Development of a Global Sustainability Index for G8+5 Countries by Using TOPSIS

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Abstract

It has been well established that sustainable development is a critical issue worldwide. Countries should consider the conservative consumption of available resources while maintaining their desired levels of economic growth. This study aimed to develop a global sustainability index for the Group of Eight + Five (G8+5) countries by using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The index is based on three criteria: the Gross Domestic Product, carbon dioxide emissions, and the World Happiness Index, which constitute the economic, environmental, and social dimensions, respectively, of sustainability. The results indicate that the TOPSIS has a competitive advantage over other multiple-criteria decision-making techniques. They also reveal the criteria weight sensitivity of the developed index. This suggests that policymakers and researchers should pay special attention to criteria selection and weighting.

Keywords
Global Sustainability Index, TOPSIS, sustainability, G8+5.

1. Introduction

It has been well established that sustainable development (SD) is a critical issue worldwide. SD initiatives aim to meet the needs of current and future generations (Schaefer and Crane, 2005). This creates a dilemma for countries as they promote conservative approaches to resource consumption while maintaining their desired levels of economic growth. Therefore, in the past two decades, developed countries and many developing countries have sponsored SD initiatives (Bilgili et al. 2017, Borland et al. 2019, González et al. 2017, Majid 2020, Zhang and Wen 2008). Given that the Group of Eight + Five (G8+5) countries are either the most developed countries (Canada, France, Germany, Italy, Japan, Russia, the United Kingdom, and the United States) or the largest emerging economies (Brazil, China, India, Mexico, and South Africa), their initiatives are supposed to represent the ideal sustainable practices that can be benchmarked. Thus, this paper argues that the economic, social, and environmental data from these 13 countries could encourage researchers and policymakers worldwide to investigate and to benchmark SD initiatives.

1.1 Objective

This study aimed to develop a global sustainability index for G8+5 countries by using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The developed index is based on three criteria: the Gross Domestic Product (GDP), carbon dioxide (CO_2) emissions, and the World Happiness Index (WHI), which constitute the economic, environmental, and social dimensions, respectively, of sustainability.

2. Literature Review

Mensah and Casadevall (2019) noted that although sustainability refers to the capacity to maintain "things" over time

(Basiago 1998), most studies (Mensah and Enu-Kwesi 2019, Milne and Gray 2013, Tjarve and Zemīte 2016) have employed this approach in the pursuit of economic, social, and environmental improvement. Taylor (2016) asserted that economic development, social equivalence, and environmental preservation are critical challenges in achieving SD. Indeed, several studies have rephrased these challenges and presented them as the pillars of SD (Mensah and Casadevall 2019). The focus of the economic aspects of sustainability should be the satisfaction of current consumption and future demand. This increases the pressures on production systems (Lobo et al. 2015); thus, critical decisions concerning financial and non-financial aspects of sustainability need to be made (Zhai and Chang 2018). Kolk (2016) asserted that the social aspect of sustainability encompasses more than the satisfaction of individual needs. It also includes the activation of the appropriate enablers. Therefore, climate change is a concurrent issue that highlights the need for improved global environmental protection initiatives (Mensah and Casadevall 2019).

The interaction of the three sustainability pillars has engendered the application of multiple-criteria decision-making (MCDM) to the investigation of sustainability issues and the appropriate solutions (Diaz-Balteiro et al. 2017). TOPSIS approaches have also been applied. For example, the TOPSIS has been applied to the determination of optimal sustainable energy sources (Bhowmik et al. 2020). Alidrisi and Al-Sasi (2017) used a TOPSIS approach to rank the Group of Twenty (G20) countries by the sources of electricity generation. More recent studies have used the TOPSIS to investigate sustainability in countries in Asia (Ikram et al. 2020, Sun et al. 2020), the European Union (EU; Balcerzak and Pietrzak 2016, Vavrek and Chovancová 2019), and the G20 (Lapinskaitė and Vidžiūnaitė 2020).

3. Technique for Order of Preference by Similarity to Ideal Solution

The TOPSIS, which was introduced by Hwang and Yoon (1981), has become one of the most attractive MCDM methods (Behzadian et al. 2012, Çelikbilek and Tüysüz 2020). It has been applied to several research and practical problems, such as those related to energy and the environment, supplier selection, and sustainable development. Several studies (Alidrisi and Al-Sasi 2017, Behzadian et al. 2012) have used a seven-step procedure in applying the TOPSIS:

1. Identify a set of alternatives $(Alt_1, Alt_i, \dots Alt_n)$ for comparison with a set of criteria, j, $(Cr_1, Cr_j, \dots, Cr_m)$ in a decision-making matrix as follows:

$$\widetilde{D} = \begin{array}{c} \\ Alt_1 \\ Alt_i \\ Alt_n \end{array} \begin{array}{ccc} Cr_1 & Cr_j & Cr_m \\ \begin{bmatrix} \tilde{r}_{11} & \tilde{r}_{1j} & r_{1m} \\ \vdots & \vdots & \vdots \\ \tilde{r}_{n1} & \tilde{r}_{nj} & \tilde{r}_{nm} \end{bmatrix} \end{array}$$

where n represents the total number of alternatives $i, i = (1, 2, \dots, n)$; m represents the total number of criteria $j, j = (1, 2, \dots, m)$; and $\tilde{r}_{ij}$ represents the corresponding value of alternatives i with respect to criterion j.

2. Normalize the decision-making matrix by finding $\tilde{b}_{ij}$ through the following formula:

$$\tilde{b}_{ij} = \frac{\tilde{r}_{ij}}{\sqrt{\sum_{i=1}^{n} \tilde{r}_{ij}^2}}$$

3. Develop the weighted version of the normalized decision matrix by using the following formula:

$$\ddot{z}_{ij} = \tilde{h}_j \times \tilde{b}_{ij}$$

4. Determine the positive ideal solution I_j^+ and negative ideal solution I_j^- as follows:

$$I_j^+ = \{(max\ \ddot{z}_{ij}\ |\ j\epsilon J), (min\ \ddot{z}_{ij}\ |\ j\epsilon\bar{J})\}; J \text{ represents the set of benefit criteria}$$

$$I_j^- = \{(min\ \ddot{z}_{ij}\ |\ j\epsilon J), (max\ \ddot{z}_{ij}\ |\ j\epsilon\bar{J})\}; \bar{J} \text{ represents the set of cost criteria}$$

5. Determine the separation measure as follows:

- The separation of each alternative, i, from the positive ideal solution I_j^+ is given by:

$$\ddot{F}_i^+ = \sum_{j=1}^{m} (\ddot{z}_{ij} - I_j^+)^2$$

- The separation of each alternative, i, from the negative ideal solution I_j^- is given by:

$$\ddot{F}_i^- = \sum_{j=1}^{m} (\ddot{z}_{ij} - I_j^-)^2$$

6. Determine the relative closeness to the ideal solution $\tilde{S}_i$ as follows:

$$\tilde{S}_i = \frac{\ddot{F}_i^-}{(\ddot{F}_i^- + \ddot{F}_i^+)}$$

The better alternative is the one with the greater value for $\tilde{S}_i$.

7. Rank the alternatives according to their values regarding $\tilde{S}_i$.

4. Data Collection

The following three criteria were employed to perform the TOPSIS: GDP, CO_2 emissions, and WHI. To collect the data for each country, two reliable sources were accessed: (1) the Key World Energy Statistics Report (IEA 2020) and (2) the World Happiness Report (Helliwell et al. 2020). The first report was used to extract the GDP and CO_2 emissions data for each country, and the second was used to obtain the WHI scores. Table 1 presents the extracted G8+5 data that were required for index development. It can be seen that Canada represents the best country in terms of the WHI score while it has the fourth-lowest GDP. Other contradicting figures can be noticed, for example, when comparing China's GDP with its CO2 emissions; which implies that these criteria are conflicting.

Table 1. World Happiness Index, gross domestic product, and carbon dioxide emissions data for the Group of Eight + Five countries

Country↓	World Happiness Index Score	GDP*	CO$_2$ emissions**
Brazil	6.376	1780.9	427.6
Canada	7.232	1654.6	547.8
China	5.124	13376.4	9528.2
France	6.664	2567.6	303.5
Germany	7.076	3575.4	696.1
India	3.573	2604.6	2307.8
Italy	6.387	1906.5	317.1
Japan	5.871	4522.6	1080.7
Mexico	6.465	1256.4	448.5
Russia	5.546	1421.7	1587
South Africa	4.814	325.9	428

UK	7.165	3082	352.4
US	6.94	19517.3	4921.1

* USD billion
** Mt of CO_2

5. Results and Discussion

Four models were analyzed to demonstrate the sensitivity of the developed sustainability index:

1. Equally weighted criteria model (Model 1): This model assumed that each criterion had the same weight (0.334).
2. WHI perspective model (Model 2):The weight of the WHI criterion was 0.50, and that of the remaining criteria was 0.25.
3. GDP perspective model (Model 3): The weight of the GDP criterion was 0.50, and that of the remaining criteria was 0.25.
4. CO_2 emissions perspective model (Model 4): The weight of the CO_2 emissions criterion was 0.50, and that of the remaining criteria was 0.25.

Table 2 and Figure 1 illustrate that the ranking of the G8+5 countries, except China and the United States, was not sensitive to the perspectives of the developed models. China and the United States performed the best in the GDP perspective model (Model 3). However, they had the worst scores in the CO_2 emissions perspective model (Model 4). In other words, and as shown in Table 2 and Figure 1, when 50% of the criteria weight was assigned to the GDP, 25% was assigned to CO_2 emissions, and 25% was assigned to the WHI, China and the United States received the highest rating. In contrast, the worst scores for China and the United States occurred when 50% of the criteria weight was assigned to CO_2 emissions, 25% was assigned to the GDP, and 25% was assigned to the WHI. It is also worth noting that the results indicate that the WHI is not a sensitive criterion. When 50% of the criteria weight was assigned to the WHI, 25% was assigned to CO_2 emissions, and 25% was assigned to the GDP, the rankings in the WHI perspective model (Model 2) were almost identical to those in the generic model (Model 1), in which each criterion was assigned the same weight (33.334%).

Table 2. Final TOPSIS score for each country by model

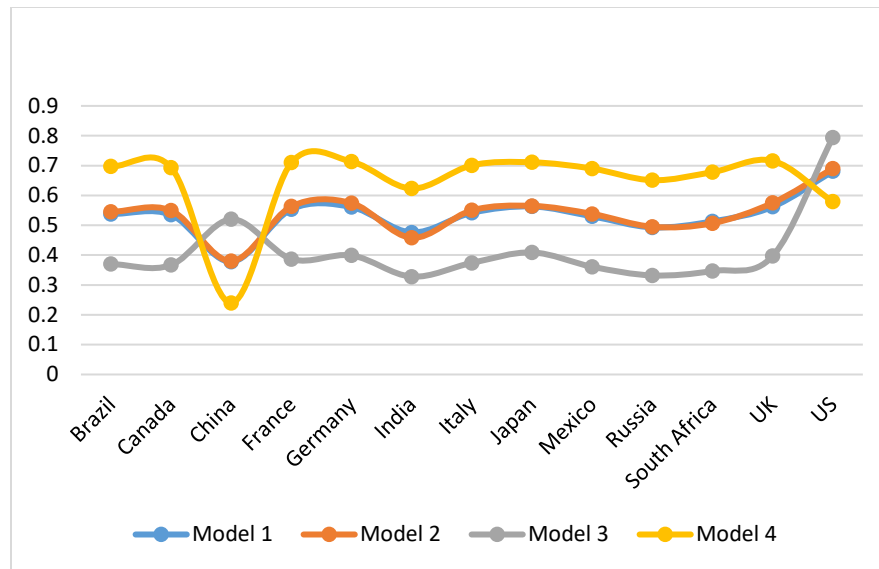| Country ↓	Equally weighted criteria model (Model 1)	WHI perspective model (Model 2)	GDP perspective model (Model 3)	CO_2 emissions perspective model (Model 4)
Brazil	0.538	0.545	0.370	0.697
Canada	0.535	0.549	0.367	0.693
China	0.378	0.380	0.520	0.240
France	0.554	0.563	0.387	0.710
Germany	0.561	0.574	0.399	0.713
India	0.476	0.458	0.328	0.623
Italy	0.542	0.550	0.374	0.701
Japan	0.563	0.565	0.409	0.711
Mexico	0.530	0.538	0.361	0.690
Russia	0.493	0.495	0.332	0.651
South Africa	0.513	0.507	0.347	0.678
United Kingdom	0.562	0.575	0.397	0.716
United States	0.681	0.690	0.794	0.579

Figure 1. Group of Eight + Five countries by model

Figure 2 presents a comparison of the equally weighted criteria model (Model 1) and the GDP perspective model (Model 3). Figure 2 indicates that in the GDP perspective model, China moved from last to second place. In contrast, the UK dropped slightly from third to fifth. The United States maintained its position at the top of the G8+5 countries. The remaining countries either maintained their positions or dropped just one level. It should be noted that in Model 1, 10 of the 13 countries scored higher than 50% (highlighted in green), and three (Russia, India, and China) scored lower than 50% (highlighted in pink). However, in Model 3, all the countries except two countries (the United States and China) scored lower than 50%.

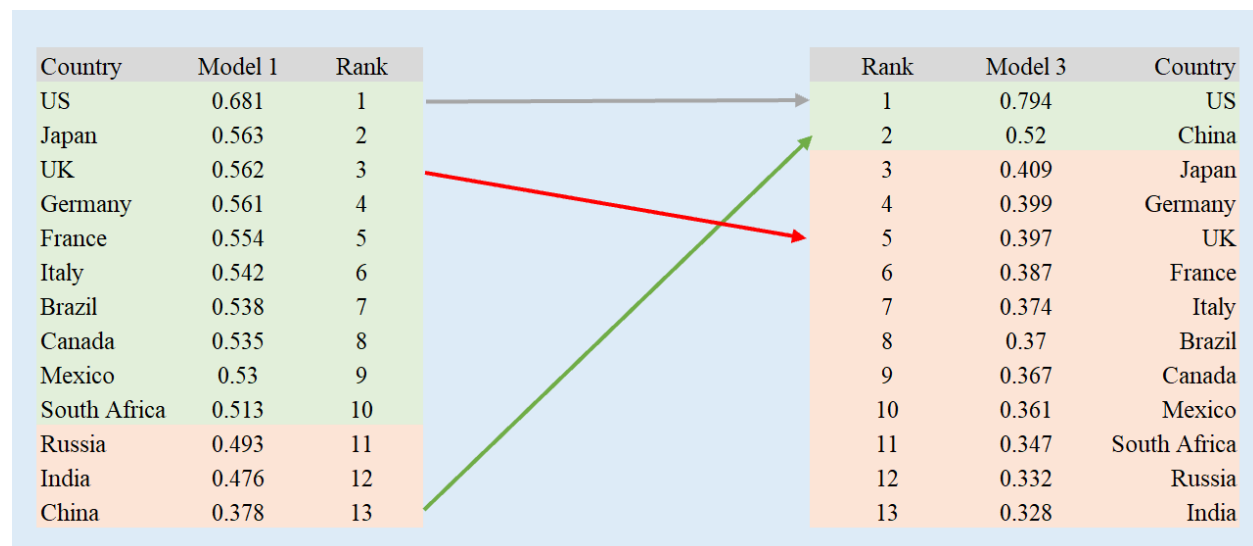| Country	Model 1	Rank		Rank	Model 3	Country
US	0.681	1		1	0.794	US
Japan	0.563	2		2	0.52	China
UK	0.562	3		3	0.409	Japan
Germany	0.561	4		4	0.399	Germany
France	0.554	5		5	0.397	UK
Italy	0.542	6		6	0.387	France
Brazil	0.538	7		7	0.374	Italy
Canada	0.535	8		8	0.37	Brazil
Mexico	0.53	9		9	0.367	Canada
South Africa	0.513	10		10	0.361	Mexico
Russia	0.493	11		11	0.347	South Africa
India	0.476	12		12	0.332	Russia
China	0.378	13		13	0.328	India

Figure 2. Comparison of the equally weighted criteria model (Model 1) and the gross domestic product perspective model (Model 3)

Figure 3 presents a comparison of the equally weighted criteria model (Model 1) and the CO_2 emissions perspective model (Model 4). It shows that in the CO_2 emissions perspective model, the United States dropped from the top of the list to the next to lowest (12). In contrast, as shown in Figure 3, the UK and Germany rose slightly from third and fourth to first and second, respectively. China maintained its position (13) with the lowest score. The remaining

countries either maintained their positions or rose just one level. The exception was Japan, which dropped just one level. It should be noted that in Model 4, all the countries except China scored higher than 50%.

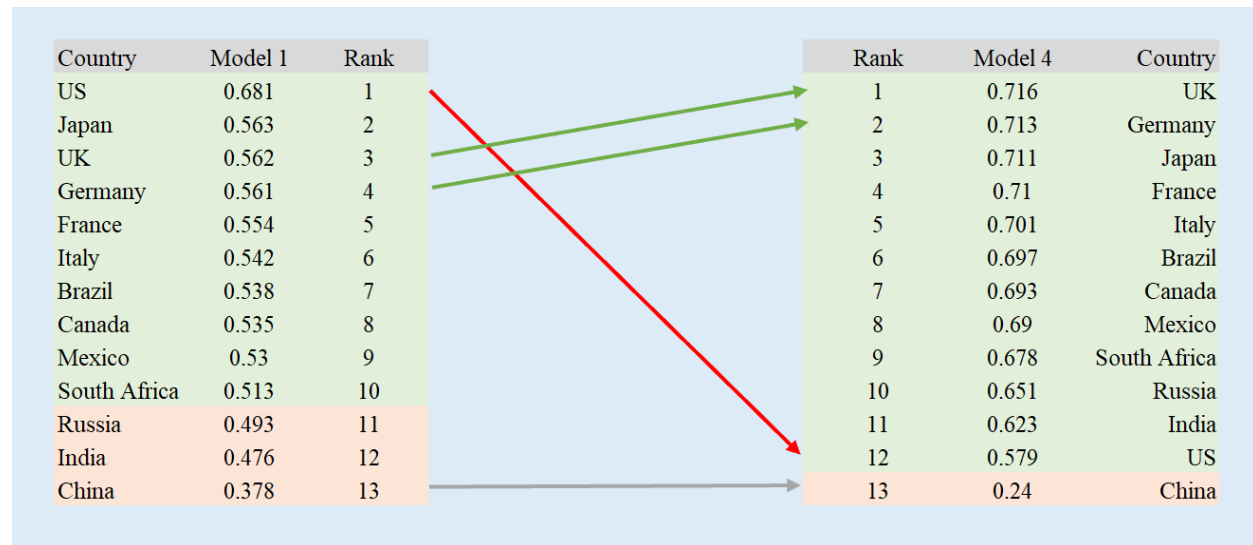| Country	Model 1	Rank		Rank	Model 4	Country
US	0.681	1		1	0.716	UK
Japan	0.563	2		2	0.713	Germany
UK	0.562	3		3	0.711	Japan
Germany	0.561	4		4	0.71	France
France	0.554	5		5	0.701	Italy
Italy	0.542	6		6	0.697	Brazil
Brazil	0.538	7		7	0.693	Canada
Canada	0.535	8		8	0.69	Mexico
Mexico	0.53	9		9	0.678	South Africa
South Africa	0.513	10		10	0.651	Russia
Russia	0.493	11		11	0.623	India
India	0.476	12		12	0.579	US
China	0.378	13		13	0.24	China

Figure 3. Comparison of the equally weighted criteria model (Model 1) and the carbon dioxide emissions perspective model (Model 4)

6. Conclusion

This paper presents the TOPSIS as a flexible MCDM tool to develop a sustainability index. Although the developed index was formulated on the basis of only three criteria and 13 alternatives, an unlimited number of criteria and alternatives (countries in this study) can be managed through the TOPSIS. This flexibility gives the TOPSIS a competitive advantage over other MCDM techniques, such as the analytic hierarchy process (AHP), goal programing, interpretive structural modeling (ISM), and the decision-making trial and evaluation laboratory (DEMATEL). Other MCDM techniques, such as the VIKOR method and the Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE), share the same competitive advantages as the TOPSIS because the criteria and alternatives in these techniques are treated almost similarly during model construction. Such an attribute offers the potential for developing an extended global sustainability index that includes all United Nations (UN) countries. However, the results of the present study indicate that the developed index is very sensitive to criteria weighting. Specifically, the results revealed an extreme difference in the rankings for the United States and China in two of the models: the GDP and CO_2 perspectives. This suggests that policymakers and researchers should pay special attention to criteria selection and weighting.

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Biography

Hisham Alidrisi is an academician with technical and management skills and formal qualifications gained through a practical background in industry and academia. He holds a bachelor's degree in industrial engineering from King Abdulaziz University (KAU), Saudi Arabia; a master's degree in engineering management from the Queensland University of Technology, Australia; and a doctoral degree from the School of Engineering at Griffith University,

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