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The Efficiency of Health Systems in European Union (EU) Countries with Undesirable Output: A DEA-Slack-Based Model Approach

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ABSTRACT

Purpose: This study was conducted to evaluate the efficiency of the health system of the EU countries by using DEA-Slack Based Measure (SBM) Model. The study also aimed to determine the healthcare resources that created a statistical difference in the efficiency status of countries.

Methodology: In the study, 27 member countries of the European Union were considered as decision-making units. Health expenditure and workforce were used as input; adult mortality rate was used as an undesirable and health status were used as desired output variables. DEA-SBM method was employed to evaluate efficiency, the Mann-Whitney U test was used to determine healthcare resources that created a statistically significant difference.

Findings: Approximately 40.74 % of countries were efficient. The number of nursing and midwifery personnel created a statistically significant difference in the efficiency status of the countries. It can be said that inefficient countries do not use their healthcare resources efficiently and they consume more health financial, technological, and workforce resources compared to efficient countries.

Originality: In addition to the input and output variables, the undesired output variable was also included in the analysis. This is considered to be the original aspect of the study.

Keywords: Efficiency, Data Envelopment Analysis, European Union, Health Systems, Slack Based Measure Model.

JEL Codes: I00, I10, C67.

Avrupa Birliği (AB) Ülkelerinin Sağlık Sistemlerinin İstenmeyen Çıktıyla Etkinliği: Aylak Tabanlı Veri Zarflama Analizi Yaklaşımı

ÖZET

Amaç: Bu çalışma, AB ülkelerinin sağlık sisteminin etkinliğini Aylak Tabanlı Veri Zarflama Analizi Modeli kullanılarak değerlendirmek amacıyla yürütülmüştür. Çalışmada ayrıca ülkelerin etkinlik durumlarında istatistiksel açıdan fark yaratan sağlık kaynaklarının belirlenmesi de amaçlanmıştır.

Yöntem: Çalışmada Avrupa Birliği'ne üye 27 ülke karar verme birimi olarak ele alınmıştır. Sağlık harcamaları ve sağlık insangücü girdi; yetişkin ölüm oranı istenmeyen çıktı ve sağlık durumu ise istenen çıktı değişkenidir. Ülkelerin etkinliğinin değerlendirilmesinde aylak tabanlı veri zarflama analizi yöntemi kullanılmış; ülkelerin etkin olup olmama durumu üzerinde fark yaratan sağlık kaynaklarının belirlenmesi ise MannWhitney U testi ile yapılmıştır.

Bulgular: Ülkelerin yaklaşık %40,74'ü etkindir. Hemşire ve Ebe sayısı ülkelerin etkinlik durumlarında istatistiksel olarak anlamlı bir fark yaratmıştır. Etkin olmayan ülkelerin sağlık kaynaklarını yeterli düzeyde etkin kullanmadıkları ve etkin ülkelere kıyasla daha fazla finansal, teknolojik ve sağlık insangücü kaynağı tükettikleri söylenebilir.

Özgünlük: Çalışmada girdi ve çıktı değişkenlerine ek olarak istenmeyen çıktı değişkeni de analize dahil edilmiştir. Bu durumun çalışmanın özgün yönü olduğu düşünülmektedir.

Anahtar Kelimeler*:* Etkinlik, Veri Zarflama Analizi, Avrupa Birliği, Sağlık Sistemleri, Aylak Tabanlı Ölçüm Modeli.

JEL Kodları: I00, I10, C67.

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1. INTRODUCTION

Recently, health systems around the world have faced some challenges due to the aging population and disability, increase in chronic diseases, increased expectations of citizens, and increased use of technology (Pastorino et al., 2019). Additionally, health systems must focus on resource and cost efficiency to provide value-added healthcare services; at the same time, they must also cope with some financial challenges while ensuring the provision of competent human resources to maintain the quality of healthcare delivery (lo Storto and Gončiaruk, 2017). The combination of demographic changes and technological developments has increased the cost of service (Jakubowski and Busse, 1998). For this reason, the current health expenditure (CHE) as a percentage of Gross Domestic Product (GDP) increases over the years. For example, in Europe while CHE of GDP was 7.69% in 2019, 8.59% in 2020 and 8.70% 2021 (WHO GHO, 2023). As is the case all over the world, member countries of the EU that have to allocate more healthcare resources than GDP have faced common difficulties in providing equal, efficient, and quality health services at affordable cost when the amount of care to be given has begun to exceed the resource base (Jakubowski and Busse, 1998). In almost all EU countries, great efforts have been made to cope with these challenges, to provide better healthcare, to increase quality, and to improve efficiency and productivity (Garel, 2018). Policymakers, private payers, and systems leaders have been looking for ways to increase the efficiency of health services (Dhaoui, 2019). Because of these reasons, the efficiency of human, materials, and financial resources in the health sector throughout Europe has become a relevant topic for both scientists and health policymakers (Asandului et al., 2014).

In the health sector, which has high levels of uncertainty and dynamic relationships, healthcare providers need to determine how they use their limited resources, such as financial resources, employees, materials, and devices, to utilize them better and to provide their services efficiently and productively (Popescu et al., 2014). On the other hand, countries have to inspect their health efficiency according to relevant health indicators and reorganize their policies and systems to improve their health status (Shetty and Pakkala, 2010). One of the preferred methods for achieving these goals is efficiency analysis (Hsu, 2014). Countries elaborate on systematically evaluating the efficiency of their health systems and comparing them with other countries (Cylus et al., 2016). This is because health policymakers are increasingly interested in comparing the performance of national health systems among countries (Varabyova and Schreyögg, 2013). Therefore, it is important to evaluate, develop, and analyze the health-related efficiencies of countries at the international level (Kaya Samut and Cafrı, 2016).

As in all systems, one of the main objectives of health systems is to ensure efficiency (Linna et al., 2006). It has been stated that the inefficiency of health systems is caused by the excess of inputs used and the deficiency of outputs (Şahin, 1999). However, it is quite difficult to define a functional relationship between the inputs and outputs in health systems. While it is possible to predict the extent of change in the output for a specific increase in input for any system, determining the direction and scale of change that inputs will cause in the outputs of health systems is quite difficult. So, in research, non-parametric Data Envelopment Analysis (DEA) is often chosen to assess how well health systems work because it doesn't need to define a specific relationship between inputs and outputs (Kocaman et al., 2012).

Traditional DEA models are either input-oriented or output-oriented, without considering slack variables. However, slack variables have an important role in the evaluation of efficiency. This method can better reveal the reasons for inefficiency compared to other efficiency measurement models (Tone, 2004). In light of these, the current study aimed to evaluate the health system efficiency of the EU countries by using the DEA-SBM model approach. We calculated the efficiency values of the countries in this context. Furthermore, the healthcare resources that created a statistical difference in the efficiency status of countries were determined. To this end, we posed the following research questions.

- What percentage of EU counties are efficient?
- Which variables creates a statistically significant difference according to the efficient status of countries?

The production process is evaluated together with the desired and undesired outputs. However, the traditional classical data envelopment analysis approach is insufficient to express the true production process by not including the undesired outputs (Cheng and Zervopoulos, 2014). To align with this concept, the study opted for the DEA-SBM method over the classical DEA method. On the other hand, although there are many studies on the efficiency of health systems in European countries, no study has been found that especially examines the efficiency of European Union countries with the DEA-SBM method. Moreover, there are studies focusing on the need for healthcare personnel, especially during the Covid-19 pandemic; the number of studies that integrate this into the analysis by prioritizing undesirable outcomes is still low. In this study, we look at healthcare resources like the health workforce and health spending, and we also include negative outcomes in our analysis to evaluate how efficiently the health systems of European Union member countries are performing. These situations are thought to be the original aspects of the study.

The rest of the paper is organized as follows: the Literature Review expressing the gap in the literature, Materials and Method detailing the methodology and method used in the study, Results presenting the findings related to the DEA-SBM method and Mann-Whitney U Test, Discussions highlighting the practical and social implications of the research, and the Conclusion, where the article ends.

2. LITERATURE REVIEW

Performance measurement is carried out to determine the position of health systems among similar systems, to monitor and control their current status with the help of measurable data. These measurements provide decision-makers with the opportunity to understand the strengths and weaknesses of the systems and to take action for units that are not functioning effectively. Efficiency, while being a dimension of performance, is important in terms of the health systems of countries. Therefore, it can be said that the analysis of efficiency holds an important place in the health field literature (Hsu, 2014). Although there are many methods used in the literature to examine efficiency in the health field, we can see that DEA has found a wide application area in the health sector, proven to be a versatile technique in the analysis of health systems, and is used globally (O’Neill et al., 2008). Since Sherman (1984) measured the efficiency of 7 university hospitals in the state of Massachusetts, USA, using DEA. DEA has been used many times in national and international studies in the field of health. It is possible to approach the application of efficiency analysis in the healthcare sector in different ways. There are studies in the literature that evaluate the performance of healthcare institutions (Jacobs, 2001; Ozcan, 2008; Nayar and Ozcan, 2008; Yiğit, 2016; Şenol and Gençtürk, 2017; Kohl et al., 2019; Çalışkan, 2020; Lindaas et al., 2024) and healthcare services (Stefko et al., 2018; Koçak, 2020; Pehlivan and Yiğit, 2022; Jung et al., 2023; Doğan, 2024). Additionally, studies examining the efficiency of vaccination areas (Valdmanis et al., 2003), immunotherapy for AIDS (Bian et al., 2004), and radiotherapy units, which play a significant role in cancer treatment (Santos and Amado, 2012), are different application areas where efficiency in the health sector is evaluated.This study evaluates the efficiencies of the healthcare systems of EU countries, so Table 1 has been included to illustrate the approach taken in some studies that examine efficiency from similar perspectives.

Table 1 shows that the efficiency of countries' healthcare systems is generally determined using traditional DEA, while SBM-DEA and its extensions are used much less frequently. Moreover, traditional methods with the radial approach tend to produce many decision units with an efficiency score of "1" (Zhou et al., 2006). Therefore, they stated that slack-based measurement has a higher distinctive power compared to traditional DEA methods. Because of, slack-based measurement is considered to constitute a better approach to reflect the nature of efficiency evaluation. Since the production process is evaluated together with the desired and undesirable outputs, and the traditional classical data envelopment analysis is insufficient to express the true production process by not including the undesirable outputs (Cheng and Zervopoulos, 2014), in this study the DEA-SBM model was preferred to be used instead of the classical DEA.

Most studies in the literature evaluate the efficiency of healthcare institutions such as hospitals and medical centers, while others focus on macro-level efficiency, such as countries. A significant portion of studies assessing macro-level evaluate the efficiency of OECD countries. In recent years, there have been studies evaluating the efficiency of health systems in countries such as Iran, Canada, Latvia, Germany, and China, as well as studies on various classifications such as ASEAN, the Western Balkans, Sub-Saharan Africa, and low- and middle-income countries. However, studies examining the efficiency of health systems specifically within the EU are still limited. Therefore, this study, which examines the efficiency of healthcare systems within EU countries using a DEA-Slack Based model, is believed to fill a significant gap in the literature, both in terms of the distinct decision-making unit and in offering an alternative method to classical DEA in efficiency analysis.

3. MATERIALS AND METHODS

3.1. Study Design

This research is an empirical retrospective multi-country cross-sectional study conducted using secondary data obtained from the World Health Organization (WHO) Global Health Observatory (WHO GHO, 2023) and Global Health Expenditure (WHO GHE, 2023) database.

3.2. Selection of Decision-Making Units (DMUs) and Variables

In the study, 27 EU member countries were considered DMUs. We ensured the homogeneity of the units by examining the efficiency of only EU countries. In the first phase, determine input, desirable, and undesirable output variables to evaluate the relative efficiency of these countries' health systems. The variables used in the study were obtained by a comprehensive literature review and were selected from the variables frequently used in studies evaluating the efficiencies of health systems at the country level (lo Storto and Gončiaruk, 2017; Asandului et al., 2014; Amponsah and Amanfo, 2017). In this direction, healthcare resources are handled as input variables (number of medical doctors per 10.000 population, number of nursing and midwifery personnel per 10.000 population, and current health expenditure per capita in US$ in current PPP). Output variables are categorized into two types: desirable outputs and undesirable outputs. Gomes and Lins (2008) suggest that we should minimize the production of undesirable outputs, as they are the result of undesirable production processes. From a moral perspective, maximizing the "Adult Mortality Rate" is undesirable. For this reason, while "Adult Mortality Rate (probability of dying between 15 and 60 years) per 1.000 population" was the undesired output, "life expectancy at birth total (LEAB) (years)" and "healthy life expectancy total (HALE) (years)" were included in the analysis as the desired output variables.

Table 1. Summary table of efficiency analysis studies conducted in the health field

Author(s)	*Methods*	*The Subject of Study*
Puig-Junoy (1998)	DEA	The evaluation of the relative efficiency of the healthcare systems in OECD countries in the 60s, 70s, and 80s within the framework of health production
Retzlaff-Roberts et al. (2004)	DEA	Addressing the efficiency of health systems in the use of health resources with the help of 1998 data from OECD countries
Lorcu (2008)	DEA	Comparison of the performance analyses of the healthcare systems of Türkiye and EU member countries
Yıldırım and Yıldırım (2011)	DEA	Determining the efficiency of EU member and candidate countries based on data from the year 2000
Kocaman et al. (2012)	DEA	Comparison of the efficiency of health systems in OECD countries
Asandului et al. (2014)	DEA	Examination of the efficiency of EU countries' health systems in 2010
Boz and Önder (2017)	DEA	Analysis of the efficiency of OECD countries' health systems in 2000 and 2013
Dincă et al. (2020)	DEA	Identification of the most efficient healthcare systems among 17 EU countries
Lupu and Tiganasu (2022)	DEA	Evaluation of EU countries' pandemic-era efficiency and identification of factors affecting efficiency
Kaya and Naldöken (2023)	DEA	A comparative study and evaluation of the health systems of G20 countries in terms of health, demographic, and economic indicators
Köse (2024)	DEA	Calculation of the health system performance of EU and OECD member countries
Manavgat and Audibert (2024)	DEA	Measuring and comparing the resilience of OECD countries' healthcare systems before and during Covid-19
Molender (2025)	DEA	Comparing the performance of member countries' public and private sectors with the help of performance indicators developed by the OECD
Mogha et al. (2015)	SBM-DEA	Determining the relative efficiency of public hospitals in Uttarakhand, India, in 2011
Ngee-Wen et al. (2020)	SBM-DEA	Evaluation of the efficiency among 20 public emergency departments in Malaysia
Dirik and Sahin (2020)	SBM-DEA	Examining the change in the efficiency of healthcare services in Turkish provinces between 2012 and 2016
Ortega-Díaz and Martín (2022)	SBM-DEA	Determining whether there is a possible trade-off between efficiency and quality in Spanish hospitals when undesirable outcomes are encountered
Hussain et al. (2024)	SBM-DEA	Evaluation of the health performance of OECD countries and examination of the role of health expenditures and management in increasing efficiency
Rashidi and Olfati (2025)	SBM-DEA	In the analysis of biological pattern recognition using cellular characteristics of breast cancer patients
Zarrin (2023)	Extended SBM-DEA	Using the 2017 data from 28 public hospitals in Germany to exemplify the efficiency for the proposed model
Yetim et al. (2023)	Weighted SBM-DEA	Evaluation of the efficiency of the healthcare systems of OECD countries
Song et al. (2025)	Meta Frontier SBM-DEA	Evaluation of the efficiency of healthcare services in various provinces of China within the framework of regional differences

Because there was a strong and positive relationship (r=0.881; p<0.05) between the desired output variables, they were treated as two separate variables in two different models, like in the study by Asandului et al. (2014). In the first model, the output variable was just HALE, and in the second model, it was just LEAB. The same input and undesired output variables were used in both models. In the first model, the output variable was only HALE, while in the second model it was only LEAB. The same input and undesired output variables were used in both models. It was also necessary to consider the relationship between the number of inputs/outputs and the number of decision-making units. In the literature, there are different views on the relationship between the number of decision-making units and the number of input/output variables. One of them is that the number of decision-making units (N) should not be less than five times the total number of input (m) and output (s) variables (Chen and Jia, 2017). When the decision-making units selected within the scope of the study (N = 27) and the sum of the number of input and output variables (a total of five for each model) are examined, it can be said that the relevant view is confirmed for both models.

3.3. Data Analysis

In the study, DEA-Slack Based Measure (SBM) Model was employed to evaluate the efficiency of the countries. Traditional DEA models are either input-oriented or output-oriented, without considering slacks variables. However, slacks variables have an important role in the evaluation of efficiency. In slack-based measurement model, both desirable (good) and undesirable (bad) input and output variables may exist. This method can better reveal the reasons for inefficiency compared to other efficiency measurement models (Tone, 2004). The main goal of slack-based measurement is to find out where the decision units stand in relation to the efficiency frontier and to reduce the objective function by identifying the highest slackness values (Park et al., 2018).

The "Undesirable Output Model" of the slack-based measurement is separable into two according to the states of the output variables. The "BadOutput Model" deals with desirable (good) and undesirable (bad) outputs independently, and the term independently mentioned here means that a change in undesirable outputs will not affect desirable outputs. While the "NonSeperable Model" establishes a connection between desired and undesirable outputs. With the connection expression mentioned here, it is explained that reducing undesirable outputs will also reduce desirable outputs (Tone, 2004). In this study, under the assumption of General Returns to Scale (GRS) models, the "BadOutput Model" was used because there was no mentioned connection between desirable and undesirable output variables. This DEA–SBM model with undesirable outputs can be formulated as follows in Equations 1-5:

Objective Function

$$\rho^* = min\ \frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{i0}}}{1+\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{r0}^g}+\sum_{r=1}^{s_2}\frac{s_r^b}{y_{r0}^b}\right)} \quad (1)$$

Constraints

$$x_0 = X\lambda + s^- \quad (2)$$

$$y_0^g = Y^g\lambda - s^g \quad (3)$$

$$y_0^b = Y^b\lambda + s^b \quad (4)$$

$$s^-,\ s^g,\ s^b, \lambda \geq 0 \quad (5)$$

$s^- \in R^m$ and $s^b \in R^{s_2}$ correspond to excess in inputs and undesirable outputs, respectively, and $s^g \in R^{s_1}$ correspond to shortage in desirable outputs. Also, these variables are called slack variables. The objective function shows an absolute decrease with respect to each s_i^-, s_r^g and s_r^b and takes values in the range of $0 < \rho^* \leq 1$.

Let there be an optimal solution $(\lambda^*, s^{-*}, s^{g*}, s^{b*})$ of the program given by Equation 1-5. In case of undesirable outputs, a necessary condition for any decision unit to be efficient is $\rho^* = 1,\ s^{-*} = 0,\ s^{g*} = 0,\ s^{b*} = 0$ that is. If the decision unit is inactive, it will be $\rho^* < 1$.

To compare how well the healthcare systems of EU countries perform, we can use tools like GAMS, LINDO, and various software made for data envelopment analysis, such as Frontier Analyst, DEA Solver PRO, On Front, Warwick, and free options like DEA Excel Solver, DEAP, EMS, and Pioneer (Babacan, 2006). In this study, the efficiencies of the healthcare systems of EU countries was evaluated. The DEA Solver PRO (Data Envelopment Analysis Solver PRO) software was used.

After determining whether the countries were efficient or not by looking at their efficiency scores, in the second step, it was determined whether there was a statistically significant difference between efficiency and inefficiency countries based on selected variables. We compared the groups using the Mann-Whitney U test. The null hypothesis was rejected at the 5% level.

4. RESULTS

The descriptive statistics for the data of the EU countries are shown in Table 2. Number of medical doctors (per 10.000 population), number of nursing and midwifery personnel (per 10.000 population), current health expenditure per capita in US$ in current PPP, and adult mortality rate (probability of dying between 15 and 60 years) per 1.000 population are below the average in more than half of the countries. However, there are relatively few countries with below-average life expectancy at birth total (LEAB) (years) and healthy life expectancy total (HALE) (years) (Table 2).

Table 2. Descriptive statistics of input, undesirable and desirable output variables

	Variables	*Mean*	*SD**	*Median*	*Min*	*Max*	*n (%)***
Inputs	Number of medical doctors (per 10.000 population)	44.71	10.97	42.64	29.74	70.62	15 (55.56)
	Number of nursing and midwifery personnel (per 10.000 population)	103.03	50.15	96.63	36.98	223.20	14 (51.90)
	Current health expenditure per capita in US$ in current PPP	3757.4	2283.3	2990.0	963.0	7636.0	17 (63.00)
Undesirable Output	Adult mortality rate (probability of dying between 15 and 60 years) per 1.000 population	84.44	32.63	71.00	52.00	155.00	18 (66.70)
Desirable Outputs	Life Expectancy at birth total (LEAB) (years)	82.88	1.96	83.50	78.60	85.70	10 (37.00)
	Healthy life expectancy total (HALE) (years)	70.00	1.97	70.90	66.20	72.40	10 (37.00)

Note: *SD: standart deviation; **: Number and percentage of countries with below-average values

The fact that the selection of input and output variables to be included in the efficiency analysis is suitable for the structural features of the decision units is closely related to the evaluation of the efficiency of DMUs. In other words, the relationship between input and output variables in the DEA methodology should not be irregular. Because in the DEA method, an increase in the input amount will lead to the formation of more outputs. At this point, the assumption of "isotonicity" between the input and output variables in the efficiency analysis should be tested. An isotonicity assumption involves calculating the inter-correlations between input and output variables to determine whether an increased amount of input leads to more output (Hwang et al., 2018). In the “isotonicity assumption,” an increase in the value of any input variable is expected not to decrease the values of any output variables, but rather to increase the value of at least one output variable (Amponsah and Amanfo, 2017; Golany and Roll, 1989). To ensure this assumption, Spearman’s rho correlation analysis should be performed between the input and output variables to be used in the efficiency analysis model. Accordingly, there is a positive correlation between Life Expectancy at birth total (LEAB) (years) and the number of medical doctors (per 10.000 population) (r=0.238), the number of nursing and midwifery personnel (per 10.000 population) (r=0.242), and current health expenditure per capita in US$ in current PPP (r=0.614). Also, there was a positive correlation between Healthy life expectancy total (HALE) (years) and the number of medical doctors (r=0.225), number of nursing and midwifery personnel (per 10.000 population) (r=0.314), and current health expenditure per capita in US$ in current PPP (r=0.704). When the correlation analysis is examined, it is seen that the relationship between the inputs and the desired outputs is positive; in other words, the “isotonicity assumption” is confirmed.

The EU countries efficiency values obtained from the first model, where HALE is the desired output, using the Slack-Based Measure “Undesirable Outputs Model” are presented in Table 3. The EU countries efficiency values obtained from the second model, where Life Expectancy at birth total (LEAB) (years) is the desired output, using the Slack-Based Measure “Undesirable Outputs Model” are presented in Table 4.

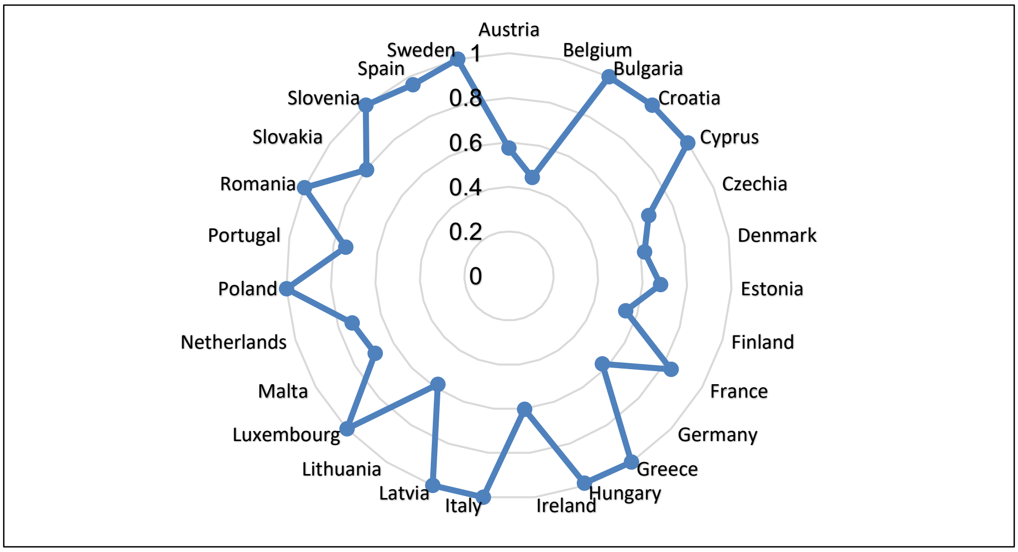
For any decision unit to be efficient in the SBM analysis undesirable outcomes model, the efficiency score must be 1.00 ($\rho^* = 1$) and the values of slack variables ($s^{-*} = 0,\ s^{g*} = 0,\ s^{b*} = 0$). If the decision unit is inefficient, the efficiency score will be less than 1.00 ($\rho^* < 1$). From the analysis results of the two models, it has been concluded that Bulgaria, Croatia, Cyprus, Greece, Italy, Latvia, Luxembourg, Poland, Romania, Slovenia and Sweden are efficient, while other EU countries are inefficient (Table 3 and Table 4). It is also possible to see the efficiency scores in Table 3 and Table 4 graphically in Figure 1.

Table 3. Slack-Based Measure analysis score of countries and projections (Model 1 - HALE)

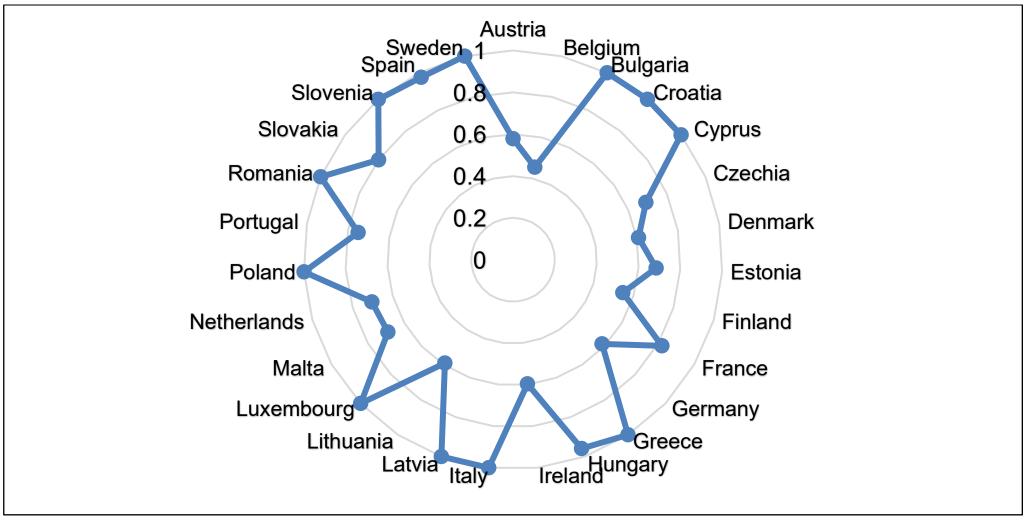
		(I) Number of medical doctors (per 10.000 population)		*(I) Number of nursing and midwifery personnel (per 10.000 population)*		*(I) Current health expenditure per capita in US$ in current PPP*		*(O) Adult mortality rate (probability of dying between 15 and 60 years) per 1.000 population*		*(O) Healthy life expectancy total (HALE) (years)*		*Sum of Change (%)*
DMU	*Score*	*Projection*	*Change (%)*	*Projection*	*Change (%)*	*Projection*	*Change (%)*	*Projection*	*Change (%)*	*Projection*	*Change (%)*	
Bulgaria	1	41.682	0.00%	47.411	0.00%	1.040.023	0.00%	135.000	0.00%	66.3	0.00%	0.00%
Croatia	1	34.655	0.00%	80.932	0.00%	1.384.119	0.00%	88.000	0.00%	68.6	0.00%	0.00%
Cyprus	1	53.753	0.00%	46.279	0.00%	2.989.653	0.00%	55.000	0.00%	72.4	0.00%	0.00%
Greece	1	63.060	0.00%	36.982	0.00%	1.845.776	0.00%	66.000	0.00%	70.9	0.00%	0.00%
Italy	1	41.263	0.00%	65.530	0.00%	3.349.602	0.00%	54.000	0.00%	71.9	0.00%	0.00%
Latvia	1	33.451	0.00%	44.004	0.00%	1.897.953	0.00%	154.000	0.00%	66.2	0.00%	0.00%
Luxembourg	1	29.851	0.00%	120.845	0.00%	7.635.702	0.00%	56.000	0.00%	71.6	0.00%	0.00%
Poland	1	37.137	0.00%	67.617	0.00%	1.159.328	0.00%	111.000	0.00%	68.7	0.00%	0.00%
Romania	1	29.739	0.00%	73.723	0.00%	963.013	0.00%	135.000	0.00%	66.8	0.00%	0.00%
Slovenia	1	32.792	0.00%	105.355	0.00%	2.774.987	0.00%	72.000	0.00%	70.7	0.00%	0.00%
Sweden	1	70.616	0.00%	215.939	0.00%	6.900.785	0.00%	52.000	0.00%	71.9	0.00%	0.00%
Hungary	0.9894	32.906	0.00%	66.044	0.00%	1.337.770	**-3.17%**	126.000	0.00%	67.2	0.00%	**-3.17%**
Spain	0.9612	45.766	0.00%	58.626	**-7.04%**	3.221.105	**-0.41%**	54.375	**-2.90%**	72.1	0.00%	**-10.35%**
France	0.8392	33.237	0.00%	108.107	**-11.51%**	3.404.755	**-36.72%**	71.000	0.00%	72.1	0.00%	**-48.23%**
Slovakia	0.7974	46.292	0.00%	60.795	**-22.56%**	1.560.247	**-7.38%**	77.168	**-25.80%**	68.5	0.00%	**-55.74%**
Portugal	0.7437	56.152	0.00%	49.019	-35.16%	1.741.729	-36.59%	72.501	-4.60%	71	0.00%	-76.35%
Netherlands	0.7357	38.355	0.00%	78.717	-30.53%	3.351.042	-48.75%	59.000	0.00%	71.4	0.00%	-79.28%
Malta	0.6943	53.085	-3.22%	45.704	-68.27%	2.952.489	-18.92%	54.316	-1.24%	71.5	0.00%	-91.65%
Czechia	0.6830	54.686	0.00%	47.031	-48.89%	1.691.935	-32.28%	70.004	-13.58%	68.8	0.00%	-94.75%
Estonia	0.6808	34.958	-9.51%	81.640	-26.97%	1.396.225	-33.34%	88.770	-25.40%	69.2	0.00%	-95.22%
Denmark	0.6171	40.746	-4.45%	64.710	-38.61%	3.307.674	-55.19%	53.324	-17.96%	71	0.00%	-116.21%
Ireland	0.6034	40.622	0.00%	65.757	-55.85%	3.300.209	-51.21%	53.841	-13.16%	71.1	0.00%	-120.22%
Lithuania	0.5824	36.056	-27.16%	65.649	-32.06%	1.125.578	-39.44%	107.769	-30.47%	66.7	0.00%	-129.13%
Germany	0.5751	40.689	-9.95%	64.619	-47.67%	3.303.015	-50.15%	53.249	-22.83%	70.9	0.00%	-130.60%
Austria	0.5740	52.639	-3.57%	45.320	-57.94%	2.927.713	-54.99%	53.860	-13.13%	70.9	0.00%	-129.63%
Finland	0.5465	40.746	-5.79%	64.710	-71.01%	3.307.674	-39.73%	53.324	-23.82%	71	0.00%	-140.35%
Belgium	0.4536	40.517	-35.25%	64.345	-68.65%	3.289.039	-42.10%	53.024	-26.36%	70.6	0.00%	-172.36%

Table 4. Slack-Based Measure analysis score of countries and projections (Model 2 - LEAB)

		(I) Number of medical doctors (per 10.000 population)		*(I) Number of nursing and midwifery personnel (per 10.000 population)*		*(I) Current health expenditure per capita in US$ in current PPP*		*(O) Adult mortality rate (probability of dying between 15 and 60 years) per 1.000 population*		*(O) Life Expectancy at birth total (LEAB) (years)*		*Sum of Change (%)*
DMU	*Score*	*Projection*	*Change (%)*	*Projection*	*Change (%)*	*Projection*	*Change (%)*	*Projection*	*Change (%)*	*Projection*	*Change (%)*	
Bulgaria	1	41.682	0.00%	47.411	0.00%	1.040.023	0.00%	135.000	0.00%	78.6	0.00%	0.00%
Croatia	1	34.655	0.00%	80.932	0.00%	1.384.119	0.00%	88.000	0.00%	81.6	0.00%	0.00%
Cyprus	1	53.753	0.00%	46.279	0.00%	2.989.653	0.00%	55.000	0.00%	85.1	0.00%	0.00%
Greece	1	63.060	0.00%	36.982	0.00%	1.845.776	0.00%	66.000	0.00%	83.6	0.00%	0.00%
Italy	1	41.263	0.00%	65.530	0.00%	3.349.602	0.00%	54.000	0.00%	84.9	0.00%	0.00%
Latvia	1	33.451	0.00%	44.004	0.00%	1.897.953	0.00%	154.000	0.00%	79.8	0.00%	0.00%
Luxembourg	1	29.851	0.00%	120.845	0.00%	7.635.702	0.00%	56.000	0.00%	84.2	0.00%	0.00%
Poland	1	37.137	0.00%	67.617	0.00%	1.159.328	0.00%	111.000	0.00%	81.9	0.00%	0.00%
Romania	1	29.739	0.00%	73.723	0.00%	963.013	0.00%	135.000	0.00%	79.3	0.00%	0.00%
Slovenia	1	32.792	0.00%	105.355	0.00%	2.774.987	0.00%	72.000	0.00%	84.1	0.00%	0.00%
Sweden	1	70.616	0.00%	215.939	0.00%	6.900.785	0.00%	52.000	0.00%	84	0.00%	0.00%
Spain	0.9761	45.766	0.00%	59.944	**-4.95%**	3.234.293	0.00%	55.152	**-1.51%**	85.7	0.00%	**-6.46%**
Hungary	0.9590	32.906	0.00%	66.044	0.00%	1.211.628	**-12.30%**	126.000	0.00%	79.6	0.00%	**-12.30%**
France	0.8214	33.237	0.00%	106.366	**-12.94%**	3.193.596	**-40.65%**	71.000	0.00%	85.1	0.00%	**-53.59%**
Slovakia	0.8005	46.292	0.00%	61.194	**-22.05%**	1.562.680	**-7.23%**	77.508	**-25.47%**	81.4	0.00%	**-54.75%**
Portugal	0.7514	56.152	0.00%	49.857	-34.05%	1.746.842	-36.40%	73.217	-3.66%	84.4	0.00%	-74.11%
Netherlands	0.7032	38.355	0.00%	74.314	-34.41%	3.141.975	-51.95%	57.511	-2.52%	83.1	0.00%	-88.88%
Czechia	0.6908	54.686	0.00%	48.051	-47.78%	1.698.161	-32.03%	70.875	-12.50%	81.9	0.00%	-92.31%
Malta	0.6892	40.728	-25.75%	64.681	-55.10%	3.306.203	-9.21%	53.300	-3.09%	83.8	0.00%	-93.15%
Estonia	0.6839	35.080	-9.20%	81.924	-26.72%	1.401.081	-33.11%	89.078	-25.14%	82.6	0.00%	-94.17%
Denmark	0.6086	40.340	-5.40%	64.063	-39.22%	3.274.640	-55.64%	52.792	-18.78%	83	0.00%	-119.04%
Ireland	0.5968	40.583	-0.10%	64.449	-56.73%	3.294.367	-51.30%	53.110	-14.34%	83.5	0.00%	-122.47%
Lithuania	0.5908	36.457	-26.35%	66.379	-31.31%	1.138.095	-38.77%	108.967	-29.70%	80.4	0.00%	-126.13%
Germany	0.5852	41.214	-8.79%	65.453	-47.00%	3.345.657	-49.51%	53.936	-21.83%	84.8	0.00%	-127.13%
Austria	0.5777	40.728	-25.39%	64.681	-39.97%	3.306.203	-49.17%	53.300	-14.03%	83.8	0.00%	-128.56%
Finland	0.5479	40.826	-5.61%	64.835	-70.95%	3.314.094	-39.61%	53.428	-23.67%	84	0.00%	-139.84%
Belgium	0.4545	40.583	-35.14%	64.449	-68.60%	3.294.367	-42.00%	53.110	-26.24%	83.5	0.00%	-171.98%



(a) Model 1- HALE



(b) Model 2 - LEAB

Figure 1. Graphical representation of efficiency scores (Model 1- HALE and Model 2 - LEAB)

The rates of change shown in Table 3 and Table 4 represent excess input and undesirable output variables, as there are no desirable output variables available for the analysis. These rates of change in inputs and undesirable outputs can help transform inefficient countries into efficient ones. For example, for Hungary and Spain, which are the countries closest to the efficiency limit, to become efficient in Model 1 and Model 2, they need to increase the values of Healthy life expectancy total (HALE) (years) and Life Expectancy at birth total (LEAB) (years), which are the desired output variables. With the increase in these variables, the rate of change in input and undesirable outputs will be "0.00." By increasing these variables, Hungary and Spain will achieve efficiency. On the other hand, Hungary has a better efficiency score than Spain because it consumes excesses in input and undesirable output variables. In other words, the sum of Spain's rates of change in input and undesirable output variables is greater than the sum of Hungary's rates of change. Therefore, we can assert that Hungary's efficiency value surpasses Spain's (Table 3, Table 4, Figure 1). Within the scope of the study, it was also examined which input and output variables would show a statistically significant difference according to the efficiency status of the countries in Table 4.

Therefore, Hypothesis 2, which meets the $p < 0.05$ condition, is accepted. Other hypotheses are rejected as they do not meet this condition. There was a statistically significant difference between efficient and inefficient countries in *"the number of nursing and midwifery personnel (per 10.000 population)" (H_2)*. The median value of inefficient countries was higher than that of efficient countries (Table 5). In other words, a significant difference in favour of inefficiency has been obtained regarding the mentioned variable in the efficiency values of EU member countries ($Z = -2.369, p < 0.05$).

Table 5. Hypotheses testing (Mann-Whitney U Test)

Hypothesis	*Median*		*Z*	*p*	*Statistical Decision*
	Efficient	*Inefficient*			
H_1: Number of medical doctors (per 10.000 population)	37.14	45.48	-1.431	0.162	Rejected
H_2: Number of nursing and midwifery personnel (per 10.000 population)	67.62	109.77	-2.369	0.017	Accepted
H_3: Current health expenditure per capita in US$ in current PPP	1898.00	4511.50	-1.579	0.121	Rejected
H_4: Adult mortality rate (probability of dying between 15 and 60 years) per 1.000 population	72.00	70.50	-0.025	0.981	Rejected
H_5: Life Expectancy at birth total (LEAB) (years)	83.60	83.50	-0.370	0.716	Rejected
H_6: Healthy life expectancy total (HALE) (years)	70.70	70.95	-0.494	0.645	Rejected

5. DISCUSSION

The importance of efficiency in resource use and expenditures in the health sector has been recognized all over the world (Purohit, 2016). The efficiency of health systems has become a relevant topic for both healthcare providers and policymakers in the health sector. In this context, it is necessary to examine the efficiency of health systems on a country basis, that is, at the macro level, and to identify methods that will increase the efficiency of health systems (Lee, 2016). Countries need to evaluate their health systems against other comparable countries and then efficiently allocate the necessary resources for their health systems. Thus, an important step will have been taken to facilitate the decision-making process for improving the performance of health systems in different countries (Abolghasem et al., 2019). In the literature, it can be stated that the efficiency of international health systems is more frequently addressed than that of regional or national scales. Additionally, studies comparing the efficiency of high-income countries' health systems by income groups are more frequently encountered (Mbau et al., 2023). Our research findings support the published literature indicating that among these countries, Spain, Slovenia (Önen and Sayın, 2017), Sweden and Romania (Dincă et al., 2020), Cyprus, Luxembourg, and Greece (Kujawska, 2018) have some of the most efficient healthcare systems. In EU member countries, the fact that Spain has the highest life expectancy at birth, and that the lowest mortality rates among people up to 65 years old are observed in Cyprus and Greece (Eurostat, 2023), as well as the higher number of doctors and nurses per 1000 people in Greece, Denmark, and Spain compared to other countries (OECD, 2021), aligns with our findings that these countries have efficient healthcare systems. Additionally, although countries like Germany and France allocate the highest share of health expenditures among EU countries (OECD, 2021), it is noteworthy that the performance of these countries' health systems is low.

“Good Health and Well-Being,” the 3rd of the 17 Sustainable Development Goals for 2030 published by the United Nations in 2015, reveals the importance of healthy life expectancy by using "ensure healthy lives and promote well-being for all at all ages" as its mission statement (WHO SDGs, 2023). However, a review of the literature indicated that Life Expectancy at birth total (LEAB) (years) was frequently used as an output variable in studies examining the efficiency of countries, whereas Healthy life expectancy total (HALE) (years) was considered an output variable in a relatively limited number of studies (Asandului et al., 2014; Hosokawa et al., 2020). According to Asandului et al. (2014), increasing the value of Healthy life expectancy total (HALE) (years) is one of the constant goals of EU policies since it will help reduce the costs of health systems and increase employees’ productivity, as well as the social benefits it provides. In this context, we thought that it would be appropriate to use both Life Expectancy at birth total (LEAB) (years) and Healthy life expectancy total (HALE) (years) as desired output variables in the study. To achieve homogeneity, only the efficiency of EU member countries was examined in the current study.

Although there are many studies on traditional classical DEA, a limited number of studies in which the DEA-SBM method was employed to do an efficiency analysis in the health sector were found. Some of these studies were carried out in microform at the level of healthcare institutions, such as hospitals, primary healthcare institutions, or clinical units (Mei et al., 2023). Some of them are studies that evaluate the health efficiencies of countries, states, and regions at the macro level. For example, Kujawska (2021) used the SBM to examine the health system efficiency of European countries. As a result of the study, a total of ten countries, including Bulgaria, Cyprus, Greece, Iceland, Ireland, Malta, Poland, Spain, Sweden, and the United Kingdom, were found to be efficient. Some of the countries that are efficient in the current study are the same. In another study, Hsu (2014) measured the health expenditure performance of European and Central Asian countries with the SBM method. This study revealed that most countries exhibit lower levels of efficiency. In the benchmarking study conducted by lo Storto and Gončiaruk (2017), the healthcare system performances of 32 European countries in 2011 and 2014 were evaluated. Liu et al. (2019) examined the health expenditure efficiency in rural China using the Super SBM model. Another study by Sinimole (2023) aimed to evaluate the efficiency of health systems worldwide in combating the epidemic.

The study found efficiency in sixteen out of 161 countries. In the study conducted by Cheng and Zervopoulos (2014), the efficiency of the health system of 171 countries was evaluated. The study used the child mortality rate under 5 years old and the maternal mortality rate as undesired output variables. As can be seen, the number of studies evaluating efficiency at the macro level using the SBM method is limited compared to studies using classical DEA. While some studies have looked at the health efficiency of EU countries using classical and dynamic network DEA, it hasn't been shown that the DEA-SBM method has been specifically applied to EU member countries. Given the research gaps identified above, this study is considered original because it specifically evaluates the efficiency of EU countries using this method.

In the last few years, many important changes have taken place in the health sector due to the new challenges brought by the pandemic (Sinimole, 2023). Especially in the period of the Covid-19 pandemic, which has affected the whole world, the health systems of the countries need to meet the health needs of the society and to enhance the health system capacity by strengthening the health services to tackle the new epidemic waves in the future (Giannopoulou and Tsobanoglou, 2020). The resources of the health system (doctors, nurses, and beds) were not sufficient to cope with the pandemic in many countries (Sinimole, 2023). In addition, with the pandemic, the issue of effective and efficient use of healthcare resources has gained importance, especially the existence of health workforce resources. In the current study, results were obtained that support this view.

5.1. Practical and Social Implications

We anticipate that the results of this study will have practical implications. The remarkable finding is that only the number of nurses and midwives significantly impacted healthcare resources. Nurses have the largest component of the health workforce in almost all EU countries. The importance of nurses, who play a key role in preserving the core values of global health systems and providing care in hospitals, long-term care facilities, and the community, has increased once again, especially during the COVID-19 pandemic (Schwerdtle et al., 2020; OECD, 2022). Based on this, the WHO has declared 2020 the “International Year of Nurses and Midwives” for its unique contributions to global health (Safeguarding Health in Conflict Coalition, 2020). According to Catton (2020), the next decade is likely to face global challenges related to pan-national infections such as Covid-19 and global warming, which affect healthcare services. The continuity and resilience of health services will depend on having enough nurses to face these upcoming challenges. For this reason, it is thought that it is important for the efficiency of the health system that countries establish a balance in terms of employment by analyzing the current situation, especially regarding the number of nurses and midwives.

One of the main goals of the countries is to achieve improvements regarding both the quality and efficient delivery of health services and how optimally they use healthcare resources (Caballer-Tarazona et al., 2010). With improvements in financial and health workforce resources, it will be possible to provide easy access to health services, reduce health inequalities, better manage health problems, and improve health outcomes in inefficient countries. The results of the current study can help policymakers identify deficiencies in national health systems, justify the need for reform, and find the top priority countries in need of reform in the health sector. Since the efficiency status plays an important role in the development, sustainability, and well-being of a country, through this study, it can be learned how each national health system compares to the others and may contribute to identifying the aspects of health systems that are open for improvement in the future. On the other hand, it should not be forgotten that the efficiencies of health systems and the health workforce resources, especially physicians, nurses, and midwives, become even more important in emergencies such as the Covid-19 global epidemic that affects the whole world or the earthquake disaster in Türkiye on February 06, 2023.

By revealing the current situation, this study is thought to benefit managers, planners, policymakers, and decision makers in the planning and delivery of health services. With the results obtained from this study, determining more appropriate policies in resource allocation, revealing how well the health systems of the countries work, continuously improving the efficiency by establishing a connection between the resources of the health systems and the outputs, developing policies that will ensure more efficient ways for the allocation of healthcare resources, balancing the distribution of resources, and redesigning the national health systems of countries. On the other hand, it is important for all stakeholders to cooperate so that the efficiency of health systems can be included in health policies. At this point, it is recommended that health managers, including nurses and midwives, who constitute the largest share among health workers, should be in contact with governments, national and international nursing and midwifery associations, and occupational chambers and develop policies in line with their opinions.

5.2. Research Limitations

The study had several limitations. One of these limitations was that the study only covers EU countries. Other world countries were not included in the study due to the necessity of homogeneity in decision-making units, which is one of the basic assumptions of the DEA-SBM method. Therefore, the results cannot be generalized to all countries in the world. In addition, environmental factors were not used while evaluating the efficiency to provide opinions on the relationship between the number of variables and decision-making units. Therefore, we conducted the analysis using the most commonly used healthcare resource variables in the literature. The results obtained from the SBM-DEA model may vary depending on the selected variables. Therefore, using a different set of variables will yield different results. Furthermore, variable selection was influenced by data availability. On the other hand, it was assumed that the secondary data obtained were accurate.

6. CONCLUSION

The study examined the efficiency of EU countries' health systems using the DEA-SBM method, creating two distinct models. Accordingly, it turned out that only 11 out of 27 countries (Bulgaria, Croatia, Cyprus, Greece, Italy, Latvia, Luxembourg, Poland, Romania, Slovenia, and Sweden) were efficient in both models, and the number of efficient countries was quite low (40.74%). It can be said that these efficient countries use their health expenditures and human resources better; in other words, they have less slack capacity to reach a healthy population compared to others. This situation can be associated with the elderly population rate, the number of pregnant women, chronic disease burden, mortality rates, immunization and vaccination policies, the health system model used, education level, income level, rural/urban population ratio, and environmental factors in countries. It would be beneficial for these countries to implement healthcare reforms that will reduce resource intensity and increase the quality of healthcare services delivery. One could argue that inefficient countries possess more slack capacity compared to their efficient counterparts. These countries are not efficient because there are still resources available for input and undesirable output variables. We recommend that these countries utilize their slack resources to become efficient.

Among the health workforce resources, only the number of nurses and midwives created a statistically significant difference in the efficiency status of the countries. The median value of inefficient countries was higher than that of efficient countries. This result shows that inefficient countries have higher resource intensity in terms of the number of nurses and midwives.

In future studies, it may be suggested to include different indicators such as education level, income and related inequalities, dietary habits, patient satisfaction, service delivery quality, health system infrastructure, and health-related environmental and lifestyle risk factors in the analysis. Countries' GDP and the share they allocate to their health systems vary. Therefore, in studies comparing health systems, countries can be analyzed by separating them into developed and developing categories. In this way, it will be possible to understand the relationships between economic, social, and health service variables that may affect the delivery of health services. Additionally, we suggest expanding the study to include longitudinal data using time series and panel data. On the other hand, the health reforms of efficient countries can be examined using policy analysis methods.

Author Contributions

Gözde Yeşilaydın: Literature review, Conceptualization, Methodology, Data Curation, Analysis, Writing and editing *Bilal Saraç:* Literature review, Methodology, Data Curation, Analysis, Writing and editing

Conflict of Interest

No potential conflict of interest was declared by the authors.

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Compliance with Ethical Standards

It was declared by the authors that the tools and methods used in the study do not require the permission of the Ethics Committee.

Ethical Statement

It was declared by the author(s) that scientific and ethical principles have been followed in this study and all the sources used have been properly cited.

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