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Evaluation of Energy Efficiency in Transportation Sector with Analytic Hierarchy Process

Merve EYÜBOĞLU[1]*, Nuriye KABAKUŞ[2]

[1]Atatürk University, Graduate School of Natural and Applied Sciences, 25240 Erzurum, Türkiye

[2]Atatürk University, Faculty of Applied Sciences, 25240 Erzurum, Türkiye

*Sorumlu Yazar/Corresponding Author
E-mail: merve.eyuboglu95@gmail.com

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ABSTRACT

Transportation is a sector of increasing importance between energy efficiency and production. Increasing the energy efficiency of this sector and effectively reducing energy consumption, which forms the economic building blocks of countries, is considered a critical step for the protection of the natural environment. The role of transportation in energy saving and alternative energy technologies in the creation of environmentally friendly cities is the main focus of this study. The aim of the study is to examine the effects of energy efficiency in the transportation sector, to identify the factors affecting energy efficiency and to offer solutions to them. Within the scope of the study, five main criteria were examined: CO_2 emissions, energy consumption, gross domestic product (GDP), crude oil barrel price and fuel consumption. These criteria have a wide range of impacts, from human health to the world economy. The relationships and importance levels between the criteria were weighted using the Analytic Hierarchy Process (AHP). It has been shown that energy consumption in the transportation sector increases CO_2 emissions by negatively affecting the environmental impacts, and at the same time, the increase in the barrel price of crude oil reduces CO_2 emissions. It has been observed that today's technology is looking for alternative energy sources because fuel consumption affects energy consumption and CO_2 emissions. A good GDP indicates the existence of a green environment with low emissions and low energy consumption. As a result, it was determined that CO_2 emissions and energy consumption were the most important criteria.

Keywords: Transportation, Energy efficiency, CO_2 emission release, Green environment, AHP.

Ulaşım Sektöründeki Enerji Verimliliğinin Analitik Hiyerarşi Prosesi ile Değerlendirilmesi

ÖZ

Ulaşım, enerji verimliliği ve üretimi arasında önemi giderek artan bir sektördür. Bu sektörün enerji verimliliğini artırmak, ülkelerin ekonomik yapı taşlarını oluşturan enerji tüketimini etkili bir şekilde düşürmek, doğal çevrenin korunması için kritik bir adım olarak kabul edilmektedir. Ulaşımın, çevre dostu kentlerin oluşturulmasında enerji tasarrufu ve alternatif enerji teknolojileri konularında oynadığı rol, bu çalışmanın ana odak noktasını oluşturmaktadır. Çalışmanın amacı, enerji verimliliğinin ulaşım sektöründeki etkilerini incelemek, enerji verimliliğini etkileyen faktörleri saptamak ve bunlara çözüm önerileri sunmaktır. Çalışma kapsamında, CO_2 emisyon salınımı, enerji tüketimi, gayri safi yurt içi hasıla (GSYİH), ham petrol varil fiyatı ve yakıt tüketimi olmak üzere beş ana kriter incelenmiştir. Bu kriterler, insan sağlığından dünya ekonomisine kadar geniş bir etki yelpazesine sahiptir. Kriterler arasındaki ilişkiler ve önem dereceleri, Analitik Hiyerarşi Prosesi (AHP) kullanılarak ağırlıklandırılmıştır. Ulaşım sektöründeki enerji tüketiminin, çevresel etkileri negatif yönde etkileyerek CO_2 emisyonunu artırdığını, aynı zamanda ham petrolün varil fiyatındaki artışın ise CO_2 emisyon salınımını azalttığını göstermiştir. Yakıt tüketiminin, enerji tüketimi ve CO_2 emisyonunu etkilemesi nedeniyle, günümüz teknolojisinin alternatif enerji kaynakları arayışına girdiği gözlemlenmiştir. GSYİH nin iyi olması, düşük emisyonlu ve düşük enerji tüketimli bir yeşil çevrenin varlığını işaret etmektedir. Sonuç olarak, CO_2 emisyon salınımı ve enerji tüketiminin en önemli kriterler olduğu saptanmıştır

Anahtar Kelimeler: Ulaşım, Enerji verimliliği, CO_2 emisyon salınımı, Yeşil çevre, AHP.

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1. Introduction

The transportation sector and energy efficiency issues are becoming increasingly important today. Since the transportation sector accounts for approximately 30% of energy consumption worldwide, reducing energy consumption in this sector plays an important role in global energy consumption (Işık and Kılıç, 2014). For this purpose, there are many different methods such as turning to renewable energy sources, increasing energy efficiency, and using vehicles that consume less energy. For example, considering that fossil fuels will run out, the trend towards alternative fuels has increased. In addition, the increase in oil prices and foreign dependency negatively affect countries. For this reason, electric vehicles consume less energy and are more environmentally friendly than fossil fuel vehicles. The implementation of these methods will help increase energy efficiency in the transportation sector.

The release of carbon dioxide emissions has significant impacts on climate change. Reducing these emissions, which cause air pollution, benefits the environment and supports social and economic progress. In addition, research shows that reducing energy consumption in the transportation sector will prevent undesirable consequences such as global warming and ozone depletion. Therefore, energy consumption in transportation plays an important role in global energy consumption.

Uçar and Çoban (2023) estimated 4 different transportation models based on CO_2 emissions and energy using the Generalized Moments method. They observed that increases in oil prices reduce emissions, increased energy consumption increases emissions and economic growth increases emissions. Ağaoğlu and Başdemir (2019) developed transportation problems in cities and solutions to these problems according to their study. They aimed for a more sustainable transportation by classifying public transportation systems. In his study, Yılmaz (2005) presented ideas and suggestions for the use of alternative energy and energy saving, the depletion of fossil fuels and the creation of green cities that aim to protect the natural environment. Dinçer and Karakuş (2020) examined the negative effects of crude oil on the economy. In their study, Bayrakçeken and Kuş (2006) mentioned the existence of alternative fuels due to the depletion of oil reserves. They mentioned the positive effects of these alternative fuels to be used in motor vehicles in both environmental and economic terms. Yetişkul and Şenbil (2010) discussed the factors affecting energy efficiency in urban transportation in their study. They mentioned the negativity of the increase in fuel costs and the benefits of using public transportation in terms of emission emissions. According to Özdemir et al. (2021), they mentioned the necessity of gasoline and diesel fuel vehicles for a green environment and transportation and considered the number of vehicles, traffic accidents, and the distribution of fuel types as criteria.

Tzeng et al. (2005) focused on the advantages of alternative fuel vehicles on emission emissions using multi-criteria decision making (MCDM). Solovieva et al. (2022) explained the impacts of developing electric transportation globally. It includes trends that support people's quality of life and comfort in the field of transportation, assessing the problems and possible solutions related to the development of electric vehicles in Kuban. They mentioned that although there are factors that hinder development, if the necessary investments are made to create the infrastructure for electric vehicles, there will be radical changes in transportation in the long term. Geng et al. (2020) wanted to conduct a demographic analysis of green transportation in China. In the study, they analyzed the variability of demographic phenomena such as household income, gender and age by considering parking fees, fuel tax and traffic congestion. Lutsey and Sperling (2008) developed three different strategies such as vehicle efficiency, low-carbon fuels and travel reduction to reduce the increasing greenhouse gases. The development of these strategies has been observed to provide benefits in terms of

greenhouse gas reduction, energy cost savings and oil security.

This study examines the effects of energy efficiency in the transportation sector with AHP by using the criteria of CO_2 emission, gross domestic product (GDP), energy consumption, crude oil barrel price and fuel consumption. According to the reviews in the literature, the fact that there are not many studies on this subject is of great importance in its preference. It differs from other studies in terms of examining the relationship between the selected criteria, comparing and ranking their superiorities. Today, energy consumption is becoming an increasingly important problem. In order to minimize energy consumption, the necessary problems should be formed and progress should be made in line with the problems. For this reason, the criteria that will reduce energy consumption and increase efficiency in the field of transportation are important in the study.

This study aims to identify the factors affecting energy efficiency on a global scale, to examine the effects of energy efficiency and to offer solutions to them. By acting in the light of these solutions, it is thought that there will be a positive transition from energy consumption in the transportation sector, which will have positive results in terms of efficiency.

2. Material and Method

2.1. Material

The data set used in the research includes five different criteria: CO_2 emissions, GDP, energy consumption, crude oil barrel price and fuel consumption (Figure 1). These criteria play an active role, especially in the fields of transportation and energy efficiency and are also of great importance in terms of green environment. When the studies conducted to examine the relationship between transportation and energy are examined, it is seen that energy consumption, CO_2 emissions, fuel consumption, oil price and GDP are used as criteria. After the literature review, it was concluded that collecting these criteria in one study would provide more comprehensive information. For this reason, the criteria were selected within the social, environmental and economic framework. CO_2 emissions are known to cause air pollution. Therefore, it affects human health and psychology socially and environmentally due to climate change. There is a linear relationship between energy consumption and fuel consumption and CO_2 emissions. Therefore, the same factors are also at play here. The increase in the price of crude oil and the GDP have shown their presence in the study of economic perspective. The relationship between these criteria and transportation is briefly explained under the following headings.

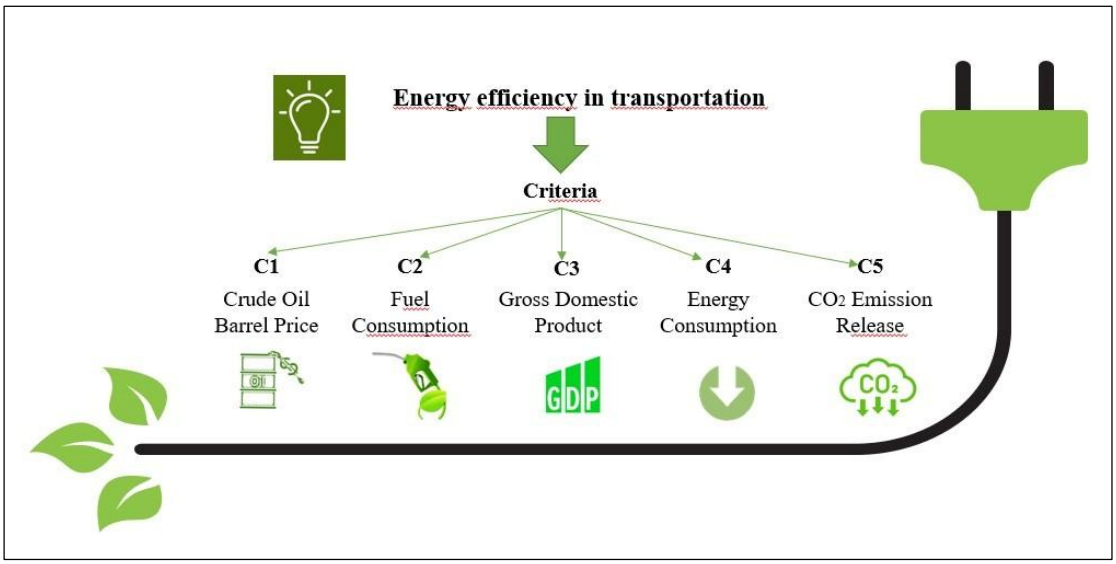

Figure 1. Criteria used in this study

2.1.1. CO_2 Emission Release

The transportation sector is one of the main sectors that cause the emission of CO_2 gas. The continuous increase in logistics and passenger traffic has also increased CO_2 emissions and triggered global warming due to its heat retention properties (Eyüboğlu, 2023). Reducing CO_2 emissions, which have been increasing in recent years, plays a major positive role on air pollution and climate change. There is a positive and significant relationship between energy consumption and CO_2. As the share of renewable energy in energy production increases, the reduction of CO_2 emissions will decrease at the same rate.

2.1.2. Energy Consumption

Energy has an important role in the economic and environmental development processes of countries and has a wide range of uses in all sectors (Güvenek and Alptekin, 2010). As of 1970, energy consumption started to increase in Turkey and became more important after the 1980s due to population growth, industrialization, and development and change in transportation (Bulut, 2020). The demand for renewable energy has increased to prevent pollution of the environment due to CO_2 emissions. Energy consumption, which is a determining factor in the economic progress of countries, is carried out intensively in the transportation sector and this energy consumption is directly proportional to the development of countries**.**

2.1.3 Gross Domestic Product (GDP)

GDP is useful for analyzing the current situation of each country at the national and international levels (Aguado and Martinez, 2012). Energy consumption in the transportation sector, consumption of fuels by type and the price per barrel of crude oil show a parallel relationship with GDP at the economic level. The better the economic income level of countries, the lower the energy consumption for a green environment, and hence the lower the CO_2 emissions. The GDP of oil-exporting countries will grow more and more.

2.1.4. Crude Oil Barrel Price

Energy resources are recognized as one of the basic components in the formation and shaping of economic life. Energy is used in many areas such as transportation, housing and industry. It is possible for countries to obtain energy from different energy sources. These sources are categorized into two classes as renewable and non-renewable energy sources. Oil is one of the non-renewable energy sources (Dinçer and Karakuş, 2020). Petroleum means oil and rock, and crude oil refers to the unprocessed form of oil (Kablamacı, 2008). Since oil is not equally distributed all over the world, countries that cannot produce oil usually import it. Accordingly, increases in oil prices adversely affect oil importing countries. On the other hand, oil exporting countries are positively affected in this sense (Yüksel et al., 2020). For the economic development of countries, macroeconomic factors such as GDP, employment and balance of payment, and increases in oil prices are considered to have important effects on the barrel price of crude oil.

2.1.5. Fuel Consumption

Increasing population, developing urbanization and the desire to provide people's comfort zone have increased the number of vehicles used day by day. For this reason, it has led to energy consumption, especially petroleum products. Fossil fuels are the most widely used fuel type in transportation today as the primary energy source (about 85%) (URL-1, 2019). When the current CO_2 emission status of gasoline and diesel use is examined, it is seen that it is very harmful to the environment (Özbay et al., 2020). In many studies, some applications have been tried to improve fuel consumption, noise pollution, CO_2 emissions of internal combustion engines (Patel et al., 2016; Ahmed et al., 2020). Increasing fuel consumption has led people to search for alternative fuels, and fuels such as biofuels, compressed natural gas (CNG), liquefied petroleum gas (LPG), which support global transportation energies, have started to be

consumed in contrast to petroleum-based fuels (Naik et al., 2016).

2.2. Method

The MCDM method was applied to the criteria determined to examine the effects of energy efficiency in the transportation sector. Among the MCDM methods, AHP was chosen and Microsoft Excel software was used for analysis. For the AHP superiority matrix, a literature review and the opinions of experts (a group of 5 academicians and 5 civil engineers) were utilized.

2.2.1 Analytic Hierarchy Process (AHP)

AHP is a general measurement theory defined by Saaty and is a multi-criteria decision-making method that determines superiority over each other based on a pairwise comparison of criteria. This method enables the determination of priorities among criteria, alternatives and criteria. AHP is an effective decision-making method especially when there are unquantifiable situations and is suitable for solving problems where decision criteria can be organized into sub-criteria in a hierarchical manner (Önder, 2014). This method is one of the most widely used methods today. Among the reasons why it is preferred more than other methods used in the literature; its simplicity, good reliability, minimal mathematical operations and mixed data types are shown. The advantages of the AHP method are that it examines the criteria and relationships in a hierarchical structure, examines the decision problem in a structured way, integrates personal opinions and transforms the choice into a logical process (Cucchiella, 2017). In the AHP method, the objective is first determined and then the criteria and sub-criteria affecting this objective are determined. According to the degree of importance in Table 1, each criterion is compared among themselves and their relative status is found.

Step 1: The criteria that play an active role for a green environment in the transportation and energy network are identified and the solution algorithm is developed.

Step 2: In this step, the comparative advantage matrix is created.

Step 3: In this step, the comparative advantage matrix is normalized.

Step 4: In this step, the criteria weights are calculated. Criteria weights are obtained by averaging the column of the normalized matrix.

Step 5: In this step, the initial matrices are multiplied by the criterion weights to create a new matrix and then the rows are summed to obtain a sum column. This sum is used to calculate the consistency index.

Then the eigenvector value of each criterion in the whole is found and the consistency ratio is checked. The consistency ratio is obtained by dividing the Consistency Index by the Random Index value. Random Index values are given in Table 2.

Table 1. Comparison Scale Recommended by Saaty (Saaty, 2008)

Importance	Definition	Description
1	Of equal importance	Both options are of equal importance.
2	Weak or light	
3	Somewhat important	One criterion is considered slightly more important than the other.
4	Reasonable plus	
5	Too important	One criterion is considered much more important than the other.
6	Strong plus	
7	Too many important	One criterion is definitely more important than the other criterion.
8	Very, very powerful	
9	Extremely important	One criterion is considered extremely important compared to the other based on various information.

Then the eigenvector value of each criterion in the whole is found and the consistency ratio is checked. The consistency ratio is obtained by dividing the Consistency Index by the Random Index value. Random Index values are given in Table 2.

Table 2. RI Values Defined for Comparison Matrices (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53	1.56	1.57	1.59

Step 6: In this step, λ_{max} is calculated.

Step 7: In this step, the consistency ratio is checked.

In this study, AHP method is preferred because it is one of the widely used MCDM. Since the AHP method is a linear weighted method that can also affect concepts that may be involved in the decision-making process such as individuals' preferences, knowledge, experience and thoughts, it has been effectively useful in this study.

3. Results and Discussion

There are 5 determining criteria that we consider in this study. Our criteria consist of CO_2 emissions, energy consumption, GDP, fuel consumption and barrel price indices of crude oil. Determining criterion weights is an important step in solving decision-making problems. In the study, the criteria were weighted using the AHP.

A matrix was created with the criteria compared between 1-9 according to the Saaty scale. Since there is no superiority of the same criteria over each other, it is 1 (Table 3).

$a_{11}=1, a_{22=1}, a_{33}=1, a_{44}=1, a_{55}=1$ **(1)**

$a_{21}=3, a_{12}=1/3=0.333$ **(2)**

$a_{31}=5, a_{13}=1/5=0.200$ **(3)**

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$a_{51}=9, a_{15}=1/9=0.111$ **(4)**

$\Sigma C1= (1+3+5+9+9) =27$ **(5)**

$\Sigma C2= (0.333+1+3+5+5) =14.333$ **(6)**

$\Sigma C3= (0.200+0.333+1+5+5) = 11.533$ **(7)**

$\Sigma C4= (0.111+0.200+0.200+1+1) =2.511$ **(8)**

$\Sigma C5= (0.111+0.200+0.200+1+1) =2.511$ **(9)**

Normalization;

$$a_{ij}'=\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad \textbf{(10)}$$

i,j=1,2,….,n was done with this equation (10). Each matrix was divided by the sum of the columns obtained in the previous step and normalized in this way (Table 4).

Table 3. Comparative advantage matrix

	C1	**C2**	**C3**	**C4**	**C5**
C1	1	0.333	0.200	0.111	0.111
C2	3	1	0.333	0.200	0.200
C3	5	3	1	0.200	0.200
C4	9	5	5	1	1
C5	9	5	5	1	1

Table 4. Normalized matrix by AHP analysis

	C1	**C2**	**C3**	**C4**	**C5**
C1	0.037	0.023	0.017	0.044	0.044
C2	0.111	0.070	0.029	0.080	0.080
C3	0.185	0.209	0.087	0.080	0.080
C4	0.333	0.349	0.434	0.398	0.398
C5	0.333	0.349	0.434	0.398	0.398

$$a'_{11}=\frac{a_{11}}{\sum K1}=\frac{1}{27}=0.037,\ldots\ldots\ldots,\ a'_{15}=\frac{a_{51}}{\sum K5}=\frac{0.111}{2.511}=0.044 \quad \textbf{(11)}$$

$$a'_{21}=\frac{a_{21}}{\sum K2}=\frac{3}{27}=0.111,\ldots\ldots\ldots,\ a'_{25}=\frac{a_{52}}{\sum K5}=\frac{0.200}{2.511}=0.080 \quad \textbf{(12)}$$

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$$a'_{51}=\frac{a_{81}}{\sum K1}=\frac{9}{27}=0.333,\ldots\ldots\ldots,\ a'_{55}=\frac{a_{55}}{\sum K5}=\frac{1}{2.511}=0.398 \quad \textbf{(13)}$$

After normalization with AHP, criteria weights were calculated with the average of each row (Table 5).

$$\bar{x}_{C1}=\frac{(0.037+0.023+0.017+0.044+0.044)}{5}=0.033 \quad \textbf{(14)}$$

$$\bar{x}_{C2}=\frac{(0.111+0.070+0.029+0.080+0.080)}{5}=0.074 \quad \textbf{(15)}$$

$$\bar{x}_{C3}=\frac{(0.185+0.209+0.087+0.080+0.080)}{5}=0.128 \quad \textbf{(16)}$$

$$\bar{x}_{C4}=\frac{(0.333+0.349+0.434+0.398+0.398)}{5}=0.382 \quad \textbf{(17)}$$

$$\bar{x}_{C5}=\frac{(0.333+0.349+0.434+0.398+0.398)}{5}=0.382 \quad \textbf{(18)}$$

The sum of the criteria weights should be 1.

$$\bar{x}_{C}=(0.033+0.074+0.128+0.382+0.382)=1 \quad \textbf{(19)}$$

Table 5. Criterion weights obtained by AHP analysis

	C1	C2	C3	C4	C5	Criteria Weights
C1	0.037	0.023	0.017	0.044	0.044	0.033
C2	0.111	0.070	0.029	0.080	0.080	0.074
C3	0.185	0.209	0.087	0.080	0.080	0.128
C4	0.333	0.349	0.434	0.398	0.398	0.382
C5	0.333	0.349	0.434	0.398	0.398	0.382

$$A \times W = \begin{bmatrix} 1 & 0.333 & \dots & 0.111 \\ 3 & 1 & \dots & 0.200 \\ \vdots & \vdots & \vdots & \vdots \\ 9 & 5 & \dots & 1 \end{bmatrix} \times \begin{bmatrix} 0.033 \\ 0.074 \\ \vdots \\ 0.382 \end{bmatrix} = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix} \quad \textbf{(20)}$$

A new matrix was obtained by multiplying each matrix with the criteria weights. Each row of this newly created matrix was summed and the total column was found (Table 6).

Table 6. Multiplying each matrix with criterion weights in AHP and obtaining the total column

	C1	C2	C3	C4	C5	Total
C1	0.033	0.025	0.026	0.042	0.042	0.168
C2	0.100	0.074	0.043	0.076	0.076	0.369
C3	0.166	0.221	0.128	0.076	0.076	0.669
C4	0.299	0.369	0.640	0.382	0.382	2.073
C5	0.299	0.369	0.640	0.382	0.382	2.073

$$\lambda_{max}=\frac{(5.069+5.001+5.220+5.422+5.422)}{5}=5.227 \quad \textbf{(21)}$$

λ_{max} was calculated by dividing the calculated total column by the criteria weights (Table 7).

$$CI=\frac{\lambda max-n}{n-1}=\frac{5.227-5}{4}=0.057 \quad \textbf{(22)}$$

$$CR=\frac{CI}{RI}=\frac{0.057}{1.12}=0.051 \quad \textbf{(23)}$$

The CI value was calculated with the equation given in this step. After this value was found, the consistency ratio was obtained by dividing the Consistency Index by the Random Index value with the CR equation. Random Index values are shown in Table 2. In the table, the Random Index value corresponds to the number of each criterion and it is seen that the Random Index value for 5 criteria is 1.12. What is important here is that the CR value is less than 0.10. If this value is less than 0.10; the problem solution is considered to be consistent. If the opposite is the case, the problem solution is considered to be inconsistent and the steps are started again by going back to the beginning until this value is met. As a result of the study, since our consistency ratio is less than 0.10, the problem solution is accepted. When AHP analysis was applied to the criteria that have an impact on energy efficiency in the transportation sector, the criteria weights were calculated as 0.033 for C1, 0.074 for C2, 0.128 for C3, 0.382 for C4 and C5 (Table 5). According to this analysis, C4 and C5 were found to be the criteria

with the highest level of importance. According to the level of importance, C3, C2 and C1 come next. It is seen that C4 and C5 are the main criteria of the transportation and energy relationship.

Table 7. Calculating λ_{max} with AHP analysis

	Total	Criteria Weights	T/CW	λ_{max}
C1	0.168	0.033	5.069	5.227
C2	0.369	0.074	5.001	
C3	0.669	0.128	5.220	
C4	2.073	0.382	5.422	
C5	2.073	0.382	5.422	

When the literature is examined, although there are studies with different methods and criteria that include transportation and energy efficiency, there is no study using the criteria affecting energy efficiency using MCDM. The criteria used in the literature are important in terms of transportation and energy efficiency concepts, but they are not sufficient. This study examines and discusses the important role of energy efficiency of the transportation sector on environmental protection by increasing the number of criteria. Increasing the energy efficiency and reducing the energy consumption of the transportation sector is considered as a critical step to reduce energy consumption, which is the economic building blocks of countries. Our findings show that energy consumption in the transportation sector increases CO_2 emissions, which negatively affects environmental impacts. However, an increase in the price of a barrel of crude oil was found to reduce CO_2 emissions. This emphasizes the importance of turning to alternative energy sources when oil prices rise. Furthermore, this study reveals that today's technology is in search of alternative energy sources and this search helps to reduce fuel consumption and CO_2 emissions. These findings highlight the need for technological innovations and policy measures to improve energy efficiency in the transportation sector. In addition, this study shows that environmentally sound growth of a country's GDP indicates the existence of an environmentally friendly environment with low emissions and low energy consumption. Therefore, policy makers and industry need to act in cooperation to ensure environmental sustainability while maintaining economic growth. As a result, CO_2 emissions and energy consumption have been identified as key criteria for measuring and improving energy efficiency in the transportation sector. Based on these criteria, policy makers and industry leaders should promote environmentally friendly practices in the transportation sector by promoting alternative energy sources, supporting technological innovation and implementing policy measures that improve efficiency. However, this study has some limitations and suggestions for future research. First, the scope of this study is not focused on a specific geographical region or country. Future research could obtain more comprehensive results by examining the differences of transportation systems in different regions and countries, increasing the number of criteria. In addition, how renewable energy sources can be more widely used in the transportation sector, how this can contribute to environmental impacts and effective policy measures can be examined. Taking these limitations into account, we believe that future research will help us to understand more deeply the impacts of energy efficiency in the transportation sector and to develop effective policies-practices for more sustainable transportation systems.

Consequently, future studies can examine the impacts of the widespread use of new technologies in the transportation sector on environmental sustainability, as well as more comprehensively address the socio-economic dimensions of environmental impacts on society and provide policy recommendations to reduce these impacts. This will lead to the development of more sustainable transportation systems and take important steps towards a more

environmentally and socio-economically balanced future.

4. Conclusions

Starting from the industrial revolution and continuing until today, phenomena such as population growth, globalization, industrialization and people's desire to expand their comfort zone have caused countries to demand more energy. Primary energy sources emit toxic gases both in terms of production and consumption. Toxic gases cause global warming and climate change. Countries need to adopt energy efficiency policies to reduce emissions. According to the literature studies examined, the criteria that trigger energy efficiency come to the fore. These are parameters such as CO_2 emission release, energy consumption, barrel price of crude oil, fuel consumption and GDP. As a result of the analysis carried out for a more livable clean environment and a more sustainable transportation, the negative effects of energy consumption, increase in fuel costs and high CO_2 emission emissions were observed. The preference of alternative fuels instead of fossil fuels has positive effects on the environment and the good GDP has positive effects on the economy. As a result of the AHP analysis, it is seen that energy consumption and CO_2 emissions are equally important and have the highest level of importance in the transportation sector, followed by GDP, followed by fuel consumption and the increase in the barrel price of crude oil.

These criteria used in the study are considered to be important for the objective of the study and to observe the impacts of countries in the transportation sector and energy context. In this context, the study has expanded the criteria and created a unique field of study that can be focused on in the literature. Energy efficiency in the transportation sector should not be limited to the criteria we use. The study can be diversified with different approaches and research. Strategies and measures that can be implemented to increase energy efficiency in the transportation sector:

- The use of electric vehicles can be encouraged instead of fossil fuels. This solution proposal can reduce CO_2 emissions by using electricity from clean energy sources.
- Emissions can be reduced by recycling waste that can be reused. Energy efficiency can be improved and air pollution triggers can be significantly reduced.
- Expanding and improving public transportation systems can reduce individual car use. Creating and supporting bicycle lanes can also increase environmentally friendly transportation options. Thus, energy efficiency of transportation can be increased.
- Encourage the development and use of new technologies to improve the fuel efficiency of cars and trucks. This can reduce energy consumption per kilometer. The widespread use of hybrid vehicles and alternative fuels instead of conventional gasoline and diesel vehicles can reduce the use of fossil fuels and ensure the use of various energy sources.
- Raising public awareness on energy consumption can increase demand for sustainable transportation options. Education campaigns and awareness-raising programs can help people make more environmentally friendly choices.
- Research should be encouraged to develop new and more environmentally friendly transportation technologies. This can contribute to finding solutions that increase energy efficiency and have less impact on the environment.

The combination of these measures will improve energy efficiency in the transport sector and support environmental sustainability, leaving a greener environment for future generations.

Author Contributions

Nuriye Kabakuş: Investigation, Methodology, Writing-original draft, Writing – review & editing, Visualization.

Merve Eyüboğlu: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing-original draft, Writing – review & editing.

Conflict of Interest

All the authors declare no conflict of interest.

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