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CO_2 Emission Efficiency Measurement: Green Logistics Perspective

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ABSTRACT

Purpose: This study aims to measure the carbon emission activities of Turkey, Azerbaijan, Kazakhstan, Kyrgyzstan and Uzbekistan and evaluate them from a green logistics perspective.
Method: Within the scope of the research, efficiency analyses were conducted using the output-oriented Data Envelopment Analysis (DEA) constant returns to scale (CRS) model and the super efficiency CRS DEA model. The input and output variables used in the research were obtained from the World Bank website.
Findings: In the research, the efficiency scores of the relevant countries were determined. It was determined that the efficiency scores of the countries were generally above 50%. The ranking of the efficient decision-making units among themselves was carried out with the super efficiency CRS DEA model. Some potential improvement suggestions were presented for the decision-making units that were not efficient.
Originality: In order to leave a livable world to future generations, green energy production should be supported and Carbon Dioxide (CO_2) emissions should be kept under control. Therefore, the efficiency assessment of countries' CO_2 emissions is of vital importance. This study has an original feature because the CO_2 emission activities of the Turkish Republics were carried out using the super efficiency CRS DEA model. This study can provide guidance to those who will conduct research on this subject and to country leaders.
Keywords: Efficiency, Carbon Emission, Logistics 4.0, Data Envelopment Analysis, Green Logistics.
JEL Code: F64, P47, O57.

CO_2 Emisyonu Etkinlik Ölçümü: Yeşil Lojistik Perspektifi

ÖZET

Amaç: Bu çalışmada Türkiye, Azerbaycan, Kazakistan, Kırgızistan ve Özbekistan'ın karbon emisyonları etkinliklerinin ölçülerek yeşil lojistik persperktifinde değerlendirilmesi amaçlanmıştır.
Yöntem: Araştırma kapsamında etkinlik analizleri çıktı odaklı Veri Zarflama Analizi (VZA)'nin ölçeğe göre sabit getiri (CRS) modeli ve süper etkinlik CRS VZA modeli kullanılarak gerçekleştirilmiştir. Araştırmada kullanılan girdi ve çıktı değişkenleri Dünya Bankası web sitesinden elde edilmiştir.
Bulgular: Araştırmada öncelikli olarak ilgili ülkelerin etkinlik skorları belirlenmiştir. Ülkelerin etkinlik skorlarının genel olarak %50'ın üzerinde olduğu tespit edilmiştir. Etkin karar verme birimlerinin kendi aralarındaki sıralaması ise süper etkinlik CRS VZA modeli ile gerçekleştirilmiştir. Etkin çıkmayan karar verme birimlerinin etkin olabilmesi için bazı potansiyel iyileştirme önerileri sunulmuştur.
Özgünlük: Gelecek nesillere yaşanabilir bir dünya bırakmak için yeşil enerji üretiminin desteklenmesi ve Karbondioksit (CO_2) emisyonunun kontrol altında tutulması gerekmektedir. Dolayısıyla ülkelerin CO_2 emisyonlarının etkinlik değerlendirmesi hayati öneme sahiptir. Bu çalışma Türk Cumhuriyetlerinin CO_2 emisyon etkinliklerinin süper etkinlik CRS VZA modeli kullanılarak gerçekleştirilmiş olması nedeniyle özgün bir niteliğe sahiptir. Bu çalışma bu yönüyle bu konuda araştırma yapacaklara ve ülke yöneticilerine yol gösterebilecek niteliktedir.
Anahtar Kelimeler: Etkinlik, Karbon Emisyonu, Lojistik 4.0, Veri Zarflama Analizi, Yeşil Lojistik.
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1. INTRODUCTION

The damage caused by carbon emissions to the environment worldwide has reached significant levels. These problems are among the issues discussed both globally and nationally. Especially the rapid increase in production with the Industrial Revolution has negatively affected the natural order of the world. Thus, these negative results have begun to be discussed today as climate change and global warming. A large part of carbon emissions is caused using fossil fuels in the energy sector. Fossil fuels used as energy sources leave solid and gaseous residues after burning, and when these wastes cannot be utilized, they cause environmental pollution (Çoban, 2015). In this context, there are significant relationships between energy consumption and CO_2 emissions (Chukurna et al., 2022). In 2019, the European Union published the European Green Deal strategy document. In this context, zeroing out net greenhouse gas emissions by 2050, green financing, sustainable agriculture, and the widespread use of renewable energy sources such as smart transportation are encouraged. It requires that innovative and smart applications that come to the agenda with Industry 4.0 be brought together in all areas with high efficiency and environmental friendliness (TÜBA, 2022). Reducing CO_2 will allow the effects of many problems such as climate change and global warming to be minimized. Renewable energy sources are essential in reducing the carbon footprint. Because the energy demand can't decrease due to ongoing economic and social activities.

Carbon dioxide is generally expressed as the negative outputs of economic activities. Due to its harmful effects on climate and human health, sustainable production and distribution have become a vital problem worldwide (Zadmirzaei et al., 2024). Today, sustainability is seen as an important solution to climate change and its effects. It is an essential issue for the logistics sector as well as in many sectors. With the increase in logistics activities, environmental sustainability issues have become even more important. Transportation systems account for 25% of CO_2 emissions and 23% of total energy consumption (Larina et al., 2021; Ulewicz et al., 2021). Logistics activities, which have become the driving force of international economic growth, are an essential source of carbon emissions. However, they have also become the driving force of economic growth (Qin and Qi, 2022). It is directly related to economic growth and high demand. Thus, a green and low CO2 operation should be the future perspective of countries. Green logistics develops a sustainable balance between economic, environmental and social goals and provides a bridge (Dekker et al., 2012). Green logistics is an activity that aims to minimize the impact of logistics activities on the environment. As a low-emission ecological transportation method, it not only contributes to the reduction of greenhouse gas emissions but also to economic growth. Therefore, in addition to economic and social support, logistics also supports environmental sustainability with the use of new energy vehicles (Larina et al., 2021). Due to transportation negatively affecting sustainable economic development by increasing fuel consumption, air pollution, and resource waste, it is necessary to give importance to the development of green logistics (Lu and Li, 2023). Because new energy logistics vehicles have the potential to reduce both costs and environmental pollution.

The CO_2 emissions in the world are directly proportional to the commercial activities of countries. The increase in trade volumes between countries causes an increase in logistics activities as well as production. According to the 2023 Greenhouse Gas Emission Inventory Report, total greenhouse gas emissions in Türkiye, which were 524.00 Mt CO_2 equivalent in 2020, increased by 7.7 percent compared to the previous year. In total greenhouse gas emissions, the largest share in CO_2 equivalent in 2021 was energy-related emissions with 71.3%. This was followed by industrial processes and product use with 13.3%, agriculture with 12.8%, and the waste sector with 2.6% (TUIK, 2023). Türkiye has been in cooperation and solidarity with the Turkic Republics, with which it shares common historical ties and common language, culture, and traditions, since their independence. It has shared its experiences with them. Although relations are not at the desired level in the meantime, serious progress has been made (Yüce, 2022). According to the data of the Republic of Türkiye Ministry of Foreign Affairs, Türkiye's trade volume with Uzbekistan, which increased by 25% in 2017, increased by 16% in 2018. It was stated that the trade volume with Azerbaijan was 5.02 billion dollars in 2021. The annual trade volume with Kyrgyzstan is 1 billion dollars, and with Kazakhstan, it is targeted to be 10 billion dollars. The Republic of Türkiye Ministry of Trade announced that Türkiye's exports to the Turkic Republics broke a historical record by increasing by 26.9% in 2023, reaching 10.2 billion dollars. In addition to the increasing trade volume, the use of renewable energy and keeping CO_2 emissions at a minimum level is of vital importance. For organizations or countries to ensure their sustainability, they need to constantly evaluate their efficiency and productivity. The study aims to conduct efficiency analyses using input and output variables from the Turkic Republics. However, data from the Republic of Turkmenistan was excluded because it was not available. For this reason, the effectiveness of CO2 emissions of Türkiye, Azerbaijan, Kazakhstan, Kyrgyzstan, and Uzbekistan is evaluated using the CRS DEA model. It is considered essential in terms of contributing to both organizations and policymakers.

The remainder of the study is organized as follows: The second section of the study includes a literature review. The third section includes the methods and data used in the study. The fourth section includes the findings of the study. The fifth section provides a general evaluation of the study.

2. LITERATURE

DEA method is widely used in many different areas such as technology, agriculture, banking, tourism, manufacturing systems, aviation, education and health (Emrouznejad and Yang, 2018; Çalışkan 2020; Menten et al., 2020; Ersoy, 2021; Ersoy and Aktaş, 2022; Xiao et al., 2023; Selamzade et al, 2023; Oukil et al., 2024; Antunes et al., 2024). As in many other sectors, studies are using the DEA method in the field of energy and logistics. Ervural et al. (2016) used the DEA method for renewable energy efficiency assessment of 81 different provinces of Türkiye. In the study, Total Renewable Energy Potential, Network Length, Total Installed Power of Renewable Energy, and Transformer Capacity were used as input variables, and Gross Energy Generation from Renewable Sources the number of Consumers were used as output variables. In the study, 81 provinces were ranked according to the results of output-oriented DEA analysis efficiency scores. A few potential improvement suggestions were presented for the provinces that were not efficient. Lu and Lu (2019) used the DEA method to examine the effects of CO_2 on the energy efficiency of 28 European countries between 2009 and 2013, selecting it as the undesirable output. In the study, labor force, real capital stock, and energy consumption were used as input variables, and the undesirable output of fossil fuel CO_2 emissions was used as the output variable. Güler et al. (2020) conducted the 2019 efficiency evaluation of 21 energy distribution companies operating in Türkiye using the DEA method. In the study, efficiency analyses were conducted using four different DEA models. The energy distribution companies that were found to be effective were ranked among themselves with the super efficiency DEA model and the most effective company was determined. Gan et al. (2021) used the DEA method to measure the green logistics effectiveness of 11 cities in Jiangxi Province, China between 2013 and 2019. In the study, capital, energy consumption, and employees were used as input variables, and demand scale, and added value of tertiary industry were used as output variables. Li et al. (2021) evaluated the carbon emission performance of 30 different regions in China between 2009 and 2015 using the fixed-sum undesirable outputs in the DEA method. In the study, capital stock, labor, and energy consumption were used as input variables, and gross domestic product and carbon dioxide emission was used as output variables. The study presented policy recommendations to improve carbon emission performance in different regions of China. Qin and Qi (2022) used the super-efficiency DEA model to determine the efficiency of the green logistics industry in Northwest China from 2010 to 2019. Four input and three output variables were used in the efficiency analysis. The study results provide some implications and suggestions for the high-quality development of a green logistics industry in Northwest China. Ersoy and Tehci (2023) conducted an efficiency evaluation of 15 companies operating in the energy sector in Türkiye using the DEA method. As a result of the efficiency analysis, four companies were found to be efficient, while the remaining 11 energy companies were found to be inefficient. Efficient companies were ranked among themselves according to the efficiency results of the super-efficiency DEA model, and the most efficient energy companies were identified. Lee et al. (2023) measured the efficiency of 27 logistics companies in Malaysia using the DEA method. Four input and four output variables were used in the study. As a result of the efficiency analysis, 15 companies were found to be effective, while the other 12 companies were found to be ineffective. Several potential improvement suggestions were made for the companies that were not found to be efficient. Yıldız (2023) evaluated the railway transportation efficiency of ten European countries and Türkiye determined according to the GNP rate. The research used data between the years 2011-2020. Data Envelopment Analysis - The Malmquist Index method was used to determine the efficiency changes depending on the years. The efficiency evaluations of the countries were made according to the total factor efficiency changes in the Malmquist Index values. Wang et al. (2023) used the DEA method and the Malmquist Index method to evaluate the CO_2 emission efficiency of the logistics sector in 9 coastal provinces of China between 2011 and 2020. In the study, Capital stock, Number of employees, and Energy consumption were used as input variables and Value added to the logistics industry, and CO_2 emissions were used as output variables. Junior et al. (2024) used the DEA method to evaluate the efficiency of CO_2 emissions in air transport for 21 countries between 2008 and 2019. In the study, the number of passengers, cargo transported, carrier departures, gross domestic product (GDP), and CO_2 emission from transportation undesirable were used as output variables, and several airports, and populations were used as input variables. According to the study results, 10 countries reached maximum efficiency in all years. Yağcı and Sözen (2024) used DEA and Malmquist Total Factor Efficiency index methods to analyze the energy efficiency and renewable energy efficiency of the European Union member countries and Türkiye between 2015 and 2017. According to the study results, the energy efficiency and renewable energy efficiency of the countries were determined, and the countries were ranked. When the literature was examined, it was determined that the super efficiency model was not used in the studies where CO2 emission efficiency was measured. This paper can contribute to the literature in this respect.

3. METHOD

3.1. Data Envelopment Analysis

Data Envelopment Analysis (DEA), developed by Farrell in 1957, is one of the most essential methods for measuring productivity in the production and service sectors (Farrell, 1957). Based on Farrell's work, DEA was developed by Charnes, Cooper, and Rhodes in 1978 with the assumption of constant returns to scale (CRS) (Charnes et al., 1978). In addition to the CRS method, which assumes that firms are efficient while on the production curve, DEA was developed by Banker, Charnes, and Cooper in 1984 with the assumption of variable returns to scale (VRS) while the search for the ideal method continued (Banker et al., 1984; Sevim et al. 2024). The basis of data envelopment analysis is based on the comparison of inputs and outputs of DMUs. DEA is accepted as a linear programming-based approach to evaluate the performance of DMUs (Cooper et al., 2011). DEA, which can express the efficiency values of decision-making units with multiple inputs and outputs as a single value, offers the opportunity to make an evaluation using multiple inputs and outputs such as cost, volume, and weight (Selamzade et al., 2023). The mathematical expression of DEA's efficiency measurement is the division of the weighted output total of the DMU by the weighted input total (Charnes et al., 1978; Yüksel, 2023).

$$\theta = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \tag{1}$$

To create a linear program in the output-oriented DEA calculation, the numerator of the Equation 1 is set equal to 1 (Charnes et al., 1978).

$$maximise \quad \theta_q \tag{2}$$

$$subject\ to \sum_{j=1}^{n} x_{ij}\lambda_j \leq x_{iq}, \qquad i = 1,2,\ldots,m, \tag{3}$$

$$\sum_{j=1}^{n} y_{kj}\lambda_j \geq \theta_q y_{kq}, \qquad k = 1,2,\ldots,r, \tag{4}$$

$$\lambda_j \geq 0, \qquad j = 1,2,\ldots,n. \tag{5}$$

The efficiency score obtained because of Equation 2 cannot be more than 1. DMUs with a value close to 1 are considered partially effective, and DMUs close to 0 are considered ineffective (Ersoy, 2021). When calculating DEA, first the units that provide maximum output with minimum input are determined from the compared DMUs, then the distances of the inefficient DMUs to the production limits (efficiency limits) are measured based on the weights obtained from the best alternative DMUs (Charnes et al., 1978). The efficiency score in DEA calculated with the CRS method can take a value between 0 and 1. In the following years, the Super Efficiency model was created by Seiford and Thrall (1990) to determine which of the effective DMUs is more effective by using DEA models. The effective DMUs in this model can take 1 or more values. Equations 6-8 are used to calculate the output-oriented CRS method Super Efficiency models (Seiford and Thrall, 1990).

$$Max\ \rho \tag{6}$$

$$subject\ to \sum_{\substack{j=1 \\ j\neq 0}}^{n} \lambda_j x_j \leq \rho x_0; \tag{7}$$

$$\sum_{\substack{j=1 \\ j\neq 0}}^{n} \lambda_j y_j \geq y_0;\ \rho,\ \lambda_j \geq 0;\ j \neq 0; \tag{8}$$

The input and output values of DMU_0 are shown as x_0 and y_0. As a result of the Super Efficiency analysis, it can be concluded that the company with a high score is better than a company with a lower super efficiency score, even if it has the same full efficiency score (1) as the others in the CRS analysis (Coelli et al., 1998).

3.2. Data of the Research

The input and output variables used in the study were obtained from the World Bank website (www.data.worldbank.org). In the efficiency analyses, the inverse of the carbon dioxide emission data ($1/CO_2$) was used as the output variable. The other two variables in Table 1 were used in the analyses as input variables.

Table 1. Variables of the research

Name	*Variables*	*Input / Output*
CO_2	Carbon dioxide emissions (Kt) ($1/CO_2$)	Output
GDP	Gross Domestic Product (constant 2015 USD)	Input
GEN	Green energy - Renewable energy consumption (% of total electricity production)	Input

The aim of the study was to determine the efficiency of Carbon dioxide emissions by taking into account the use of green energy - renewable energy consumption in the Turkic Republics. However, since the relevant data from the Republic of Turkmenistan could not be accessed, carbon emission activities of the Republics of Azerbaijan, Kazakhstan, Kyrgyzstan, Türkiye, and Uzbekistan were conducted.

4. RESULTS

4.1. CRS Model Analysis Results

The carbon footprint efficiency results calculated for the constant return to scale CRS method of the Data Envelopment Analysis of the Turkic Republics are presented in Table 2. CO_2 carbon dioxide emissions were used as outputs in the CRS analyses, GDP and Renewable energy consumption variables were used as inputs, and the years 1990-2020 were used as DMU in Table 2. In the CRS analysis Azerbaijan was effective in 1990, 1995, and 1996, Kazakhstan in 1998, 1999, Kyrgyzstan in 1995, 2001, and 2002, Türkiye in 1990, and Uzbekistan in 1995 and 2000. It was observed that the effectiveness scores of the Turkic Republic were generally not very high over the years. This situation is also seen from the effectiveness averages. As can be seen from Table 2, the efficiency score averages were 67.1% in Azerbaijan, 69.2% in Kazakhstan, 78.6% in Kyrgyzstan, 85.3% in Türkiye, and 74.6% in Uzbekistan. The highest and lowest effectiveness scores were in Azerbaijan. The years in which the closest scores to the efficiency score were obtained were 97.0% in Azerbaijan and Kazakhstan in 1997, 94.5% in Kyrgyzstan in 2005, 98.4% in Türkiye in 1991, and 96.9% in Uzbekistan in 1996. When the years in which the Turkic Republics received the lowest efficiency scores were examined, Azerbaijan had the lowest efficiency scores in 2010 (39.9%), Kazakhstan (48.4%), Uzbekistan in 2017 (46.4%), Kyrgyzstan (49.5%), and Türkiye in 2019 (60.2%).

Table 2. Carbon dioxide emission efficiency of countries

Year	*Azerbaijan*	*Kazakhstan*	*Kyrgyzstan*	*Türkiye*	*Uzbekistan*
1990	1	0.625	0.778	1	0.808
1991	0.942	0.658	0.763	0.984	0.830
1992	0.548	0.704	0.786	0.944	0.856
1993	0.471	0.712	0.860	0.926	0.805
1994	0.872	0.595	0.820	0.917	0.893
1995	1	0.764	1	0.921	1
1996	1	0.855	0.860	0.870	0.969
1997	0.970	0.970	0.870	0.848	0.954
1998	0.882	1	0.932	0.813	0.885
1999	0.843	1	0.887	0.860	0.785
2000	0.792	0.930	0.884	0.907	1
2001	0.954	0.838	1	0.947	0.932
2002	0.726	0.684	1	0.932	0.793
2003	0.551	0.628	0.826	0.950	0.710
2004	0.526	0.700	0.912	0.900	0.762
2005	0.440	0.591	0.945	0.941	0.634
2006	0.495	0.530	0.944	0.913	0.823
2007	0.415	0.576	0.886	0.941	0.808
2008	0.451	0.752	0.857	0.943	0.865
2009	0.507	0.748	0.844	0.897	0.612
2010	0.399	0.660	0.859	0.802	0.523
2011	0.437	0.618	0.704	0.840	0.729
2012	0.483	0.643	0.617	0.789	0.588
2013	0.519	0.694	0.599	0.770	0.670
2014	0.575	0.746	0.536	0.863	0.607
2015	0.538	0.637	0.582	0.720	0.525
2016	0.622	0.499	0.655	0.681	0.526
2017	0.635	0.484	0.602	0.712	0.464
2018	0.613	0.513	0.531	0.692	0.531
2019	0.669	0.553	0.495	0.602	0.486
2020	0.913	0.555	0.515	0.607	0.749
Average	0.671	0.692	0.786	0.853	0.746

The graph arranged with the efficiency results in Table 2 is shown in Figure 1. Although there was a partial increase in the efficiency scores of the countries between 1990 and 2000, there was a decrease in the efficiency scores after 2000. It was determined that there was an increase in the efficiency scores of Azerbaijan and Uzbekistan in 2020, while there was no change in the efficiency scores of other countries.

4.2. Super Efficiency CRS Model Analysis Results

The CRS model can determine efficient decision-making units, but it does not allow ranking of effective decision-making units. The super-efficiency CRS model is a method used to determine which of the efficient decision-making units is the most effective and to rank the effective decision-making units among themselves (Seiford and Thrall, 1990; Coelli et al., 1998; Ersoy, 2021; Selamzade et al., 2023). Table 3 shows the Super Efficiency scores calculated to determine which country is more efficient. As can be seen in Table 3, Azerbaijan reached the highest efficiency level in 1990. Kazakhstan had the highest efficiency score in 1999. Kyrgyzstan, on the other hand, achieved the highest score in 1990.

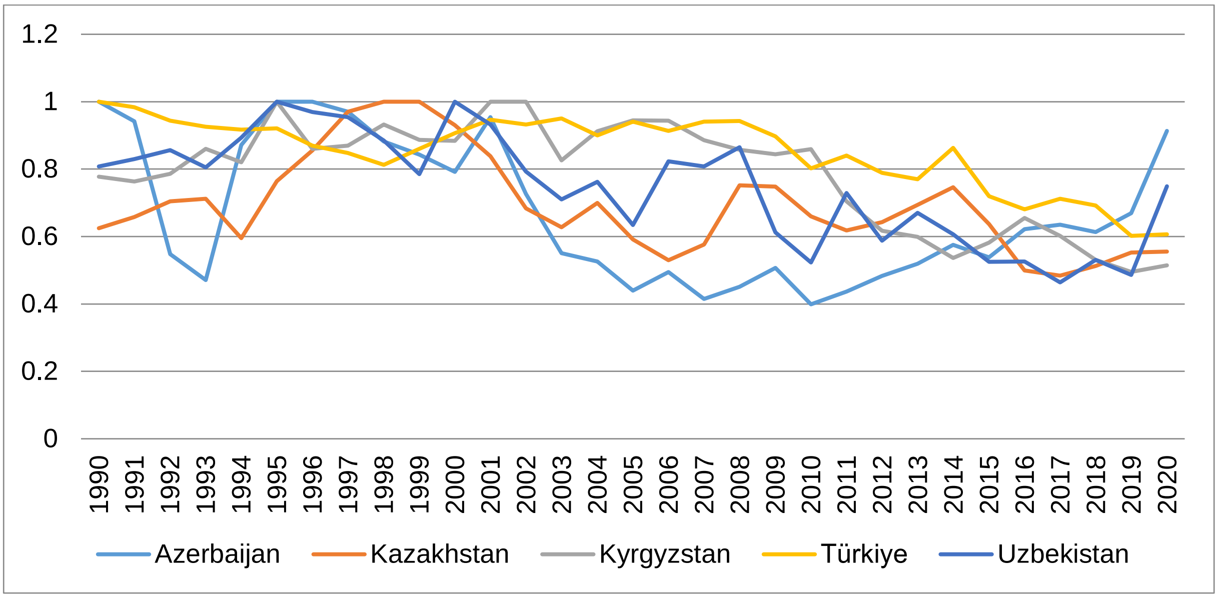

Figure1. Carbon dioxide emission efficiency of countries

Table 3. Super efficiency scores

Year	*Azerbaijan*	*Year*	*Kazakhstan*	*Year*	*Kyrgyzstan*	*Year*	*Türkiye*	*Year*	*Uzbekistan*
1990	1.082	1999	1.070	1995	1.193	1990	1.040	2000	1.100
1996	1.069	1998	1.049	2001	1.053			1995	1.070
1995	1.051			2002	1.015				

It was determined that Türkiye was super-efficient in 1990. Uzbekistan reached highest efficiency score in 1990. CO_2 Emission Reduction Proposal for Countries' Inefficient Years can be seen in Table 4.

Table 4. CO_2 emission reduction proposal for countries' inefficient years

		Efficiency	
Country	*Year*	*Score*	*%*
Azerbaijan	1997	0.970	-2.97
	2010	0.399	-60.13
Kazakhstan	1997	0.971	-2.92
	2017	0.484	-51.57
Kyrgyzstan	2005	0.945	-5.54
	2019	0.495	-50.45
Türkiye	1991	0.984	-1.62
	2019	0.602	-39.75
Uzbekistan	1996	0.969	-3.1
	2017	0.464	-53.57

5. CONCLUSION

Today, with increasing environmental concerns and industrial developments, it becomes clear that environmental problems should be evaluated together with supply chain management, and thus more crucial should be given to green supply chain management. Green supply chain management includes activities such as green production, green logistics, green marketing, and green energy (Tatar and Özer, 2017). Since any disruption in logistics activities in the supply chain will cause an increase in carbon emissions, managers are advised to look for green alternatives in logistics activities (Wiedmann et al., 2010; Amiruddin et al., 2021; Turgut and Budak, 2022). The current study aims to analyze the carbon emission activities of the Turkic Republics using the DEA method. According to the CRS DEA analysis results, effective decision-making units were determined. Efficient decision-making units were ranked using the super-efficiency CRS DEA model. Several potential improvement suggestions were presented for the decision-making units that were not effective to become effective. According to the potential improvement suggestions made because of the efficiency analyses, it is possible to say that energy production and consumption have a key role in the development of countries and that more essentials should be given to green energy production to keep CO_2 emissions under control.

It is possible to say that increasing the use of green energy in logistics operations reduces carbon emissions. This situation is expected to have a positive effect on reducing carbon emissions in the entire supply chain management indirectly. According to the results of this study, it is consistent with other studies in the literature that more importance should be given to the concepts of green energy and green logistics to reduce CO_2 emissions (He et al., 2017; Herold and Lee, 2017; Tatar and Özer, 2017; Jiang et al., 2020; Amiruddin et al., 2021; Turgut and Budak, 2022). However, since the research results are directly related to the input and output variables used in the analysis, changes in the variables can affect the results. In fact, in this study, efficiency analyses were performed using CRS DEA method. When evaluated from this perspective, it was seen that the efficiency results obtained with DEA were relative.

The current study has some limitations. One of the limitations of the study is that only data from 5 Turkic Republics can be used in the study. Another essential limitation is that DEA analyses were performed with only 1 output variable. Another limitation is that the analyses covered the years 1990-2020. In future studies, efficiency measurements can be applied using different input and output variables. In addition to the DEA method, studies can be conducted using multi-criteria decision-making methods or different methods.

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