterly data from 2000 to 2012. They find the presence of the EKC hypothesis, as well as the adjustment of deviations for long-term balance is asymmetrical.

Bekun (2022) investigate the effects of renewable energy, non-renewable energy, EG, and investment in the energy sector on CO₂ emissions in the Indian economy. Canonical cointegration regression (CCR), fully modified least squares (FMOLS), and dynamic least squares (DOLS) were used to analyze the data for the period 1990 to 2016, and Granger causality analysis was used to determine the direction of causality between variables. Their results show that there is a negative relationship between CO₂ emissions and renewable energy. Moreover, Belaid and Youssef (2017) explore the complex causal relationship involving CO₂, electricity generation use, fossil-based electricity consumption, and sustainable growth in Algeria using the 1980–2012 autoregressive global delayed cointegration approach. Their findings find that, in the long run, income activity and unsustainable electricity use are detrimental to climate development, while renewable energy use has a beneficial effect on the climate. Liu et al. (2023) investigate the impact of energy consumption, economic development, and urbanization on carbon emissions in China. The panel cointegration and pooled mean group (PMG-ARDL) test are used in the analysis of data for the period 1995–2020. The results obtained have proven that urbanization has no significant effect on EQ, while energy consumption significantly increases environmental damage. A similar study done by Ahmad et al. (2019) emphasized that energy consumption in China has an increasing effect on carbon emissions. Yan et al. (2023) aim to identify carbon emissions factors from developing low- and middle-income countries. According to their results, it has been found that using energy efficiently and increasing the share of renewable energy in national energy consumption profiles can reduce carbon emissions. In contrast, while urbanization exerts emission-increasing effects, the

corresponding effects of financial development and international trade are uncertain.

Logistics and CO₂ emissions nexus

The logistics sector is vital as it serves an integral role in the daily life and development of nations. It also provides trade and growth by establishing links between different places. On the other hand, the logistics sector is one of the most considerable sectors for CO₂ worldwide, especially since transportation activities consume a significant amount of fossil energy, which detrimentally impacts the environment and accumulates global CO₂. Moreover, it is expected that enco will further increase in the future due to the growth of freight transportation (Irfan et al. 2023; Isik et al. 2020; Shafique et al. 2020; Timilsina and Shrestha 2009; IEA 2017; Linton et al. 2015). Existing research on the transport sector mainly explores the impact of various factors on CO₂ emissions. However, more work is needed to achieve consensus. This section summarizes the studies between logistics and transportation and EQ, EPol, ED, and CO₂.

Lin and Omoju (2017) examined the impact of private investment in the transport sector and the mode of transport infrastructure urbanization on transport CO₂ emissions in eight Asian countries (China (1990–2013), Indonesia (1990–2012), India (1996–2013), Malaysia (1992–2013), Pakistan (1995–2010), Philippines (1995–2013), Thailand (1990–2004), Vietnam (2006–2010)). The STIRPAT, panel cointegration, and fully modified ordinary least squares (FMOLS) methods were used in the analysis of the data. According to the results, while the increase in income and population increases transportation CO₂ emissions, technological developments reduce CO₂ emissions from the transportation sector. In addition, private investment in the transport sector and the availability of railway infrastructure reduce transport CO₂ emissions, Asian countries with more railway infrastructure and private sector investment in the transport sector tend to have lower CO₂ emissions than the transport sector. Umar et al. (2020a) examine the effects of EG, innovation, findev, and transportation infrastructure on CO₂ emissions using data from 1971 to 2018 in China. The results of the Bayer-Hanck cointegration and wavelet coherence approach show that there is an important cointegration equation between CO₂ emissions, innovation, findev, transport infrastructure, and real GDP. In addition, innovation was an important determinant of CO₂ emissions from 2007 to 2013, and in the long run, there is a negative correlation between CO₂ emissions and findev, with transportation causing significant CO₂ emissions in 2000 to 2015 and 1985 to 1989 periods.

Zhang et al. (2022) investigate the impact of freight and passenger transportation on EPol (in terms of particulate matter 2.5) in BRICS countries through econometric

analysis with the annual data from 1990 to 2018. Findings show that they substantially contribute to a higher concentration of particulate matter. But the effect of FT is almost double that of passenger transportation. Saidi and Hammami (2017) investigated the causal relationships among FT, EG, and ED in 75 countries through the GMM from 2000 to 2014. They found that FT, EG, power use, and trade increase ED. Shafique et al. (2020) analyze the correlation between cargo transport, economic development, CO₂, enco, and urbanization in Singapore, South Korea, and Hong Kong. The Johansen cointegration and FMOLS and Granger causality test are employed from 1995 through 2017. According to the results, FT is largely impacted by GPD and enco. In addition, bidirectional causality has been found between GDP and FT in Singapore, whereas a unidirectional causality from GDP to FT has been found in South Korea and Hong Kong. Chen et al. (2021) for the period of 2005–2016 and Zeng and Wei (2021) between 2005 and 2017 analyzed energy efficiency using data from 30 provinces in the transportation sector (TSec) in China. Their findings reveal that energy efficiency changes in transportation vary across regions, decreasing from eastern to western regions. A similar study was done by Irfan et al. (2023) for India from 2000 to 2014 through FMOLS and DOLS. The results show that the increase of 1% in energy efficiency will reduce CO₂ in the TSec by more than 1%. Saboori et al. (2014) investigate the long-term relationships among the TSec and CO₂ for the OECD countries with the data from 1960 to 2008. Findings confirm the bi-directional causality between TSec enco and CO₂. Similar study was done by Danish et al. (2018) in Pakistan. Their results confirm a positive link between energy use in TSec and EQ.

Isik et al. (2020) examine the factors affecting CO₂ in the TSec in Türkiye. They apply the logarithmic average Divisia index method and find that CO₂ is driven mainly by upward EG, followed by population and emission intensity effects. In addition, the overall effect of transport density (tonne/day) shows a significant reduction potential. Fleet efficiency and fuel-switching incentives appear to have had a positive impact on emissions reductions from 2000 to 2010. Alshehry and Belloumi (2017) for Saudi Arabia and Go et al. (2020) for Malaysia investigate the transport-emissions link within the framework of the EKC hypothesis. The ARDL bounds test is used to investigate the dynamic connection between TSec emissions and EG. According to the findings, the validity of the EKC hypothesis for TSec emissions is denied. On the contrary, Kharbach and Chfadi (2017) analyze the relationship between CO₂ and enco in the road TSec and EG in Morocco. They use cointegration analysis to check whether the EKC hypothesis is valid. According to the results, although EG will lead to a decrease in emissions in the TSec, it supports the EKC hypothesis. Ahmed et al. (2020) investigate the TSec's CO₂ in India for the period of

1980–2015. The results indicate that EG and highway enco boost emissions. In addition, while road-related infrastructure increases transportation emissions, urbanization reduces emissions. Zhang and Nian (2013) investigated the variables associated with TSec emissions in China from 1995 to 2010. The regional data and Pedroni cointegration approach are employed for empirical analysis. According to the results, it is seen that EG, population growth, and oil prices increase emissions related to the TSec, while electricity consumption and freight turnover (vehicle ton-km) decrease emissions.

Timilsina and Shrestha (2009) investigated the CO₂ factors for Asian economies. The decomposition analysis is used to analyze the data from 1980 to 2005. It has been demonstrated that GDP per capita, increase in population, and changes in transport energy intensity are the key drivers of the TSec CO₂ growth. Andrés and Padilla (2018) investigated the drivers of GHG emissions for the TSec using panel data analysis from 1980 to 2014 for European economies. Their results confirm that both transport energy density and transport volume contribute substantially to GHG emissions. Hydrocarbons, carbon monoxide, and nitrogen oxides from aircraft flights also make them a major contributor to global warming. Shabir et al. (2022) evaluate the impact of foreign direct investment (FDI) and energy consumption of the transportation sector on CO₂ emissions in ASEAN-5 (Philippines, Malaysia, Thailand, Indonesia, and Singapore). It uses a nonlinear autoregressive distributed lag model (NARDL) to analyze data for the period 1980–2019. The results show that the EKC relationship between income and CO₂ emissions is valid only for Singapore, while income growth positively affects CO₂ emissions for Indonesia, Malaysia, the Philippines, and Thailand. FDI and energy consumption in the transport sector also significantly affect CO₂ emissions in selected countries, excluding Singapore. In addition to the above studies, Pan et al. (2013) measured the CO₂ emissions of road and rail transport and concluded that road transport is an important factor in the growth of CO₂ emissions in France. Wang et al. (2020) decomposed the factors affecting CO₂ emissions from the transport sector in China, including passenger and freight transport, and the results show an increase in CO₂ emissions from both modes. Engo (2019) examined the decoupling relationship between energy-related CO₂ emissions in Cameroon and the results show that CO₂ emissions increase with the growth of the transport sector.

In summary, the studies show that the TSec plays a major role in affecting CO₂ in terms of EQ. While the direction of existing findings on transport and environmental links is not certain, they also show how sensitive the EPoI impacting TSec is to the modes and scales of the TSec. Therefore, these studies do not provide a precise and clear relationship. Moreover, these studies often provide evidence that assumes a symmetrical relationship between the TSec and the environment. In the literature on the subject, the number

of studies dealing with the effects of transportation infrastructure is negligible. This deficiency is one of the main motivation sources in our study.

Econometric methodology

Data

Turkiye's data covering the period from 1990 to 2021 is used for empirical analysis. CO₂ is the dependent variable that covers the period of 1990–2021 and is compiled from the <http://globalcarbonatlas.org> website. Per capita income, energy consumption, and the amount of freight transported by rail and road cover the period of 1990–2021 and data is compiled from World Bank, <http://enerdata.net>, and OECD websites, respectively. Financial development index data includes the period of 1990–2021 and data is obtained from the IMF official website. All the variables are used in empirical analysis based on their natural logarithms. In addition, the time path graphs of the variables are given in Table-A1 in the “Supplementary information.”

Econometric method

The mathematical backgrounds of the models used in the study are summarized below. The ARDL method has been used in the analyses because of its advantages such as obtaining reliable results and consistent coefficients for small samples, allowing variables to have different degrees of stationarity, and also allowing to predict of short- and long-term relationships between the variables (Feng et al. 2023; Shuaibu et al. 2022; Usman et al. 2022; Ngoc and Awan 2022; Ali et al. 2022). The ARDL bounds testing model has become prevalent due to its various advantages over traditional cointegration analysis. It also eliminates the problems related to omitted variables and autocorrelation by predicting the short- and long-run components of the model concurrently (Haug and Ucal 2019; Hamuda et al. 2013; Srinivasan et al. 2012). ARDL analysis does not require all series to be stationary at the same level, and ARDL testing requires that the variables are not stationary at I(2) and above (Alam and Adil 2019; Churchill et al. 2019; Jalil and Feridun 2011). In this approach, the unconstrained error correction model is first determined in the following mathematical notation framework:

$$\begin{aligned} \Delta \ln \text{co}_2 = & \alpha_0 + \sum_{i=1}^m \beta_{1i} \Delta \ln \text{co}_{2t-i} + \sum_{i=0}^n \beta_{2i} \Delta \ln \text{findev}_{t-i} + \sum_{i=0}^p \beta_{3i} \Delta \ln \text{pgdp}_{t-i} \\ & + \sum_{i=0}^r \beta_{4i} \Delta \ln \text{enco} + \sum_{i=0}^s \beta_{5i} \Delta \ln \text{rail} + \sum_{i=0}^l \beta_{6i} \Delta \ln \text{road} \\ & + \delta_1 \ln \text{co}_{2t-1} + \delta_2 \ln \text{findev}_{t-1} + \delta_3 \ln \text{pgdp}_{t-1} \\ & + \delta_4 \ln \text{enco}_{t-1} + \delta_5 \ln \text{rail}_{t-1} + \delta_6 \ln \text{road}_{t-1} + \varepsilon_t \end{aligned} \quad (1)$$

In this notation, α is the constant term; Δ difference operator; ε error term; and $m, n, p, r, s,$ and t are lag lengths. The fact that the data shows a time series feature and stationarity is an important criterion in such a series may cause problems in the use of the classical least-squares approach. For example, if the variables are not stationary at the level, the variables should be included by taking their first or second differences. This situation may cause problems in regression models based on the likelihood approach, in terms of the model’s unbiasedness, neutrality, and producing accurate estimates. Because of this, it is not very suitable to use classical least-squares approximations in such series (Nguyen and Kakinaka 2019). In addition, a relationship appears among explanatory variables and error terms, creating an endogeneity problem when two variables are cointegrated. In that case, the variables lose their asymptotic properties (Berke 2012). Therefore, asymptotic unbiasedness, consistency, and asymptotic efficiency properties may be lost among the asymptotic properties that the estimator may have. To overcome such problems, the fully modified least squares (FMOLS) method proposed by Phillips and Hansen (1990), canonical cointegration regression (CCR) proposed by Stock and Watson (1993), and dynamic least squares method proposed by Park (1992) (three methods have been proposed, namely DOLS). These approaches provide accurate tests for small sample sets and robust, reliable controls on the estimated regression (Umar et al. 2020b). The FMOLS is a semi-parametric approach to eliminate the problems of correlation and is asymptotically neutral and effective (Khan et al. 2020a; Chen and Huang 2013). The DOLS is a method that eliminates the feedback situation

in the cointegration system and provides an asymptotically efficient estimator. Moreover, the method determines the long-term coefficients between the variables by adding ΔX_t , premise and lagged values of the difference of independent variables to the model (Liu 2018; Ibrahim and Hanafy 2020).

Empirical analysis and findings

In order to get common info about the data, descriptive statistical information is needed. In this respect, descriptive statistical information of data is presented in Table 1. Accordingly, the fact that the mean and median values presented in panel A are the same or close to each other indicates that this distribution is symmetrical, which gives a priori information that the variables show a normal distribution. The fact that the mean and median values of the variables are generally close indicates that the distribution is symmetrical and normally distributed. Since the probability values of the Jarque-Bera test are $p > 0.05$, it can be said that the variables excluding the *findev* show a normal distribution. *lnpgdp* has the highest standard deviation among the variables considered in the study. The biggest difference between the maximum and minimum values among the existing variables belongs to this variable. Correlation analysis results are shown in panel B. Accordingly, CO₂ emissions in Turkey are positively related to all other independent variables.

In order to have more information about the structure of the variables, a general evaluation can be made about the stationary condition by examining the time path graphs given

Table 1 Descriptive statistics and correlation analysis

Variables	lnco ₂	lnfindev	lnpgdp	lnenco	lnrail	lnroad
Panel A: Basic statistics						
Mean	5.594	− 0.940	8.706	4.493	9.223	12.010
Median	5.610	− 0.845	8.946	4.481	9.190	12.052
Maximum	6.100	− 0.617	9.434	5.091	9.674	12.560
Minimum	5.021	− 1.630	7.714	3.922	8.885	11.034
Std. Dev.	0.338	0.288	0.582	0.353	0.210	0.420
Skewness	− 0.114	− 0.888	− 0.270	0.023	0.561	− 0.794
Kurtosis	1.694	2.921	1.419	1.820	2.464	3.092
JB	2.341	4.085	3.719	1.859	2.064	3.376
Prob.	0.310	0.129	0.155	0.394	0.356	0.184
Panel B: Correlation matrix						
lnco ₂	1.000					
lnfindev	0.938	1.000				
lnpgdp	0.934	0.872	1.000			
lnenco	0.995	0.930	0.909	1.000		
lnrail	0.876	0.781	0.778	0.891	1.000	
lnroad	0.943	0.956	0.844	0.947	0.783	1.000

in Table A1 in the ‘‘Supplementary information.’’ Graphs of six different variables of the country generally tend to increase and decrease. Since most of the series is trending upwards or downwards, if the model is estimated without a trend, it may not show some important characteristics of the data. For this reason, it has been tested whether data is stationary or not over the fixed and trended model. The results of the unit root test are given in Table A2. According to the ADF unit root test, all of the variables are stationary at the level of 1%, 5%, and 10% significance I(1) at the first differences in the fixed and trended model. Since the series are stationary around the deterministic trend, they may be affected by the slope parameter or structural breaks in the constant term. Therefore, performing a traditional ADF unit root test without considering such structural breaks in the model may cause false results and decrease the predictive power of the model.

Therefore, the ADF unit root test with structural break is applied to determine structural break, as the majority of the series included trends. In addition, the unit root test with structural break is used with the presumption that the country may have experienced important economic, social, and political developments in the relevant period. According to the results of the ADF test with structural breaks, all series are stable at different significance levels, level I(0) and/or at first differences

I(1). At this stage, it is tried to determine whether there is a long-term connection among the variables or not through the ARDL bounds testing. This test is based on the F-statistics or Wald test and the null and alternative hypotheses are given below (Tursoy and Faisal 2018).

$$H_0 : \varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = \varphi_5 = \varphi_6 = 0 \text{ (There is no cointegration)}$$

$$H_1 : \varphi_1 \neq \varphi_2 \neq \varphi_3 \neq \varphi_4 \neq \varphi_5 \neq \varphi_6 \neq 0 \text{ (There is a cointegration)}$$

If the test statistic goes over the upper limit, it is concluded that there is a cointegration relationship. If it falls within the limits, the test is inconclusive; in other words, test evidence is insufficient. If it is smaller than the lower limit, a long-term relationship cannot be found (Pan and Mishra 2018; Jalil and Mahmud 2009). Limit test results are shown in Table 2.

According to the test results, H_0 is rejected and the H_1 hypothesis is accepted that there is a cointegration link among the series. From this point of view, it can be said that there is a long-term link between CO_2 and findev, per capita income, freight carried by road and rail, and enco in Turkiye. The short-run and long-run coefficient estimates and diagnostic test results obtained with the ARDL model are shown in Table 3.

After determining the cointegration link among variables, it is first necessary to predict the long-term link between variables. The results of the model whose mathematical representation has been made below are presented in panel A in Table 3.

$$\ln CO_2 = \alpha_0 + \sum_{i=1}^m \alpha_{1i} \ln CO_{2t-i} + \sum_{i=0}^n \alpha_{2i} \ln findev_{t-i} + \sum_{i=0}^p \alpha_{3i} \ln pgdp_{t-i} + \sum_{i=0}^r \alpha_{4i} \ln enco + \sum_{i=0}^s \alpha_{5i} \ln rail + \sum_{i=0}^t \alpha_{6i} \ln road + \varepsilon_i \tag{2}$$

findev is defined by the financial development index as having a statistically considerable impact on CO_2 . However, this effect is in the direction of increasing carbon emissions in Turkiye. The financial ecosystem in Turkiye transfers resources for expenditures or opportunities to increase carbon emissions to individuals/businesses through financial institutions and financial markets, which are its two sub-mechanisms. Gross domestic product (GDP) per capita has an increasing impact on CO_2 , and this effect is statistically significant. Accordingly, individuals in Turkiye make consumption and investment expenditures in a way that will increase CO_2 as their income increases. Although the increase in the amount of freight transported by rail has a reducing effect on CO_2 , this effect is statistically considerable. When the amount of freight transported in domestic transport modes is evaluated in terms of Turkiye in 2019, it is seen that 92.6% was transported by road, 5.1% by rail, and 2.4% by air. In addition, while the amount of freight transported in transport modes in 2019 was compared with the year 2000, the share of road transport in Turkiye decreased from 94 to 92.6% and the share of railway transport decreased from 5.8 to 5.1%. It is observed that the

share of air transport increased from 0.2 to 2.4%. Despite the increase in the amount of freight transported by road in Turkiye, it reduces CO_2 emissions. This negative effect obtained with the ARDL model was also confirmed in the cointegration regression models, and it was proved to be a statistically significant result with the DOLS model. There is a broad consensus in the existing literature that the amount of cargo transported by road has an increasing effect on carbon emissions. At this point, this result needs to be explained to Turkiye. It can be attributed to four reasons: First of all, the tightening of pollution and noise limits, especially in new vehicles today, greatly reduces local externalities related to loading (Leonardi et al. 2015), and accordingly, it provides less fuel consumption in new generation motor vehicles. As a matter of fact, approximately 47% of trucks and 34% of trucks in Turkiye are under the age of 10 (TUIK 2019). Secondly, it may be possible to change the type of fuel by switching to LPG, which is more environmentally friendly than gasoline and diesel. Thirdly, it can be said that, depending on the increase in awareness of logistics businesses/services, manufacturing companies have started to work with logistics companies to utilize from economies

of scale within the scope of outsourcing. Accordingly, as a result of logistics companies increasing their vehicle capacity utilization rates (e.g., ensuring that vehicles are returned in full by logistics companies), there may be a decrease in CO₂ per load (logistics service CO₂ emissions). Finally, infrastructure investments on the roads between production and consumption points (double roads, highways, tunnels, bridges, etc.) may have resulted in a reduction in CO₂ due

to the shortening of travel times (e.g., a journey that used to take 8 h between Istanbul and Izmir now takes only 3.5 h). In addition, higher traffic fines (e.g., related to speeding and tachograph) and increased use of technology in the TSec (e.g., navigation) are among the reasons that reduce CO₂. In the next stage, a functional pattern of ARDL error correction model, which was developed to investigate the short-run dynamics between variables, is given below:

$$\Delta \ln \text{co}_2 = \alpha_0 + \sum_{i=1}^m \lambda_{1i} \Delta \ln \text{co}_{2,t-i} + \sum_{i=0}^n \lambda_{2i} \Delta \ln \text{findev}_{t-i} + \sum_{i=0}^p \lambda_{3i} \Delta \ln \text{pgdp}_{t-i} + \sum_{i=0}^r \lambda_{4i} \Delta \ln \text{enco}_{t-i} + \sum_{i=0}^s \lambda_{5i} \Delta \ln \text{rail}_{t-i} + \sum_{i=0}^t \lambda_{6i} \Delta \ln \text{road}_{t-i} + \lambda_7 \text{ECM}_{t-1} + \varepsilon_i \tag{3}$$

ECM refers to the error correction term and the coefficient (λ) must be negatively signed and statistically considerable (Paul 2014). The (λ) indicates the rate of returning to long-run equilibrium after a short-run shock (Folarin and Asongu 2019). The results of the estimation are shown in panel B in Table 3. Financial development and the level of road freight have similar effects on CO₂ with long-term consequences. In Turkiye, the enco has an increasing effect on CO₂ in the short term, and this finding is in line with long-term results. The short-term impact of rail transport in Turkiye is similar to the long-term findings. Moreover, it was observed that the deviations that occurred in the short term disappeared in the long term. As a matter of fact, the error correction coefficient has taken values in accordance with the theoretical expectations as expected (Narayan and Smyth 2006). Accordingly, the effect of a short-term shock that causes deviations in the long-term balance may disappear in the coming period (year).

According to the diagnostic test results in Table-3 (Panel-C), it is understood that ARDL models do not have any autocorrelation (Breusch-Godfrey LM Test), changing variance (Breusch-Pagan-Godfrey) problem, and there is no modeling error (Ramsey Reset Test). In addition, it is understood that the error term in the models developed has a normal

distribution (Jarque-Together Normality Test). Diagnostic test results for ARDL models verify the stability, reliability, and validity of the generated models. Also, it was observed that long-run coefficients obtained with the ARDL bounds test according to CUSUM and CUSUM-Q graphs have not exceeded the critical values, so the coefficients belonging to the model are stable.

At this point, analysis with cointegration regression methods was performed to confirm the ARDL test results and thus to obtain robust empirical evidence for the results of the variables. Table 4 shows the long-term estimations of FMOLS, DOLS, and CCR models for Turkiye.

Table 2 ARDL bounds testing analysis for cointegration

Model: $\ln \text{co}_2, \ln \text{findev}, \ln \text{pgdp}, \ln \text{enco}, \ln \text{rail}, \ln \text{road}$

Country	Opt. Lag Str.	F-stat.	Sig. Lev	Critical values	
				Lower I(0) bound	Upper I(1) bound
Turkey	(1,2,1,1,2,2)	7.457	%10	2.49	3.38
			%5	2.81	3.76
			%2.5	3.11	4.13
			%1	3.5	4.63

Optimal ARDL patterns are determined automatically at a maximum of 2 lags length levels

Models are estimated by the restricted linear trend

Table 3 ARDL coefficient estimates and diagnostic analysis

	Coeff.	p value
Panel A: Long run		
lnfindev	0.165	(0.007)***
lnpgdp	0.081	(0.000)***
lnenco	1.068	(0.000)***
lnrail	-0.119	(0.015)**
lnroad	-0.094	(0.016)**
@trend	-0.008	(0.028)**
Panel B: Short run		
C	3.341	(0.000)***
$\Delta(\ln \text{findev})$	0.106	(0.005)***
$\Delta(\ln \text{findev}(-1))$	-0.091	(0.015)**
$\Delta(\ln \text{pgdp})$	0.004	(0.832)
$\Delta(\ln \text{enco})$	0.866	(0.000)***
$\Delta(\ln \text{rail})$	-0.049	(0.109)
$\Delta(\ln \text{rail}(-1))$	0.066	(0.023)**
$\Delta(\ln \text{road})$	-0.025	(0.505)
$\Delta(\ln \text{road}(-1))$	-0.093	(0.019)**
CointEq(-1)	-1.282	(0.000)***
J-B Normality	0.816	
B-G LM test	0.021	
B-P Godfrey	0.796	
Ramsey reset	0.847	

Significance—*** 1%, ** 5%, * 10%

Table 4 Cointegration regression analysis

Country	Turkey		
	FMOLS	DOLS	CCR
Infindev	0.092 (0.005)***	0.146 (0.012)**	0.100 (0.013)**
lnpgdp	0.086 (0.000)***	0.077 (0.001)***	0.090 (0.000)***
lnenco	0.909 (0.000)***	1.736 (0.000)***	0.919 (0.000)***
lnrail	− 0.057 (0.058)*	− 0.390 (0.000)***	− 0.063 (0.132)
lnroad	− 0.057 (0.037)**	− 0.160 (0.003)***	− 0.053 (0.109)
c	2.103 (0.000)***	3.165 (0.004)***	2.054 (0.000)***
@trend	− 0.002 (0.272)	− 0.023 (0.000)***	− 0.003 (0.285)

Significance—*** 1%, ** 5%, * 10%, respectively

First of all, it should be noted that FMOLS and DOLS is the most functional model in terms of the significance of independent variables. It must be said that the findings from the cointegration regression analysis largely agree with the empirical findings from the ARDL bounds test. In this context, it was found evidence that findev has a positive effect in Turkiye, which is consistent with the ARDL model findings. The cointegration regression model findings show that the increase in per capita income in Turkiye increases CO₂, which is consistent with the empirical results from the ARDL analysis. Empirical results on the effect of enco on CO₂ and the magnitude of this effect overlap with the ARDL model results, and strong evidence is obtained in this regard. The empirical findings related to the variables of the amount of freight transported by rail and road have a significant reducing effect on CO₂.

Conclusion and policy recommendations

Increasing carbon emissions due to factors such as energy use, increasing world population, industrialization, and decreasing green areas with the industrial revolution are the main responsible for global warming and climate change. Developments in this area contain risk factors that may affect businesses, countries, and the whole world. This study is aimed to specify the effect of logistics and financial and economic indicators on CO₂ and to obtain various and strong evidence by performing analyses with methods such as the ARDL bound test and cointegration regression analysis covering the period of 1990–2021.

The empirical findings reveal that the amount of CO₂ tends to increase in Turkiye. The results obtained from the study can be listed as follows:

1. The financial ecosystem in Turkiye has an increasing effect on CO₂. These findings are similar to the results obtained from the studies (Usman et al. 2020; Shoaib et al. 2020; Saud et al. 2018; Ahmad et al. 2018; Saidi and Mbarek 2017; Abid 2016). As of the examined period, the transfer of funds to individuals and/or institutions through financial institutions and financial markets, which are sub-mechanisms of the financial system in Turkiye, is used in choices that increase CO₂.
2. Per capita income has an increasing effect on CO₂ in Turkiye. This show that the EKC hypothesis is valid in Turkiye. These findings are similar to the results obtained from the studies (Khan et al. 2022, Adedoyin et al. 2021, Khan et al. 2020b, Munir et al. 2020, Ghazali and Ali 2019, Sadiq et al. 2023, Benli 2020, Öztürk and Öz 2016, Belaid ve Youssef 2017). Similar to the financial ecosystem, the economic ecosystem directs the individuals in Turkiye make consumption and investment expenditures that increase CO₂. Also, this finding may indicate that public is unaware of environmental degradation.
3. The effect of enco on CO₂ is positive in Turkiye. These findings are similar to the results obtained from the studies (Khan et al. 2020b, Munir et al. 2020, Khobai and Le Roux 2017, Sadiq et al. 2023, Guven et al. 2020, Benli 2020, Öztürk and Öz 2016, Belaid ve Youssef 2017, Liu et al. 2023, Ahmad et al. 2019). This situation may indicate that Turkiye still use fossil fuels in enco.
4. The effect of rail and road freight transport on CO₂ is negative. These findings are similar to the results obtained from the studies (Lin ve Omoju 2017, in terms of infrastructure; Isik et al. 2020, in terms of transport density; Kharbach and Chfadi 2017; Zhang and Nian 2013, in terms of freight turnover (vehicle-ton-km); Ju et al. 2023, Adebayo et al. 2022a, Adebayo et al. 2022b, Mujtaba et al. 2022, Lei et al. 2022, Xue et al. 2022, Sohail et al. 2022, Bekun 2022, Batool et al. 2022, Sheraz et al. 2022, Kirikkaleli et al. 2022, Sahoo and Sahoo 2022). It may be due to the efficiency of logistics companies, the use of vehicles with new-generation engines and widespread use of electric trains, and improvements in rail and road transportation infrastructure in Turkiye such as bridges, roads, and tunnels to shorten the distance between spaces may have reduced fossil fuel consumption. These findings are also similar to Zhu and Xiong (2023)'s study.

Logistics, transportation, financial ecosystems, and energy use decisions are generational, so making them

greener and more sustainable is the primary responsibility of current decision makers for our social and environmental progress. It is thought that the findings and results contain important recommendations especially for decision-makers, researchers, and practitioners in Turkiye. In this context:

1. The financial ecosystem in Turkiye can be directed primarily to private sector investments that reduce carbon emissions by decision-makers, and for this purpose, this process can be managed with incentives or additional taxes during resource allocation. The financial sector can contribute to the prevention of environmental pollution by providing financial resources for clean energy projects such as green bonds. However, in terms of public authorities, developed countries can be taken as an example in order to reduce the positive effect of financial development on environmental pollution first and then to create a negative effect.
2. Turkiye should turn to alternative renewable energy sources instead of fossil fuels in energy consumption. In this context, applications should be developed to encourage the production and use of renewable energy sources such as biofuels.
3. The environmentally friendly economic growth model should be adopted and disseminated through education (in schools, workplaces, etc.). In this context, the interaction of the citizens of the country with environment in terms of the products they consume should be revealed and the level of awareness should be increased. The production and consumption of environmentally friendly products should be supported with various incentives, and if necessary, additional sanctions should be increased and CO₂-reducing consumption preferences should be directed.
4. In terms of freight transport, the use of more railways can contribute to CO₂ reduction. In addition, policy-makers in Turkiye should continue to invest in land and rail transport infrastructure, which is effective in reducing emissions, and also provide incentives to increase the private sector's use of environmentally friendly transport infrastructure.

When evaluated in general, the study shows that the current financial development and energy consumption-based growth models are not suitable for the Turkish economy, despite the positive environmental results obtained from the transportation systems. However, it seems that the current growth model is not environmentally friendly, and consumption preferences need to be changed. In this context, it is recommended to emphasize cautious growth policies, encouraging the use of financial resources in clean areas, clean FDI inflows, and energy efficient transportation systems. The

study is specific to Turkiye. Therefore, the results cannot be generalized. However, remarkable results and recommendations are presented, especially for developing countries such as Turkiye. In studies to be carried out at night, the effects on CO₂ emissions can be measured by using different time intervals, different variables, and different country data for transportation.

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Data availability Data available at <https://figshare.com/s/fd242755da8e44b95ede>

Declarations

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