Is Health Systems Sustainability Measurable? - Operationalizing SDG Targets using SSP-TOPSIS Approach

Aleksandra Bączkiewicz[1 [0000−0003−4249−8364]], Jarosław Wątróbski[1,2 [0000−0002−4415−9414]], Iga Rudawska[3 [0000−0002−2173−931X]]

[1] Institute of Management, University of Szczecin, ul. Cukrowa 8, 71-004 Szczecin, Poland
[2] National Institute of Telecommunications, ul. Szachowa 1, 04-894 Warsaw, Poland
[3] Institute of Economics and Finance, University of Szczecin, ul. Mickiewicza 64, 71-101 Szczecin, Poland
{aleksandra.baczkiewicz,jaroslaw.watrobski,iga.rudawska}@usz.edu.pl

Abstract. The sustainability of health systems is examined through the lens of quality of care, emphasizing its long-term impact on public health. This paper presents research that extends traditional healthcare evaluation by integrating health outcomes with system resilience and environmental effects, in addition to financial costs. It uses a multi-criteria decision analysis (MCDA) approach using the Sustainable Development Goals (SDGs) for health. A key challenge with widely used MCDA methods, particularly those from American schools, is their compensatory nature. These methods allow poor performance in some criteria to be compensated by advantageous performance in others, which is inconsistent with strong sustainability paradigm. To address this limitation, this paper presents the Strong Sustainability Paradigm based Technique for Order Preference by Similarity to Ideal Solution (SSP-TOPSIS) method, a novel approach designed to reduce compensatory effects in multi-criteria assessments. The contribution enhances understanding of sustainable health systems and offers a sophisticated tool for policymakers seeking to balance health care quality, resilience, and environmental impact in line with strong sustainability principles.

Keywords: Healthcare evaluation · Sustainability · Decision support system · Strong sustainability paradigm.

1 Introduction

The domain of health systems sustainability is quality of care, taking into account the responsibility of health services on patients now, but also in the future. This long-term perspective accentuates the health system's impact on communities (public health domain) and on the environment, and consequently on the health of the entire population. Sustainability will therefore broaden the approach to the value of health care to estimate health outcomes in relation to

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the impact on the community (through system resilience) and the environment, in addition to the financial costs [20]. Therefore the purpose of this paper is to apply the Multi Criteria Decision Analysis (MCDA) approach to measure health systems sustainability using Health Targets in Sustainable Development Goals (SDG) as reference points [14]. To the authors' best knowledge, it is the first attempt of such kind. Previous works [8, 10, 29] concentrated on the triple bottom line and lacked direct application of SDG indicators. Therefore authors' study has the same potential to contribute to the state of the art in the field of the sustainability of health systems.

Despite the many advantages and applicability of MCDA methods in sustainability assessment, an important limitation among the popular and widely used group of multi-criteria methods derived from the American school is their compensatory character [27]. This implies that in assessments carried out using these methods, there is a possibility that weak values within certain criteria may be compensated for by outstanding values achieved against other criteria [24]. This phenomenon is undesirable from the point of view of the strongly sustainable development paradigm, which dictates the pursuit of favorable values within the widest possible range of criteria [31]. In the context of the limitations indicated, the purpose of this article is to present a multi-criteria SSP-TOPSIS method (the Strong Sustainability Paradigm based Technique for Order Preference by Similarity to Ideal Solution) for modeling compensation reduction to assess the sustainability of health systems in selected countries.

2 Literature review

Health systems sustainability has become a key area of research, reflecting the need for healthcare organizations to balance quality care with public health (disease prevention, not just treatment), system resilience (for example, in the face of a pandemic), the environment and financial accountability. This initial concept synthesizes the approach proposed by The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015 (https://sdgs.un.org/goals). It emphasizes the multifaceted nature of sustainability in healthcare. One of the fundamental aspects of sustainability in health systems is the integration of social (including economic) and environmental issues into a quality improvement framework. According to Veltman et al. (2020) [28] quality of care should include environmental impact. The authors suggest that healthcare organizations need to adopt a multi-directional approach to achieve sustainability. Baid & Damm (2021) [5] present similar findings, proposing the SusQI framework and incorporating sustainability into traditional quality domains such as performance and patient experience. The relationship between sustainability and quality improvement is also supported by Mortimer et al. (2018) [20] who argue that sustainability should be viewed as a quality domain in healthcare, extending the responsibility of healthcare services to future generations. Based on the literature review we propose a different approach incorporating SDG Health Targets and indicators.

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Main Criteria	Sub-criteria	Relevant Studies	Proposed Measures (Relevant to SDG Target)
G_1 - Quality of Health Care	Patient Safety	Hurst & Jee-Hughes (2001) [13], Caunic (2019) [7], Kim & Jeon (2020) [15]	C_1 - Maternal mortality ratio (A.3.1.1), C_2 - Neonatal mortality rate (A.3.2.2)
	Effectiveness of Treatment		C_3 - Mortality rate attributed to cardiovascular disease, cancer, diabetes or chronic respiratory disease (A.3.4.1), C_4 - Suicide mortality rate (A.3.4.2)
	Transmission Stability		C_5 - Number of new HIV infections per 1,000 uninfected population (A.3.3.1), C_6 - Tuberculosis incidence per 100,000 population (A.3.3.2)
G_2 - Quality of Public Health	Effectiveness of Prevention of Harmful Stimulant Intake	Martin et al. (2024) [18], Arbour et al. (2023) [1], Livingood et al. (2018) [17]	C_7 - Harmful use of alcohol, defined according to the national context as alcohol per capita consumption (aged 15+) within a calendar year in liters of pure alcohol (A.3.5.2), C_8 - Age-standardized prevalence of current tobacco use among persons 15+ (A.a.1)
	Effectiveness of Prevention of Moral Hazard		C_9 - Death rate due to road traffic injuries (A.3.6.1)
G_3 - Financial Protection	Risk Protection	Murray & Frenk (2000) [21], Hurst & Jee-Hughes (2001) [13]	C_{10} - Coverage of essential health services – Index 2UN (A.3.8.1)
	Availability of Financial Resources		C_{11} - Proportion of total government spending on essential services i.e. health, social protection, education (B.1.a.2)
G_4 - System's Resilience	System's Robustness	Paschoalotto et al. (2023) [23], Fallah-Aliabadi et al. (2020) [11], Foroughi et al. (2022) [12]	C_{12} - Proportion of the target population covered by all vaccines included in their national program (3.b.1)
	System's Capacity		C_{13} - International Health Regulations (IHR) capacity (A.3.d.1)
	Availability of Human Resources		C_{14} - Health worker (doctors) density and distribution (A.3.c.1), C_{15} - Health worker (nurses) density and distribution (A.3.c.1)

Table 1: Structure model to measure the sustainability of health systems in the context of SDG health targets (reference to the SDG indicators in brackets).

We also apply MCDA as a robust method allowing multidimensional assessment of health systems sustainability. The preliminary framework is presented in Table 1. MCDA methods find application in the evaluation of problems requiring the consideration of multiple aspects, as they allow the consideration of many often conflicting criteria in the evaluation of multiple alternatives simultaneously [32].

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However, many of the popular MCDA methods especially those originating from the American school, such as the Analytical Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Weighted Sum Method (WSM), or Multi-Attribute Utility Theory (MAUT) are compensatory in nature meaning that weaker performance of alternatives against a certain criterion can be offset by better performance against other criteria [27]. This phenomenon can cause an option that is very good against one criterion to be rated highly despite poorer performance for another criterion. This is not consistent with the strong sustainability paradigm, which assumes that certain criteria are not compensated by other criteria [24].

Multi-criteria approaches that support strong sustainability can be indicated. Among them are methods derived from the European school, like the Preference Ranking Organization METHod for Enrichment of Evaluation (PROMETHEE) and ELimination and Choice Expressing the Reality (ELECTRE) family of methods [30]. However, these methods are characterized by a more complicated algorithm compared to popular compensation methods, and not all of them produce quantitative results. The identified research gap became the motivation for the development of the SSP-TOPSIS approach, which allows for extending compensatory methods with the ability to model compensation reduction. The proposed approach makes it possible to maintain the simplicity of the known methods and reduce their shortcoming, i.e. compensability.

3 Methodology

This research aims to analyze the health systems sustainability of European Union countries, USA and Switzerland in terms of 15 evaluation criteria C_1-C_{15} belonging to four main dimensions G_1-G_4 listed in Table 1, where UK means United Kingdom. The conducted investigation uses the most recent and complete data obtained from United Nations, SDG Indicators Database (`https://unstats.un.org/sdgs/dataportal/database`). The particular data sources are included in a supplementary file named "data sources" provided on GitHub at the link `https://github.com/energyinpython/SSP-TOPSIS-for-health-systems-assessment`.

3.1 The SSP-TOPSIS method

The SSP-TOPSIS method was developed on the basis of the principles of the widely used MCDA method called TOPSIS, which incorporates the distance of evaluated variants from two vectors representing ideal and anti-ideal solutions. The proposed method includes a novel stage that enables modeling criteria compensation reduction, which is a significant limitation of multi-criteria methods originating from American school represented by TOPSIS. The discussed stage incorporates compensation reduction by subtracting the Mean Deviation of the performance value MD calculated in relation to particular criteria. MD is the difference between the performance of the alternative for a considered criterion

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and the mean performance within the criterion across all alternatives multiplied by the value of the sustainability coefficient. The sustainability coefficient s is a component for modeling compensation reduction and yields real values from 0 to 1. By default, it can be adjusted to the value of the standard deviation from the normalized decision matrix within each criterion. Detailed steps of the presented SSP-TOPSIS method are given below.

To determine the weights of the criteria representing their relevance, the authors chose an objective weighting method called Criteria Importance Through Inter-criteria Correlation (CRITIC) [25]. This method determines the criteria weights based on the values in the decision matrix, taking into account their variability among the alternatives within each criterion. The choice of this weighting technique is justified by the fact that the weighting values determined using it are most evenly distributed among the criteria considered compared to other objective weighting methods, as shown in Figure 1. This effect is in line with the assumptions of the investigation, according to which the significance of the criteria should be evenly distributed and no criterion should be overly favored or omitted.

Step 1. Compute the Mean Deviation MD_{ij} for each performance value incorporated in the decision matrix, subtracting the mean value $\overline{x_j}$ from performance values x_{ij} for each C_j criterion. Then, multiply the outcome by the value of the s_j coefficient. Coefficient s_j denotes the sustainability coefficient, which reflects the level of the compensation reduction of criteria performance. The sustainability coefficient takes real values from 0 to 1. Criteria are numbered by $j = 1, 2, \ldots, m$. High values of s_j represent relevant reductions in the compensation of a j-th criterion performance value. On the other hand, low values of s_j denote a low reduction of the compensation of a particular j-th criterion. The complete procedure of Mean Deviation calculation is carried out using Equation (1).

$$MD_{ij} = (x_{ij} - \overline{x}_j)s_j \tag{1}$$

Step 2. Associate 0 values to these MD_{+ij} for profit criteria C_{+j} that are lower than 0. If MD_{+ij} is lower than 0 it means that x_{+ij} is lower than $\overline{x}_{+j}$. Assign 0 values for these MD_{-ij} for cost criteria C_{-j} that are higher than 0. It denotes that r_{-ij} are higher than $\overline{x}_{-j}$. The procedure described in this step is carried out as Equation (2) demonstrates,

$$MD_{ij} = 0 \, \forall \, MD_{+ij} < 0 \ \vee \ MD_{-ij} > 0 \tag{2}$$

where MD_{ij} defines Mean Deviation values computed for criteria C_j. This stage is relevant because the purpose of it is to prevent unintended improvements in performance values outlying from the mean toward the worse.

Step 3. Subtract MD_{ij} values from performance values x_{ij} included in decision matrix x_{ij} according to Equation (3).

$$t_{ij} = x_{ij} - MD_{ij} \tag{3}$$

The rest of the steps are analogous to the classic TOPSIS method.

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Step 4. Perform the normalization of the decision matrix, which is demonstrated in Equation (4) with chosen normalization technique, for example the Minimum-Maximum normalization or Vector normalization, which is the default normalization for the TOPSIS method. In Minimum-Maximum normalization, normalized values represented by r_{ij}^{+} for profit criteria and r_{ij}^{-} for cost criteria are achieved through the application of Equation (5). After performing normalization, each criterion is already transformed to profit criteria.

$$T = [t_{ij}]_{m \times n} = \begin{bmatrix} t_{11} & t_{12} & \cdots & t_{1n} \\ t_{21} & t_{22} & \cdots & t_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ t_{m1} & t_{m2} & \cdots & t_{mn} \end{bmatrix} \tag{4}$$

$$r_{ij}^{+} = \frac{t_{ij} - min_j(t_{ij})}{max_j(t_{ij}) - min_j(t_{ij})},\ r_{ij}^{-} = \frac{max_j(t_{ij}) - t_{ij}}{max_j(t_{ij}) - min_j(t_{ij})} \tag{5}$$

Step 5. Compute the weighted normalized decision matrix. For this aim, multiply values in the normalized decision matrix by corresponding criteria weights w_j as Equation (6) shows.

$$v_{ij} = r_{ij} w_j \tag{6}$$

Criteria weights were calculated using the CRITIC method.

Step 6. Determine the Positive Ideal Solution (PIS) using Equation (7) and Negative Ideal Solution (NIS) using Equation (8). PIS contains the maximum values of the weighted normalized decision matrix, while NIS contains its minimum values. Due to the previous normalization of the decision matrix, converting criteria into profit and cost is not required.

$$v_j^{+} = \{v_1^{+}, v_2^{+}, \ldots, v_n^{+}\} = \{max_j(v_{ij})\} \tag{7}$$

$$v_j^{-} = \{v_1^{-}, v_2^{-}, \ldots, v_n^{-}\} = \{min_j(v_{ij})\} \tag{8}$$

Step 7. Compute distance from PIS D_i^{+} and NIS D_i^{-} for each alternative according to Equation (9). The default metric for distance computing in the TOPSIS method is Euclidean distance.

$$D_i^{+} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^{+})^2},\ D_i^{-} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^{-})^2} \tag{9}$$

Step 8. Compute the score for each examined alternative according to Equation (10). The C_i value is always within the range of 0 to 1. The alternative that has the highest C_i value is the ranking leader. The ranking is built by sorting alternatives according to preference values in descending order.

$$C_i = \frac{D_i^{-}}{D_i^{-} + D_i^{+}} \tag{10}$$

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4 Results

The preliminary stage of the research was the selection of an objective weighting method for determining the significance values of evaluation criteria. The goal was to choose a technique that would return the most evenly distributed significance values since the authors did not intend to significantly favor or underestimate any criterion. The authors determined the criteria weights from a dataset employing six objective weighting methods including Entropy, Gini coefficient-based [4], IDOCRIW (Integrated Determination of Objective CRIteria Weights) [6], CILOS (Criterion Impact LOSs) [3], Angular [26], and CRITIC (CRiteria Importance Through Intercriteria Correlation) [25] weighting methods. The CRITIC method produced the desired result, as demonstrated in Figure 1. As can be seen in the presented bar chart, neither value of the CRITIC criteria weights has a significant outlying value compared to the other criteria.

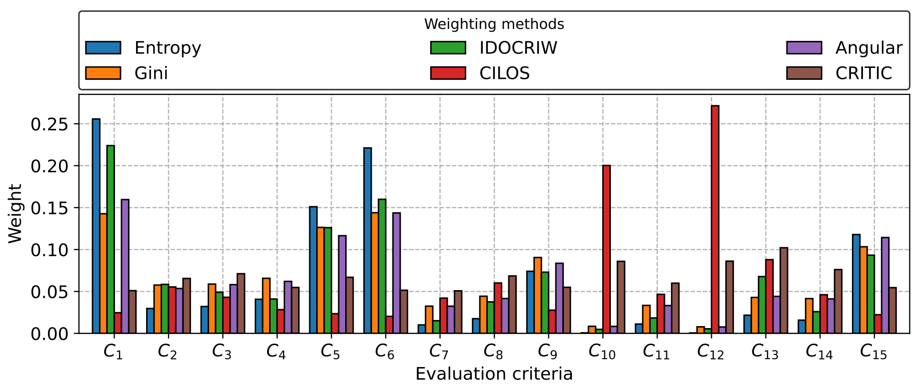

Fig. 1: Criteria weights determined with different objective weighting methods.

The first part of the research conducted using the proposed SSP-TOPSIS multi-criteria method involves comparing the results of the newly developed method with criterion compensation reduction and the classic TOPSIS compensation method. The sustainability coefficient in the SSP-TOPSIS method was set as the standard deviation of the data for each criterion (s=std). The results are shown in Table 2.

It can be noted that the leader of both rankings is Belgium. This indicates that this country has favorable and balanced values in relation to a wide number of evaluation criteria. In second place in both rankings came the USA, and in third place was France. Place 4 in the SSP-TOPSIS ranking was achieved by Lithuania, which was ranked 5th in the TOPSIS ranking. The more favorable score obtained in the reduced-compensation method than in the classical method testifies to balanced and favorable performance values in many of the

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evaluation dimensions represented by the individual criteria. An analogous situation is observed for Germany, which ranked 8th in the TOPSIS ranking and 10th in the SSP-TOPSIS ranking. Hungary, on the other hand, gained 4th place in the TOPSIS ranking while it was 5th in the SSP-TOPSIS ranking. This means that Hungary does not have enough favorable values in a sufficient range of evaluation criteria to remain in 4-th place for compensation reduction.

Table 2: Results of SSP-TOPSIS compared to TOPSIS results.

Country	TOPSIS score	TOPSIS rank	SSP-TOPSIS score s=std	SSP-TOPSIS rank s=std
Austria	0.4647	18	0.4836	19
Belgium	0.5651	1	0.5868	1
Bulgaria	0.4764	15	0.5008	12
Croatia	0.4617	19	0.4939	15
Cyprus	0.3834	29	0.4022	31
Czechia	0.5100	6	0.5349	6
Denmark	0.3805	30	0.4080	30
Estonia	0.3747	31	0.4095	29
Finland	0.4871	11	0.5087	11
France	0.5297	3	0.5514	3
Germany	0.4953	10	0.5172	8
Greece	0.4114	27	0.4269	28
Hungary	0.5219	4	0.5371	5
Ireland	0.4280	25	0.4577	25
Italy	0.4103	28	0.4456	26
Latvia	0.4789	13	0.4991	13
Lithuania	0.5175	5	0.5409	4
Luxembourg	0.4769	14	0.4951	14
Malta	0.4273	26	0.4451	27
Netherlands	0.4714	16	0.4930	17
Norway	0.4492	21	0.4699	23
Poland	0.4664	17	0.4908	18
Portugal	0.4609	20	0.4790	20
Romania	0.5037	8	0.5172	9
Slovakia	0.4441	22	0.4729	22
Slovenia	0.4412	23	0.4604	24
Spain	0.4366	24	0.4752	21
Sweden	0.5087	7	0.5266	7
Switzerland	0.4960	9	0.5140	10
UK	0.4800	12	0.4937	16
USA	0.5451	2	0.5759	2

Czechia and Sweden were also among the well-rated countries. The countries that showed the weakest performance were Cyprus, Denmark and Estonia. These countries are at the bottom of both rankings, which denotes that they have much worse performance values within many criteria, which the favorable values achieved for other criteria cannot compensate for even in the lack of compensation reduction.

The next stage of the research involved conducting a sensitivity analysis with a stepwise increasing the sustainability coefficient value representing the degree of reduction in criteria compensation. Sustainability coefficient values

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were increased by 0.1 starting from 0.0 all the way up to 1.0 within the individual criteria groups of the model: G_1 displayed in Figure 2, G_2 illustrated in Figure 3, G_3 presented in Figure 4, G_4 demonstrated in Figure 5, and in the final step for all criteria shown in Figure 6.

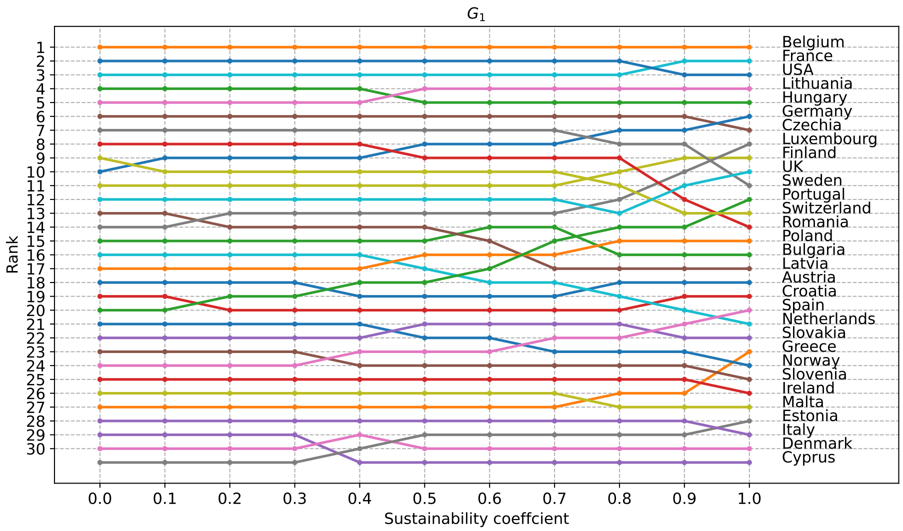

Fig. 2: Rank shifts caused by increasing criteria compensation reduction in G_1.

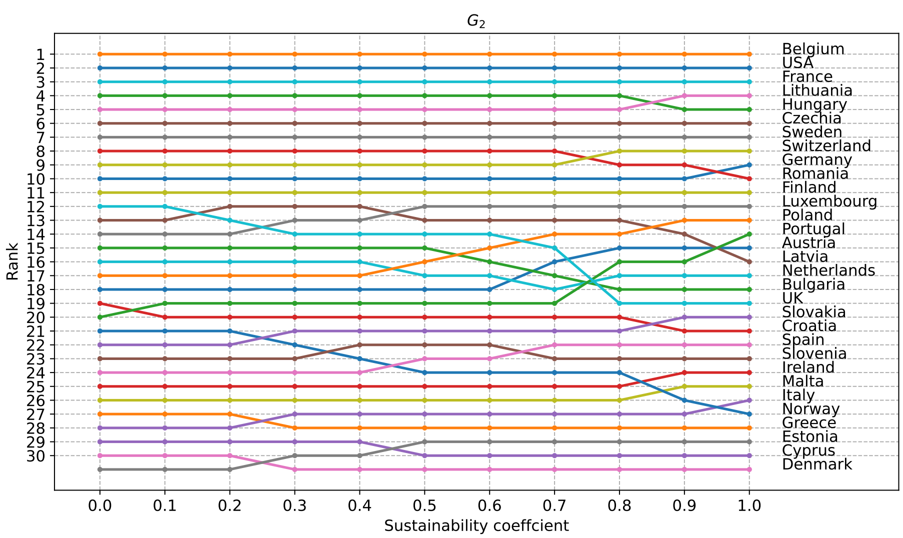

Fig. 3: Rank shifts caused by increasing criteria compensation reduction in G_2.

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When, during increasing compensation reduction, a country advances or remains in a stable position it means that its performance values have favorable and balanced values within a wide range of criteria. On the other hand, if with increasing compensation reduction the country falls in the ranking it implies that it achieves favorable values within certain criteria that allow it to compensate for the weak values achieved for other criteria. In the case of increasing compensation reduction, the possibility of compensating for weak values is reduced, so the country achieves worse rankings. In the case of compensation reductions within the G_1 criteria, it can be observed that the largest decrease with an increase in compensation reduction was registered for Romania and the Netherlands. In contrast, the countries that advanced the most with the increase in compensation reduction were Portugal and Luxembourg. When reducing compensation in the G_2 criteria group, the largest decrease was observed for the United Kingdom and Norway, while the largest promotion was demonstrated by Portugal.

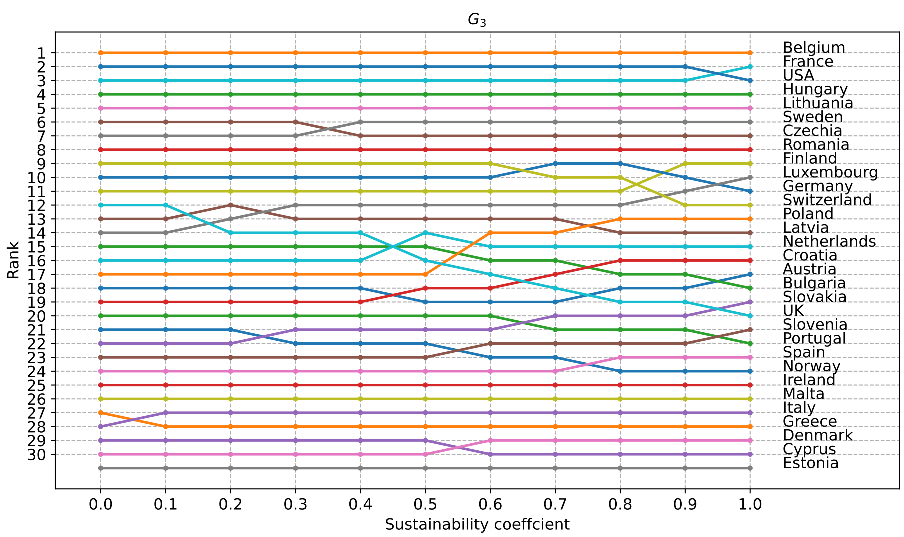

Fig. 4: Rank shifts caused by increasing criteria compensation reduction in G_3.

When reducing the compensation of the G_3 criteria group, the largest decrease was observed for the United Kingdom, and the largest promotion was demonstrated by Poland and Luxembourg. The increasing reduction in the compensation of the G_4 criteria group resulted in the greatest dynamics of changes in places among all criteria groups. The G_4 group had the most shifts with the largest range compared to the other groups. With increasing compensation reduction, the largest promotion was reported for Spain, Croatia, Bulgaria, Ireland, and Italy, and the largest decrease was shown by Hungary, Luxembourg, the United Kingdom, and Romania.

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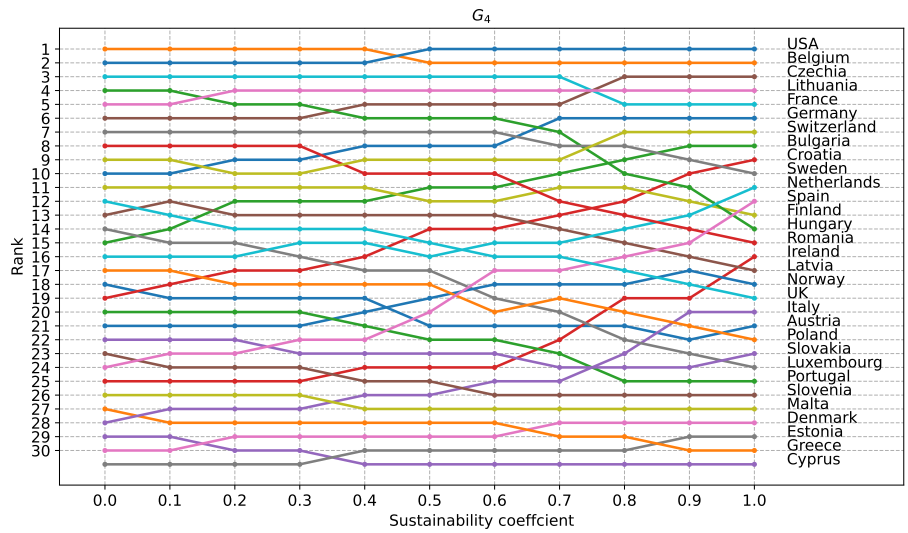

Fig. 5: Rank shifts caused by increasing criteria compensation reduction in G_4.

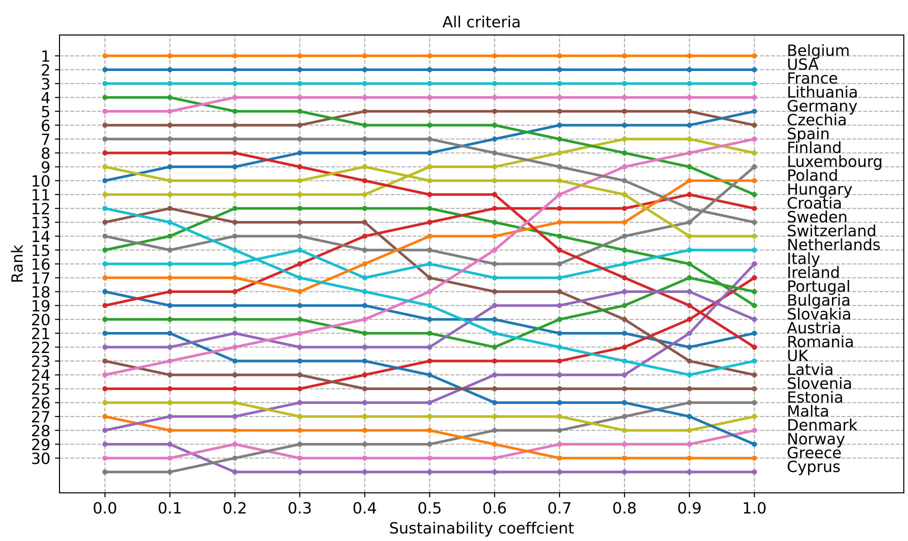

Fig. 6: Rank shifts caused by increasing compensation reduction of all criteria.

The high dynamics of the results when reducing the compensation of the G_4 criteria group indicates that there is a high sensitivity in the health system's resilience of the evaluated countries to the variability within this criteria group,

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which is determined by the large range of discrepancies in the performance values achieved by the evaluated countries against these criteria. For comparison, an analysis of the impact of compensation reductions on the SSP-TOPSIS ranking was also carried out with all criteria considered, resulting in the greatest dynamics of change with the widest range. In this case, Spain and Italy showed the greatest potential for advancement, while the largest decrease was recorded for Romania. The results obtained show that Belgium, the US, France, and Lithuania are among the countries ranked at the top regardless of the increasing reduction in compensation. The results received from the sensitivity analysis confirm the sustainability and stability of the performances achieved by these countries within a sufficiently broad group of criteria.

5 Discussion

Our results are consistent with those obtained by other authors [2,14,19] who emphasize the importance of sustainable development and adapting health policies to local needs and country health policies although our work is unique in terms of the applied method. Similar conclusions have been made by Konarzewska [16] who analyses the 12 indicators proposed by Eurostat to measure the achievement of Agenda 2030 Goal 3 on health and well-being. The study shows the dynamics of the values of these indicators between 2002 and 2017 and compares the situation in 28 EU countries in 2017, applying univariate and multivariate statistical analysis. The results show the varying situation of EU countries in the pursuit of healthy lives and well-being of citizens.

The European Commission's 'State of Health in the EU' [9] initiative aims to facilitate access to information on health systems, expertise and best practices for health policy makers. Our study can be used as a reference in this context and be helpful to prepare the reports, such as 'Health at a Glance: Europe' [22] , which assess progress in building effective, accessible and resilient health systems in EU countries.

With our research, we open the scientific discussion on not only the need to tailor health goals to the specific conditions of each country, but first of all on the measurement of the SDG 3 health targets monitoring the progress toward sustainable health systems. Regular monitoring of progress and the use of available data and analysis, such as that provided by our work, are key to the effective setting and achievement of well-being and welfare in European countries. The methodical contribution is a proposal for solving this problem of sustainable health systems assessment of the SSP-TOPSIS method, which reduces criteria compensation, thus supporting the paradigm of strong sustainability.

In this research, criteria according to the WHO Impact Framework GPW 13 [33] were used to build the model, following the availability of data for selected countries. The few criteria for which Eurostat does not update data or countries do not report them were discarded. The model adopted criteria from group A, i.e. Health targets (SDG 3). In further work, the authors plan to expand the model to include criteria from group B, i.e. Health related SDG targets.

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6 Conclusions

The paper presents a multi-criteria SSP-TOPSIS method for compensation reduction and confirms its applicability in decision support systems for assessing the sustainability of healthcare systems using the proposed author's evaluation model as an example. The modeling of compensation reduction in the proposed method provides broader analytical capabilities compared to the classical TOPSIS method and enables reliable sustainability assessment. Directions for future work include expanding the model to include additional evaluation criteria and extending other multi-criteria methods to include compensation reduction modeling capabilities. Benchmarking with more data is also required. Another interesting direction for further work is to analyze the long-term dynamics of the model's indicators using temporal MCDA methods.

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