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Effects of the Increase in Motor Vehicles on Environmental Protection Expenditures and Traffic Safety: An Examination Using Grey Incidence Analysis Method

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Abstract

Global environmental pollution is increasingly becoming one of today's most pressing issues, and the situation is becoming increasingly alarming day by day due to greenhouse gas emissions causing climate change. Industrialization and urban growth adversely affect the quality of air, water, and soil, reduce biological diversity, and endanger human health. In this regard, increasing and efficiently using environmental protection expenditures is a crucial criterion for reducing harmful emissions as well as achieving sustainable development goals. The increase in the number of motor vehicles has a significant impact on environmental protection expenditures. Exhaust gases from vehicles are one of the main causes of air pollution, which, especially in large cities, reduces air quality. Increasing air pollution causes health problems as well as environmental damage, forcing governments and local administrations to allocate more financial resources to improve air quality and reduce emissions. In this study, using data obtained from the Turkish Statistical Institute (TURKSTAT) for the period 2013-2022, grey relational grades of environmental protection expenditures, greenhouse gas emissions, and the number of road accidents according to the number of motor vehicles were calculated. It can be observed that the expenditure on environmental protection for motor vehicles, for which the grey-scale relationships have been separated, is approximately 78%. Additionally, the greenhouse gas emissions are approximately 95%, while the number of road accidents is approximately 98%.

Keywords Grey Relational Analysis, Motor Vehicles, Environmental Protection Expenditures, Greenhouse Gas

Jel Codes C6, C61, N7, N70

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1. Introduction

Environmental pollution is the process of degradation of air, water, and soil quality that results directly from human activities and harms the planet's ecosystems. Industrial waste, agricultural activities, and especially the burning of fossil fuels increase the number of harmful particles and gases in the atmosphere, triggering this pollution. Environmental protection expenditures are financial investments made by governments and the private sector to prevent, reduce, or reverse these damages. These expenditures include waste management, improvement of air and water quality, sustainable development projects, and environmental restoration projects. Greenhouse gas emissions, particularly gases such as carbon dioxide (CO_2), methane (CH_4), and nitrogen oxides (NO_x), cause global warming and climate change. A significant portion of these emissions originates from machines consuming fossil fuels, such as motor vehicles. The increase in motor vehicle usage not only contributes to air pollution and greenhouse gas emissions but also leads to noise pollution and waste problems. Consequently, this situation increases environmental protection expenditures and forces governments to reshape their environmental policies (Değirmenci & Aydın, 2020; Haftacı & Soylu, 2007).

Many studies have been conducted on environmental and economic issues. For instance, Kelen (2014) examined the effects of motor vehicle emissions on human health and the environment, detailing their contributions to air pollution, toxic properties, and control systems. The dynamic relationships between environmental protection expenditures, economic growth, and income inequality have been examined in numerous studies, with analyses presented on the impact of environmental protection expenditures on economic growth and their connections with income inequality for selected OECD countries (Değirmenci & Aydın, 2020; Haftacı & Soylu, 2007). Both studies emphasize the significant effects of environmental expenditures and policies on both human health and economic growth. In this transition, the complex relationships between environmental expenditures, economic growth, and income inequality are considered alongside studies on controlling motor vehicle emissions, demonstrating the interdependence between the environment and the economy. Additionally, it can be said that energy consumption has a statistically significant and positive effect on environmental pollution, while trade openness negatively affects environmental pollution. However, environmental protection expenditures do not have a statistically significant effect on environmental pollution. These results indicate that the effectiveness of environmental protection expenditures implemented at the regional level in Turkey needs to be increased (Recepoğlu, 2021).

On the other hand, in recent years, grey system theory has been widely used in many academic studies, and its importance is steadily increasing. The ability of this theory to handle uncertainty and incomplete information makes it a valuable tool in various disciplines. Especially in fields such as engineering, economics, environmental sciences, and social sciences, grey system theory provides effective results in the analysis of complex and uncertain systems. The flexible structure and practical applicability of grey system theory allow researchers to conduct more reliable and comprehensive analyses when working with incomplete or uncertain data. There are also many research articles where Grey Relational Analysis is used together with other methods, (Altıntaş, 2020; Özdemir & Kılıçarslan, 2021). For instance, for the year 2020, the significance levels of the Global Innovation Index components were determined for G7 countries within the scope of the ENTROPY method. Subsequently, the innovation performances of the countries were calculated using the ENTROPY-based Grey Relational Analysis method, and the ranking and scaling values of the calculated scores were compared with the countries' innovation performance rankings within the Global Innovation Index (Altıntaş, 2020). Therefore, grey system theory has become an important part of modern research and analysis methods. It is particularly frequently used in forecasting under uncertainty, optimization, and solving optimization problems, (Aydemir & Sahin, 2019; Aydemir & Turhan, 2022a; 2022b; Turhan & Aydemir, 2021; Şahin & Aydemir, 2019).

In this study, the effects of the number of motor vehicles on environmental protection expenditures, greenhouse gas emissions, and the number of road accidents were examined using the grey relational analysis method based on data provided by the Turkish Statistical Institute (TURKSTAT) for the period 2013-2022. Grey Relational Analysis (GIA) is a multi-criteria decision-making method that is particularly useful in situations where data is incomplete or uncertain. One of its distinguishing features compared to other methods is its ability to be applied in scenarios with limited or ambiguous information, making it advantageous for analyzing complex and dynamic systems. But in highly complex problems with numerous criteria, GIA may fall short compared to more sophisticated methods (Dang et al., 2020; Du et al., 2021; Javanmardi et al., 2020).

This study consists of four main sections. The first section covers the significance of the study and other important research related to the topic in the literature. The second section provides a detailed explanation of the application steps of the method used in the study, along with its advantages and disadvantages. In the results section, tables consisting of real data were created. The grey relational degrees between environmental protection expenditures, greenhouse gas emissions, and the number of road accidents, according to the number of motor vehicles, were calculated. The results obtained here are original. Finally, in the discussion section, the results were interpreted, and solution suggestions were derived.

2. Methodology

2.1. Grey Incidence Analysis (GIA)

Grey Incidence Analysis (GIA), also known as Grey Relations Analysis, was developed by Prof. Dr. Julong Deng from Huazhong University of Science and Technology. It is one of the most widely used models within grey system theory. GIA utilizes a specific concept of information, defining situations with no information as black and those with perfect information as white. The procedure of grey incidence analysis is given as follows for n observation data on m sequences (Deng, 1989; Lin & Wu, 2011; Liu et al., 2011; Zhai et al., 2009):

Step 1: To begin, establish the initial pattern (or average pattern) for each sequence. This involves determining the baseline or typical behavior of the data within each sequence, which serves as a reference point for further analysis.

$$X_1' = \frac{X_i}{x_i(1)} = ((x_i')(1), (x_i')(2), ..., (x_i')(n)), k = 0, 1, 2, ..., n \tag{1}$$

Step 2: Find the absolute difference sequences. This involves calculating how much each data point deviates from the established initial or average pattern. By determining these differences, it becomes easier to analyze the variations and similarities between the sequences.

$$\Delta_i(k) = |x_0'(k) - x_i'(k)| \tag{2}$$

$$\Delta_i = (\Delta_i(1), \Delta_i(2), ..., \Delta_i(n)), i = 0, 1, 2, ..., m \tag{3}$$

Step 3: Calculate the maximum and minimum differences for each sequence. This means identifying the highest and lowest values of the deviations from the initial or average pattern. By determining these extremes, you can better understand the range and variability within the data sequences.

$$M = \Delta_i(k) \tag{4}$$

$$m = \Delta_i(k) \tag{5}$$

Step 4: Find the grey incidence coefficients for each sequence. This process involves determining the specific values that quantify the relationship between each sequence and the reference pattern, which is essential for assessing their degree of similarity according to grey incidence analysis.

$$\gamma_{0i}(k) = \frac{m + \zeta M}{\Delta_i(k) + \zeta M}, \zeta \in (0, 1) \tag{6}$$

Here $k = 1, 2, ..., n$ and $i = 1, 2, ..., m$. Also, ζ is a coefficient that takes a value between 0 and 1 and is usually taken as 0.5.

Step 5: Calculate the grey incidence degrees for each sequence. This involves determining the extent to which each sequence is related to the reference pattern, providing a measure of their similarity based on the grey incidence analysis methodology.

$$\gamma_{0i} = \frac{1}{n}\sum_{k=1}^{n} \gamma_{0i}(k), i = 0, 1, 2, ..., m \tag{7}$$

The generalized grey incidence analysis model also receives much attention from the researchers about the advantages of practical calculations and easily applied the large number of research problems (Şahin & Aydemir, 2019). In this study, using the number of motor vehicles as a reference, the degree of closeness and similarity of this parameter to the parameters of environmental protection expenditures, greenhouse gas emissions and the number of road accidents was calculated using a quantitative method.

3. Results

It is known that motor vehicles are an important factor in the formation of many environmental and safety problems. Today, as the number of motor vehicles increases year by year, even day by day, many environmental and safety problems are also increasing at the same speed and rate. The data used in this study covers the period 2013-2022. The tables consist of data on the number of motor vehicles, environmental protection expenditures, greenhouse gas emissions and the number of road accidents. Table 1 consisting of data for the period considered is given below.

Table 1. Raw data table for the period 2013-2022

Year	Indicator			
	Number of Motor Vehicles	Environmental Protection (TL)	Greenhouse Gas Emission (CO_2 equivalent) (Million Tons)	Numbers of Road Accidents
2013	17939447.00	21110986662.00	440.20	1207354.00
2014	18828721.00	24262138313.00	459.49	1199010.00
2015	19994472.00	25201923514.00	474.97	1313359.00
2016	21090424.00	27402904608.00	501.11	1182491.00
2017	22218945.00	34195697085.26	528.57	1202716.00
2018	22865921.00	38034278922.19	523.11	1229364.00
2019	23156975.00	38293841616.83	508.73	1668144.00
2020	24144857.00	41842976016.51	523.99	983808.00
2021	25249119.00	66361965015.31	564.39	1186353.00
2022	26482847.00	140256537760.73	502.73	1232957.00

As can be seen from the Table 1, there are huge differences in numerical values between the data to be used for the parameters discussed. In order to eliminate these differences and obtain more meaningful results, standardization was first carried out. For this purpose, Eq. 1, Eq. 2 and Eq. 3 given above was used. The tables of the initial pattern obtained from the calculations and the absolute difference series created based on the pattern are given below, respectively.

Table 2. Initial pattern table created for the period 2013-2022

Year	Indicator			
	Number of Motor Vehicles	Environmental Protection (TL)	Greenhouse Gas Emission (CO_2 equivalent) (Million Tons)	Numbers of Road Accidents
2013	1.00000	1.00000	1.00000	1.00000
2014	1.04957	1.14927	1.04383	0.99309
2015	1.11455	1.19852	1.07899	1.0878
2016	1.17565	1.29804	1.13838	0.97941
2017	1.23855	1.61981	1.20075	0.99616
2018	1.27462	1.80163	1.18835	1.01823
2019	1.29084	1.81393	1.15568	0.96752
2020	1.34591	1.98205	1.19036	0.81485
2021	1.40746	3.14348	1.28213	0.98261
2022	1.47624	6.64377	1.14205	1.02121

Table 3. Absolute difference series table created for the period 2013-2022

Year	Indicator			
	Number of Motor Vehicles	Environmental Protection (TL)	Greenhouse Gas Emission (CO2 equivalent) (Million Tons)	Numbers of Road Accidents
2013	0.00000	0.00000	0.00000	0.00000
2014	0.00000	0.14927	0.04383	0.00691
2015	0.00000	0.19852	0.07899	0.08780
2016	0.00000	0.29804	0.13838	0.02059
2017	0.00000	0.61981	0.20075	0.00384
2018	0.00000	0.80163	0.18835	0.01823
2019	0.00000	0.81393	0.15568	0.03248
2020	0.00000	0.98205	0.19036	0.18515
2021	0.00000	2.14348	0.28213	0.01739
2022	0.00000	5.64377	0.14205	0.02121

Then, the minimum and maximum values of absolute differences are gotten from the Table 3. Also, the grey incidence coefficients are obtained with using the Eq. 6 and the results are given as Table 4 in detail for the period 2013-2022.

Table 4. Grey incidence coefficients of sectors for the period 2013-2022

Year	Indicator			
	Number of Motor Vehicles	Environmental Protection (TL)	Greenhouse Gas Emission (CO2 equivalent) (Million Tons)	Numbers of Road Accidents
2013	0.00000	1.00000	1.00000	1.00000
2014	0.00000	0.94976	0.98471	0.99756
2015	0.00000	0.93427	0.97277	0.96983
2016	0.00000	0.90447	0.95326	0.99276
2017	0.00000	0.81991	0.93358	0.99864
2018	0.00000	0.77877	0.93743	0.99358
2019	0.00000	0.77614	0.94771	0.98862
2020	0.00000	0.74183	0.9368	0.93843
2021	0.00000	0.56831	0.90911	0.99387
2022	0.00000	0.33333	0.95207	0.99254

Lastly, the grey incidence degrees are calculated by using the grey incidence coefficients averagely for each sector and it is given as Table 5 with the period 2013-2022. Eq. 7 was used to calculate these coefficients.

Table 5. Results of grey incidence degrees (GID)

Indicator	GID
Number of Motor Vehicles	0.00000
Environmental Protection (TL)	0,78068
Greenhouse Gas Emission (CO2 equivalent) (Million Tons)	0,95274
Numbers of Road Accidents	0,98658

Considering the obtained coefficients;

i. Environmental protection expenditures have a moderate relationship with the number of motor vehicles. This shows that the number of motor vehicles may affect environmental protection expenditures or that these expenditures are aimed at reducing the environmental impacts caused by motor vehicles. For example, increasing the number of vehicles may lead to increased environmental protection measures and budgets.

ii. Greenhouse gas emissions have a strong relationship with the number of motor vehicles. This high GID value indicates that motor vehicles are an important source of greenhouse gas emissions. Increasing the number of vehicles also causes the number of emissions to increase. This indicates that policies to reduce greenhouse gas emissions should also take into account the number and use of motor vehicles.

iii. Traffic accidents have a very strong relationship with the number of motor vehicles. This very high GID value shows that traffic accidents may increase with the increase in the number of motor vehicles. This situation indicates that traffic safety measures and training should be increased. The increase in the number of motor vehicles may require improvements in road infrastructure and traffic regulations.

In this study, the grey relational degrees between environmental protection expenditures, greenhouse gas emissions, and the number of road accidents were presented in relation to the number of motor vehicles. The significance levels of the variables addressed here can be calculated using the ENTROPY method, and the performance of the variables can be ranked again using the ENTROPY-based Grey Relational Analysis method.

4. Discussion

According to the analysis results, the relationship between the number of motor vehicles and environmental protection expenditures was calculated to be approximately 78%. This finding indicates that the increase in motor vehicle usage triggers environmental issues such as air pollution and waste management, necessitating more financial resources to be allocated by the government and local authorities for environmental protection and improvement efforts. Additionally, the relationship between the number of motor vehicles and greenhouse gas emissions was determined to be 95%, indicating that a large portion of emissions from fossil fuel combustion is due to motor vehicles. This significantly contributes to environmental threats such as global warming and climate change. Finally, the relationship between the number of motor vehicles and the number of road accidents was calculated to be 98%.

The analysis results show that the number of motor vehicles has significant effects on environmental and safety components. In particular, greenhouse gas emissions and traffic accidents have a strong relationship with the number of motor vehicles. Environmental protection expenditures show a moderate relationship. With these findings, the following suggestions can be offered;

i. Considering that environmental impacts increase with the increase in the number of motor vehicles, environmental protection measures and expenditures need to be increased. It is especially important to encourage low-emission and electric vehicles.
ii. Considering that motor vehicles contribute significantly to greenhouse gas emissions, strategies to reduce these emissions should be developed. These strategies may include measures such as controlling the number of vehicles and using clean energy sources.
iii. Traffic safety should be increased, taking into account the effect of the number of motor vehicles on traffic accidents. In this context, road infrastructure should be improved, traffic regulations should be made more effective and driver training should be increased.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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