Ekonomi, Politika & Finans Araştırmaları Dergisi, 2024, 9(2): 323-335
Journal of Research in Economics, Politics & Finance, 2024, 9(2): 323-335
Araştırma Makalesi / Research Article, https://doi.org/10.30784/epfad.1364140

TECHNOLOGY ORIENTED STRUGGLE AGAINST CLIMATE CHANGE IN TRANSPORTATION SECTOR: AN EMPIRICAL INVESTIGATION*

Taşımacılık Sektöründe İklim Değişikliğine Karşı Teknoloji Yönlü Mücadele: Ampirik Bir İnceleme

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Keywords: Transportation Sector, Climate Change Mitigation, Innovation, Patent

JEL Codes: Q54, Q55, R40

Abstract

The transportation sector is one of the most important sectors in which greenhouse gas emissions (GHG) are the highest, thus causing the global warming problem to rise. One of the most effective and international solutions to this problem is considered to be a technology-oriented struggle, and the development of green technologies is encouraged by global authorities. The study aims to investigate the success of the technology-oriented struggle against global warming in the transport sector. In analyses, data on transportation-related greenhouse gas emissions, the number of patents (transport-related climate change mitigation technologies), trade openness, and GDP per capita of 12 OECD countries years between 1999-2017 were used. To identify the long-run and short-run relationship among variables, the Cross-Sectional Autoregressive Distributed Lags Estimator (CSARDL) and also the Mean Group (MG), Augmented Mean Group (AMG), and Common Correlated Effects Mean Group Estimators (CCE) were applied. According to the estimators' findings, no evidence was found that the number of patents and trade openness affected greenhouse gas emissions, but it was determined that GDP positively affected greenhouse gas emissions. As a result, it can be said that the technology-oriented struggle against climate change in the transportation sector alone isn't sufficient to reduce transportation-related GHG emissions.

Anahtar Kelimeler: Ulaştırma Sektörü, İklim Değişikliğinin Azaltılması, Yenilik, Patent

JEL Kodları: Q54, Q55, R40

Öz

Ulaştırma sektörü, sera gazı emisyonlarının (GHG) en yüksek olduğu ve dolayısıyla küresel ısınma sorununun büyümesine neden olan en önemli sektörlerden biridir. Bu sorunun en etkili ve küresel çözümünün teknoloji odaklı mücadele olduğu düşünülmekte ve yeşil teknolojilerin geliştirilmesi küresel otoriteler tarafından teşvik edilmektedir. Bu çalışma, ulaştırma sektöründe küresel ısınmaya karşı teknoloji odaklı mücadelenin başarısını ölçmeyi amaçlamaktadır. Analiz için 12 OECD ülkesinin 1999-2017 yılları arasındaki ulaştırma kaynaklı sera gazı emisyonları, patent sayısı (ulaşımla ilgili iklim değişikliğini azaltma teknolojileri), ticari açıklık ve kişi başına düşen GSYİH verilerinden yararlanılmıştır. Bu çerçevede değişkenler arasındaki uzun ve kısa dönemli ilişkinin belirlenmesi amacıyla yatay kesit otoregresif dağıtılmış gecikme tahmincisi (cross-sectionally augmented autoregressive distributed lag – CS ARDL) ve ek olarak Ortalama Grup (Mean Group MG), Artırılmış Ortalama Grup (Augmented Mean Group - AMG) ve Ortak İlişkili Etkiler Ortalama Grup Tahmin Edicileri (Common Correlated Effects-CCE) kullanılmıştır. Kullanılan tüm tahmin edicilerin bulgularına göre, patent sayıları ve ticari açıklığın sera gazı emisyonlarını etkilediğine dair herhangi bir kanıt bulunamamış, fakat GSYİH'nın sera gazı emisyonlarını olumlu yönde etkilediği tespit edilmiştir. Sonuç olarak, ulaştırma sektöründe iklim değişikliğine karşı teknoloji yönlü mücadelenin, ulaşım kaynaklı GHG emisyonlarını azaltmada tek başına yeterli olamadığı söylenebilir.

[*] The study is an expanded version of the paper "Technology Oriented Struggle Against Climate Change in Transportation Sector: An Empirical Investigation" at the congress "ECONEFE'23 in Istanbul, Turkey on 20-21 May 2023.

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1. Introduction

Sustainable development is a broad subject with its cultural, social, economic, spatial, and environmental dimensions interacting with each other (Kaypak, 2011: 22). However, the most critical focus lies on the challenges that stem from the inherent interplay between the economy and nature. Because the continuity of the economic organization depends on ensuring harmony between the environment and the economy, with policies that will not result in the detriment of the environment (Kılıç, 2012: 207). The transportation sector, which relies on the utilization of fossil fuels, is one of the sectors that play a leading role in this balance that needs to be established between the environment and the economy.

The transportation sector, which makes it possible to reach social or economic opportunities, is directly related to economic growth and development with the space and time benefit it creates, as well as human well-being, quality of life, social equity, and social inclusion (Bakker et al., 2014: 337, 338). In the global economic order, where the free movement of capital, people, services and goods is important, the transportation sector has a very critical place in terms of its role (Seçilmiş and Konu, 2021: 249). Years between 2006 and 2020, the value of transportation services in the world increased from US$ 717,20 bln to US$ 955,20 bln (33% increase) in terms of imports and from US$ 580,30 bln to US$ 819,20 bln (41% increase) in terms of exports (UN, 2021: 286). Increasing passenger and freight transport mobility causes an increase in transport-related energy demand, as it requires a faster and more flexible transport system (Intergovernmental Panel on Climate Change [IPCC], 1996: 22). As a result of the growth and development of the transportation industry, the adverse impact of the sector on energy use and the environment are also increasing.

Environmental issues stemming from transportation are closely tied to the strategies, policies, and programs implemented in the field of transport. These adverse effects unfold gradually over time, often leading to irreversible consequences (Fenley et al., 2007: 64). Achieving sustainable transportation involves managing the adverse environmental impacts while simultaneously meeting its economic, and social responsibilities (Longshurst et al., 1996: 199).

Sustainable transportation, which is defined differently in various institutions and research (Bakker et al., 2014: 343; Ahn and Park, 2022: 1171), in its most basic form; it is the ability to satisfy the existing transportation demand without the risk of depriving future generations of their needs, making it an integral part of sustainable development strategies. For transport to be sustainable, it must fulfill three fundamental criteria: first, the consumption of renewable resources must not exceed their natural replenishment rates; second, the use of non-renewable resources should be balanced with the development of sustainable renewable alternatives; and third, the emission of pollutants should stay within the environment's assimilative capacity. (Fenley et al., 2007: 64). GHGs, which constitute the most important part of the pollution emission mentioned in the last condition, trap some of the energy from the sun in the atmosphere and cause the planet to warm up. GHG gases emitted by the transportation industry include hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs), nitrous oxide (N2O) and carbon dioxide (CO_2). Nitrogen oxide (NOx) released from aircraft is another type of gas that creates a radiation effect on ozone (IPCC, 1996: 4). Figure 1 shows the sectoral distribution of emissions of GHG from energy use. After energy industries, the sector of transportation stands as the second-largest emitter of GHG emissions.

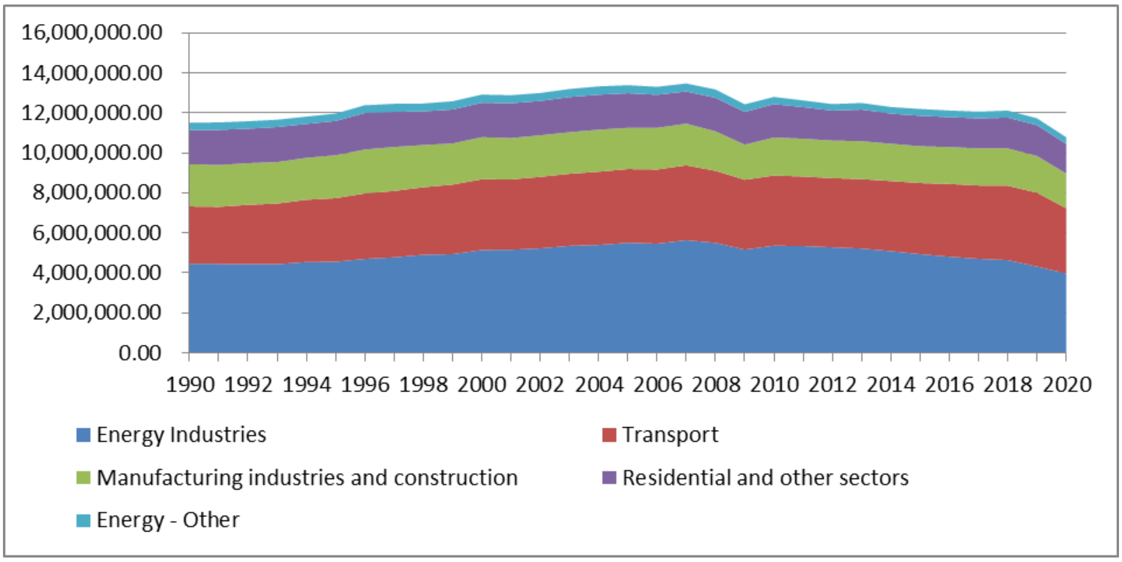

Figure 1. Sectoral Distribution of GHG Emissions from Energy in OECD Countries (1990-2020)
Source: OECD

According to the Second Assessment Report (SAR II) of the IPCC (1995), which emphasizes the relationship between the transportation sector and climate change and provides detailed information, it has been reported that, with the 1990 figures, the three sectors with the highest energy consumption are industry, housing/trade and transportation and the these sector's shares of CO_2 emissions are 45%, 29%, and 21%, respectively. Among these sectors, CO_2 emissions from transportation sector energy use have been reported to have recorded the fastest growth in the last two decades. In the SAR II, three technological developments that can be made to curtail the transport sector's GHG emissions are emphasized: alternative energy sources, infrastructure changes, and energy efficiency improvements. The cost-effectiveness of technological advances in these three areas may vary according to individual and national level accessibility to resources, know-how, institutional capacity, technology, and local market conditions. Energy efficiency improvements include the development of fuel-saving technologies in vehicles, new designs, techniques, and production lines for this purpose. Alternative energy sources include the advancement of technologies that enable the production of fuel from sources of renewable energy, and it is predicted that these fuels can reduce GHG by at least 80% in vehicle operations. Infrastructure changes include the development of technologies that will provide convenience in transportation infrastructure and transportation systems designs, such as traffic and fleet management, transitions between transportation modes, and thus create GHG-reducing effects (IPCC, 1996).

There are various studies suggested that the political support for the technology-oriented struggle against climate change has achieved its purpose and is quite effective in the development of new Technologies (Johnstone et al., 2010; Su and Moaniba, 2017; Dechezleprêtre et al., 2019; Panepinto et al., 2021). In this context, Figure 2 illustrates the number of patent applications made to the European Patent Office (EPO) between 1990 and 2022 (the data for 2022 reflect the last update date of October 19, and it is possible that the number of applications will increase further at the end of the year). According to Figure 2, it is noteworthy that the number of patent applications has an increasing trend, and the rate of increase has increased considerably, especially after the 2000s. Cumulatively, between 1990 and

2022, a total of 1,226,226 technology patent applications for efforts to mitigate climate change within the transportation sector were filed (the cumulative total number of patents for the same period for all sectors was 76,049,979).

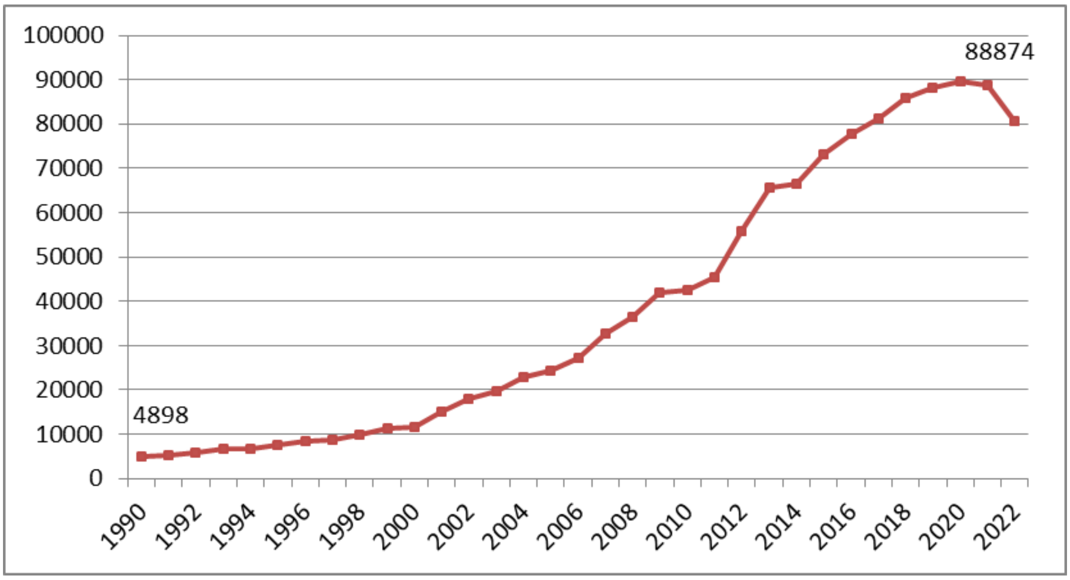

Figure 2. Quantity of Patents on Transportation CCMTs (Y02T)
Source: EPO

Many countries have agreed to implement the global common goals and measures Under the purview of the United Nations Framework Convention on Climate Change (UNFCCC) in the fight against global warming. The advancement, diffusion, and adoption of eco-friendly technologies are among the most important tools that can be used to achieve these common goals (Su and Moaniba, 2017; Ferreira et al., 2020). In line with the awareness created and policies developed in the national and international context, it can be said that innovative activities towards climate change are given importance at the global level and significant increases are experienced in the efforts to fight against technology.

As a result of the awareness created and policies developed in the national and international arena, it is cannot be ignored that innovative activities towards climate change are given importance at the global level and significant increases are experienced in the efforts to combat technology. However, the extent to which these innovative activities are successful in combating climate change bears a question mark. Based on this, the aim of this study is to explore whether the developed technologies have effectively reduced GHG emissions and to determine the success of the technology-oriented policy for combating transportation-induced global warming. More precisely, the aim is to examine the success of the technology-oriented struggle with climate change for sustainable transportation.

In the literature review, it was determined that there is no study that empirically measures the GHG emissions reducing effect of technologies developed for climate change directly in the transportation sector, based on existing data and, it is hoped that the study will contribute to this gap. For the purpose of the study, the long-term and short-term relationship between greenhouse gas emissions from transportation and the number of patents (transport-related CCMTs, trade openness and GDP per capita were tested using the CSARLD estimator. Additionally, second-generation panel model estimators MG, AMG, and CCE were used to test the robustness of CSARDL results. Data from 12 OECD countries between 1999 and 2017 were used in the analysis.

The study is structured as follows: In the second part, previous academic studies on the subject will be included; In the third part, the data set and the method will be explained; In fourth part, the findings will be presented; In the fifth section, the results will be given.

2. Literature Review

The focus of this study is the technology-oriented struggle against climate change. There are many studies in the literature about technology and climate change. In general terms, it can be seen that the political support given to the technology-oriented fight against climate change has achieved its purpose and is quite effective in the development of new technologies, revealed by various studies in the literature. Dechezleprêtre et al. (2013) investigated the factors affecting technology transfer to reduce greenhouse gas emissions. In the study conducted on 96 countries between 1995 and 2007, it was stated that restrictions on international trade and foreign direct investments had a negative impact on the spread of local technological talents and climate-friendly technologies. In the study by Raiser et al. (2017), in which they examined patents, intellectual property rights, and innovation in reducing global warming, it was stated that patents, which economically encourage technology development, pose an obstacle in the fight against climate change by restricting global access to emission-reducing technologies. Princiotta (2021) emphasized that greenhouse gas emissions threaten the habitability of the planet in his review study, and emphasized that there is a need for mitigation actions covering all countries and sectors as soon as possible in order to limit global warming. R&D on up-and-coming clean energy and CO_2 Removal Technologies have been proposed as two important key actions. Caravella et al. (2021), based on the analysis of patent data on EU CCMTs, stated that there is a need for a mission-oriented technology policy with low-carbon and energy-reliable additional directed investments for the complete decarbonization model. Pasimeni et al. (2021) examined the economies of the US, Europe, Japan, and China in research seeking global evidence of what has been achieved so far in CCMTs. Among the findings of the study are the issues that these countries have made significant progress in the technology-oriented struggle, but that there is a need for more continuous and joint efforts in this struggle, and that international climate agreements should be supported more in order to encourage clean energy innovation, organize international cooperation, and increase positive competition.

There are very few studies on technology and combating climate change on the basis of the transportation sector. Wright and Fulton (2005) examined the scope and cost of reducing emissions from the transportation sector of developing countries using different options. Focusing particularly on fuel technology, the study concluded that a diversified package of measures for mode switching would be the most cost-effective tool in reducing greenhouse gas emissions. Chapman (2007) examined the effectiveness of technological and behavioral solutions in reducing GHG emissions from car use, road freight, and aviation. It was stated that a combination of behavior change and technology development policies could be countervailing. Feng et al. (2020) aimed to determine the CO2-blocking technology and efficiency factors related to transportation in China, and it was revealed that the factors that make the biggest contribution to reducing CO_2 emissions are energy-saving technology, production technology, potential energy density, and production efficiency. Hussain (2022) analyzed the 2000-2020 data of 35 OECD countries in his study, in which he examined the effects of transportation-related technologies developed for climate change on the economy and the environment. According to the analysis, and findings made with CS-ARDL; CCMTs for transportation have a negative impact on transportation efficiency.

There are also many studies in the literature that develop scenarios to mitigate greenhouse gas or CO_2 emissions of the transportation sector (Rajan, 2006; Andres et al., 2011; Stanley et al., 2011; Dedinec et al., 2013; Miotti et al., 2016; Ülengin et al., 2018; Moreira and Pacca, 2020). In these studies, the importance of technological developments in the fight against climate change in the transportation sector, some predictions for the future with various alternative solutions, the effectiveness of existing policies and the fight against climate change in different transportation modes are discussed. Among these studies, empirical ones are mostly based on future scenarios and do not analyze the relationship between existing data.

Although there are many studies that test the effectiveness of the technology-oriented fight against climate change on a macroeconomic scale (Álvarez-Herránz, 2017; Jordaan et al., 2017; Su and Moaniba, 2017; Al Mamun et al., 2018; Ahmad et al., 2020; Ferreira et al., 2020) no study with similar content on the transportation sector was found in the literature review. It is thought that this study will contribute to the literature by measuring how successful innovative activities in the transportation sector are in combating climate change.

3. Data and Methodology

In this study, we investigated the relationship between greenhouse gas emissions and innovation in transportation, trade openness and GDP in selected OECD countries. OECD countries panel group includes Australia, Austria, the United States, Canada, the United Kingdom, Germany, Denmark, Finland, the Republic of Korea, Switzerland, Netherlands and Sweden for which data was available. The data used in the study covers the years between 1999 and 2017. Table 1 represent the used variables, symbols of variables and source of data.

Table 1. Used Variables and Data Source

Variable	Abbreviation	Data Source
Greenhouse gas emission (Tranportation related)	lnghg	OECD
Patent numbers (CCMTs related to transportation)	lnpt	OECD
Trade openess (The sum of a country's exports and imports as a share of that country's GDP)	lnto	Our World in Data
GDP Per Capita	lnpc	World Bank

To represent the environmental effect, greenhouse gas emissions have been used, while as an indicator of innovation, transport-related patent numbers were used. Trade openness and GDP per capita are also considered as they are directly linked to the transportation sector. Therefore, these two variables were included in the analysis as control variables.

Table 2. Descriptive Statistics

Variable	Obs.	Mean	Std.Dev.	Min	Max
lnghg	228	10,978	1,400	9,292	14,444
lnpt	228	3,614	1,484	0	7,095
lnto	228	4,276	0,431	3,098	5,061
lnpc	228	10,702	0,287	9,662	11,363

Descriptive statistics of mean, maximum, minimum, and standard deviation of variables used in this study are taken part in Table 2. Utilizing the logarithm of the series transforms the variables into a linear form, thereby minimizing variance. Consequently, employing logarithms in the analysis of series with diverse fluctuations and substantial numerical values yields more convenient outcomes for econometric analyses. Therefore all variables have been used in logarithmic form. In this framework, the model used in the paper is constructed as below:

$$lnghg = \alpha_0 + \beta_1 lnpt_{it} + \beta_2 lnto_{it} + \beta_3 lnpc_{it} + \varepsilon_{it} \quad (1)$$

In this model, lnghg is the dependent variable while lnpt, lntr, and lnpc are independent variables. β represents the partial slope coefficient, εit is error term and α is the intercept.

In this study, firstly the Pesaran (2015) cross-sectional dependence test was used. According to the results of the cross-sectional dependence analysis, the use of first-generation or second-generation unit root tests and panel estimators was specified. In line with cross-sectional dependency test results CIPS unit root test that the second-generation unit root test (Pesaran, 2007) was applied. To detect the heterogeneity of the series, Pesaran and Yamagata (2008) Slope Homogenity Test was applied. To identify the long-run and short-run relationship among variables, the cross-sectional autoregressive distributed lags (CSARDL) estimator (Chudik and Pesaran, 2015) which allows working with series that are stationary at different levels and cross-sectional dependency was used. Also, for the purpose of testing the robustness of the CSARDL results, the second-generation panel model estimators were used to analyze the relationship between the variables in the long run. In this framework, the Mean Group (Pesaran and Smith, 1995), Augmented Mean Group (Eberhardt and Bond, 2009), and Common Correlated Effects Mean Group (Pesaran, 2006) estimators were applied.

4. Findings

Pesaran's (2015) cross-sectional dependency test was appropriate to detect the presence of cross-sectional dependence between the variables. According to the test results in Table 3, the hypothesis that there is no cross-sectional dependence between the data analyzed at a significance level of 1% for all variables, was rejected. Therefore, for analyzing the stationarity of the series a second-generation panel unit root test that eliminates the cross-sectional dependency problem was used.

Table 3. Pesaran (2015) Cross-sectional Dependence Test

	lnghg	lnpt	lnto	lnpc
CD	3.269***	22.763***	18.792***	32.577***

Note: *** refers 1% significance level.

Table 4. CIPS Unit Root Test Results

Variables	Constant		Constant and Trend	
	Level	**First Difference**	**Level**	**First Difference**
lnghg	- 1.087	- 3.109***	- 1.763	- 3.514***
lnpt	- 3.598***		- 3.644***	
lnto	- 1.904	- 3.272***	1.962	- 3.361***
lnpc	- 1.315	- 2.449***	- 1.188	- 2.769*

Note: *** and * refer to a significance level of 1% and %10 respectively.

In this framework, the results of the applied CIPS unit root test (Pesaran 2015) are in Table 4. According to the results of the CIPS unit root test in Table 4, it was found that lnghg, lnto and lnpc series were stationary at first differences i.e. I(1) while lnpt series was stationary at level i.e. I(0).

Table 5. Pesaran and Yamagata 2008 Slope Homogenity

	t stat	p value
$\tilde{\Delta}$	11.225***	0.000
$\tilde{\Delta}$adj	13.076***	0.000

Note: *** refers to a significance level of 1%.

According to the Delta heterogeneity test findings in Table 5, the H_0 hypothesis can be rejected at 1% significance level and the series exhibit heterogeneous properties.

Table 6. CS ARDL Estimation Results

Variable	Dependent Variable: lnghg				
	Long Run			**Short Run**	
	Cofficient / (Prob.)	**St.Errors / (T- Stat)**	**Variable**	**Cofficient / (Prob.)**	**St.Errors / (T- Stat)**
lnpt	0.0002943 (0.962)	0.0061177 (0.05)	**Δlnpt**	0.0013331 (0.896)	0.0102236 (0.13)
lntrd	0.0015757 (0.979)	0.0588444 (0.03)	**Δlntrd**	-0.0127137 (0.889)	0.0913343 (-0.14)
lnpc	0.3736831*** (0.000)	0.0700457 (5.33)	**Δlnpc**	0.5790555*** (0.000)	0.1228687 (4.71)
			Ect(-1)	-1.507113*** (0.000)	0.0627812 (-24.01)

Note: *** refers to a significance level of 1%.

In Table 6, the results of CS-ARDL estimation results are given. According to the CS-ARDL test results, no significant relationship was found between GHG and the number of transportation-related patents and trade openness in the short term and long term. Analysis results show that there is a positive relationship between GDP per capita and GHG. According to the coefficient estimates, a 1% increase in GDP per capita causes an increase of 0.57% in the short term and 0.37% in the long term. According to the results, the ECT which show the stability of the model, is statistically significant at the %1 significance level and its coefficient is negative (-1.507113) as expected. The fact that the error term coefficient is negative, statistically significant, and between -1 and -2 indicates that the system has reached equilibrium with gradually decreasing fluctuations in the long term (Alam and Quazi, 2003; Narayan and Smith, 2006; Karagöl et al. 2007; Hacıimamoğlu, 2023).

Table 7. Panel MG, AMG, CCEMG Estimation Results

Variables	MG Coefficients	AMG Coefficients	CCEMG Coefficients
lnpt	- 0.0018137	0.00645575	0.0015637
lntrd	- 0.0669059	0.0123082	0.0236089
lnpc	0.3826792 **	0.6672834 ***	0.5549773***

Note: *** and ** refers to a significance level of 1% and 5% respectively.

The results of Panel MG, AMG, and CCEMG estimation which made for the robustness check of CS-ARDL estimation results are included in Table 7. For all estimators, no significant relationship was found between GHG and trade openness and the number of transportation-related patents. According to MG, AMG and CCEMG coefficient estimates indicate 0,382%, 0.667%, and 0.554 positive correlation between GDP per capita and GHG, respectively. These test results which made for robustness correspond to CS-ARDL findings.

5. Conclusion

The transport sector is an important source of greenhouse gas emissions due to its energy consumption and fossil fuel use. These emissions, especially CO_2 emissions, contribute to global warming and climate change by increasing the greenhouse gas concentration in the atmosphere. The transportation sector, which consists of road, sea, air, and railway, is the second sector with the largest share in total GHG emissions with each component. Therefore, The transportation sector holds a significant role in addressing climate change.

Measures such as promoting sustainable and low-carbon transport systems, increasing energy efficiency, using alternative fuels, developing public transport networks and expanding green logistics practices help minimize the environmental footprint of the transport sector and be effective in combating climate change. With both global policy makers and academic studies, it is predicted that the most effective of these measures is technology-oriented struggle.

In the study, in order to investigate the reality of this prediction, the relationship between GHG (transport originating) and the number of patents (technology developed for climate change in the transport sector) was tested using 1999-2017 data of 12 selected OECD countries. Trade openness and per capita GDP, which are directly related to the transport sector, are other variables used in the analysis. According to the findings of all used estimators, no effect has been observed that transportation-related climate change mitigation patent numbers and trade openness affect GHG emissions. However, all estimators indicate that GDP positively impacts GHG emissions. This finding supports the studies of Mazzarino (2000), Fan and Lei (2016), Andrés and Padilla (2018), and Ghannouchi et al. (2023) who found a positive correlation between GDP growth and greenhouse gas emissions from transportation. As economies grow and develop, the volume of activities such as manufacturing, construction, tourism, and logistics increases, and accordingly, the need for both private and public transportation vehicles may increase. The result obtained from this study can similarly be interpreted as increasing economic growth in selected OECD countries causing an increase in transportation demand and, accordingly, increasing fuel consumption causing an increase in greenhouse gas emissions.

According to the result obtained from the study, technologies developed for combating climate do not have a mitigating effect on climate change. This result supports the study findings of Chapman (2007), Dechezleprêtre et al. (2013), and Raiser et al. (2017) in the literature. It can be thought that the use of patents has not become widespread, most of them have not yet started to be used in production methods, and therefore technology diffusion has not been fully realized. While green technologies are being produced on the one hand, and the demand for transportation is constantly increasing with the effect of globalization on the other, this may be the reason why the findings of the study are not compatible with the political predictions.

As a result, it has been revealed that it is insufficient to combat climate change by developing technology alone. In addition to the technology-oriented struggle, policy arrangements based on more holistic solutions are needed, such as encouraging the use of effective technologies, preventing the provision and use of environmentally harmful transportation services through taxation and other deterrent regulations, raising the awareness of society to use environmental technologies and encouraging the use of environmental technologies. Sustainable transportation will be able to achieve success with globally audited plans in which social solutions as well as technical solutions are adopted, cared for and sustained by all economic units.

Declaration of Research and Publication Ethics
This study which does not require ethics committee approval and/or legal/specific permission complies with the research and publication ethics.

Researcher's Contribution Rate Statement
The authors declare that they have contributed equally to the article.

Declaration of Researcher's Conflict of Interest
There is no potential conflicts of interest in this study.

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