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ÜLKELERİN SÜRDÜRÜLEBİLİR KALKINMA ENDEKSLERİNİN DEĞERLENDİRİLMESİ: KÜRESEL SÜRDÜRÜLEBİLİRLİK HARİTASI

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ÖZET

Bu çalışma, literatürde sürdürülebilir kalkınmayı ölçmek için geliştirilmiş endekslerin, sürdürülebilir kalkınmanın çok boyutlu doğasını yeterince kapsamadığı iddiasından yola çıkarak, seçilmiş 12 Sürdürülebilir Kalkınma endeksini incelemeyi ve 86 ülke açısından farklılık olup olmadığını belirlemeyi amaçlamıştır. Bu amaç doğrultusunda, seçilen endeksler sürdürülebilir kalkınmanın farklı alt boyutlarına farklı oranlarda odaklandığı göz önüne alınarak, çevresel, sosyal ve ekonomik boyutlara atanmıştır. Böylelikle ekonomik boyut tek bir endeksten, çevresel boyut 3 endeksten, sosyal boyut ise 8 endeksten oluşmuştur. Çevresel ve sosyal boyut için belirlenen endeksler, alt göstergeler arası bağlılıktan doğan korelasyonlarından arındırılmak adına Temel Bileşenler Analizi ile bileşenlerine ayrılmıştır. Sonuçlar, hem çevresel hem de sosyal boyutların tek bileşenden oluştuğunu göstermektedir. Temel bileşen analizi sonuçlarından elde edilen bileşenler ve ekonomik boyuttaki endekse göre ülkelerin mekansal dağılımları incelenmiş ve her bir boyut için elde edilen mekansal dağılımların ülkeler arasında farklılık gösterdiği ortaya koyulmuştur. Bunu takiben, sürdürülebilir kalkınmanın karmaşık doğasının bütünsel bir yansımasını sağlama iddiasında olan Sürdürülebilir Kalkınma Hedefleri Endeksi'nin (SDGI) mekânsal dağılımına ilişkin karşılaştırmalı bir analiz yapılmıştır. Bu karşılaştırma, temel bileşenler analizinden elde edilen mekansal dağılımlarla yapılmıştır. Sonuçlar, sürdürülebilir kalkınmayı ölçtüğünü iddia eden endekslerin aslında farklı boyutlara odaklandığını ve bu durumun ülkelerin mekansal dağılımlarının değişmesine neden olduğunu göstermektedir. Ekonomik, sosyal ve çevresel boyutlar için hazırlanan mekansal dağılım haritalarında özellikle Q_2 ve Q_3 kantil gruplarında farklılık gözlemlenirken, her bir boyut ile SDGI'ye ait mekansal dağılım haritası arasında yapılan karşılaştırmada da yine Q_2 ve Q_3 kantil gruplarında farklılaşma olduğu görülmektedir. Ek olarak, her boyutta Q_1'de yer alan ülkelerin sıralaması SDGI için de değişmezken, her boyutta Q_4'te yer almasına rağmen SDGI'de Q_3'e düşen Amerika, Avustralya ve Meksika gibi ülkeler göze çarpmaktadır. Bu durum,

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genellikle bir veya iki boyuta odaklanan endekslerin, sürdürülebilir kalkınmanın karmaşık yapısını yeterince yansıtamadığına işaret etmektedir.

***Anahtar Kelimeler**: Temel Bileşenler Analizi, Mekansal Dağılım, Sürdürülebilir Kalkınma Endeksleri.*

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EVALUATION OF SUSTAINABLE DEVELOPMENT INDICES OF COUNTRIES: GLOBAL SUSTAINABILITY MAP

ABSTRACT

This study, based on the claim that the indices developed in the literature to measure sustainable development do not adequately capture the multidimensional nature of sustainable development, aims to examine 12 selected sustainable development indices and determine whether there are differences across 86 countries.For this purpose, the selected indices were assigned to environmental, social, and economic dimensions, taking into account that they focus on different sub-dimensions of sustainable development at different rates. Thus, the economic dimension consists of a single index, the environmental dimension consists of 3 indices, and the social dimension consists of 8 indices. The indices for the environmental and social dimensions were decomposed into their components using Principal Component Analysis in order to remove correlations arising from interdependence between sub-indicators. The results show that both environmental and social dimensions consist of a single component. The spatial distribution of countries according to the components obtained from the results of the principal component analysis and the index in the economic dimension were analyzed, and it was revealed that the spatial distributions obtained for each dimension differ among countries. Following this, a comparative analysis is conducted on the spatial distribution of the Sustainable Development Goals Index (SDGI), which claims to provide a holistic reflection of the complex nature of sustainable development. This comparison is made with the spatial distributions derived from the principal components analysis.The results show that the indices claiming to measure sustainable development actually focus on different dimensions, which leads to changes in the spatial distribution of countries. In the spatial distribution maps prepared for the economic, social, and environmental dimensions, differences are observed, especially in the Q_2 and Q_3 quantile groups, while the comparison between each dimension and the spatial distribution map of the SDGI also shows that there are differences in the Q_2 and Q_3 quantile groups. In addition, while the ranking of countries ranked in Q_1 in each dimension remains unchanged for the SDGI, countries such as the United States, Australia, and Mexico, which are ranked in Q_4 in each dimension but fall to Q_3 in the SDGI, stand out. This indicates that indices that generally focus on one or two dimensions do not adequately reflect the complex nature of sustainable development.

Keywords: *Principal Component Analysis, Spatial Distribution, Sustainable Development Indices.*

JEL Codes: *C38, O57, Q01.*

1. INTRODUCTION

Sustainable development represents an approach that is evaluated as a whole with its economic, social, and environmental dimensions throughout the world, and takes into account the needs of future generations. Monitoring, evaluating, and improving development progress was first discussed at the United Nations Conference on Environment and Development in Rio de Janeiro in 1992 (UN, 1992). Development goals were initially adopted by the United Nations General Assembly in 2000 as the Millennium Development Goals (MDGs), covering the period 2000-2015. The MDGs consist of 8 goals and 21 targets, mainly focusing on ending poverty. In this sense, it has been criticized for presenting a narrow perspective with very few indicators. Another criticism is that it includes consolidated targets for using resources for a specific goal rather than targeting the elimination of inequalities within countries (Odera and Mulusa, 2019; 96).

The Sustainable Development Goals (SDGs) were adopted in September 2015 as a follow-up to the Millennium Development Goals. These goals set global development targets for the period 2015–2030. Although officially adopted on this date, the concept of sustainable development was first introduced in 1987 in the Brundtland Report. (Tuazona et al., 2013). It emphasized meeting the needs of the present generation without harming natural resources or the environment while equally addressing the needs of future generations. The Sustainable Development Goals are considered an advanced version of the Millennium Development Goals, which preceded them and included targets to be achieved by 2015. Their focus on the concept of 'sustainability' represents a dynamic framework that plans for future peace and prosperity as part of their claim to '*provide a shared blueprint for peace and prosperity for people and the planet, now and into the future*' (UN, 2023).

The introduction of the Sustainable Development Goals shifted the evaluation of development from being solely based on Gross Domestic Product (GDP) to a new framework (Kwatra, et al., 2020). The concept of sustainable development encompasses three primary dimensions: economic, social, and environmental. These dimensions are considered to represent the complex and multidimensional nature of development (Gilbert et al., 1996; Goodland and Daly, 1996; Boggio and Cortina, 2010).

In alignment with the Sustainable Development Goals, the themes of the development objectives have also evolved, and 17 main goals[1] with 169 targets have been identified to encompass the three primary dimensions of development: economic, social, and environmental. These 17 goals, addressing

[1] 17 Goals: No Poverty, Zero Hunger, Good Health and Well-Being, Quality Education, Gender Equality, Clean Water and Sanitation, Affordable and Clean Energy, Decent Work and Economic Growth, Industry Innovation and Infrastructure, Reduced Inequalities, Sustainable Cities and Communities, Responsible Consumption and Production, Climate Action, Life Below Water, Life on Land, Peace Justice and Strong Institutions, Partnership for the Goals (UN, 2023).

issues such as achieving gender equality and combating climate change, are not standalone objectives but rather encompass interconnected challenges in development. The universal goals set in this direction are grounded in the concept of global public goods, eliminating the sharp distinction between developed and developing countries regarding issues like the environment, health, and economic growth (Odera and Mulusa, 2019; 97). The Sustainable Development Goals take a comprehensive developmental perspective and aim to find universal solutions for the interconnected challenges of development.

The rapid increase in global population, widespread environmental pollution, exhaustion of natural resources, climate change, and the accelerated and more advanced nature of global trade all elevate the importance of sustainable development for countries. Within this framework, it is widely acknowledged that the simultaneous cooperation of countries can be a key factor in achieving success in sustainable development (Liberatore, 2009; Sebestyén et al.,2020).

The approach of establishing universal goals for sustainable development is also reflected in the measurement of achievements in the three sub-dimensions of the sustainable development goals. Various indices have been proposed to measure changes in these sub-dimensions, each aiming to rank countries based on their accomplishments across different sets of indicators. These indices serve to analyze changes while measuring progress toward the goals set for sustainable development. Most of them aim to demonstrate how well the system is performing against the set targets (Tatlıdil and Ünal, 2010). However, many existing sustainable development indices have faced criticism for employing weak data, selecting inappropriate indicators, attempting to narrow down the multidimensional structure of development to a limited and relatively few dimensions, and not considering intangible factors (Aziz et al., 2015). Therefore, by evaluating the existing indices in terms of their suitability for each sub-dimension of development, it can be ensured that more accurate information is provided within the framework of the multidimensional and complex structure of sustainable development for decision-makers who examine these indices.

Sustainable development is presented as a model that guarantees the well-being of future generations. For this reason, achieving sustainable development goals in the contemporary world holds major importance for countries. Although many indices claim to measure sustainable development, they mostly measure only its sub-dimensions. Therefore, it is important to classify indices and indicators according to these basic dimensions in the study. In this context, the aim of study is to systematically categorize existing indices into three main dimensions—economic, social, and environmental—in order to assess sustainable development for practical purposes and use in policymaking.

The study aims to decompose 12 different index that claims to measure sustainable development in the literature, into components using the Principal Component Analysis (PCA) method. Therefore, by eliminating the dependency between the indices assigned to each dimension, the performance of countries in terms of sustainable development dimensions can be compared. In this context, by examining the focus levels of 12 different sustainable development indices on social, environmental, and economic dimensions, the PCA method was applied to the dimensions and the spatial distributions of 86 countries whose data were accessed according to the components obtained as a result of the analysis were examined. It was concluded that spatial distributions differed according to the components. Then, focusing on an index covering all dimensions of sustainable development, the spatial distribution of this index was examined in detail and the results obtained were compared with the main components.

2. SUSTAINABLE DEVELOPMENT INDICES AND ANALYTICAL STUDIES: LITERATURE REVIEW AND EVALUATION OF METHODS

When analyzing the headings of the Sustainable Development Goals, it is anticipated that using a single index to measure progress towards the desired target may be misleading because the sub-indicators representing the goals are interconnected. Additionally, various indices are calculated by international organizations such as the United Nations and the World Bank for the sub-dimensions of the sustainable development goals. Since most existing indices address only one dimension of sustainable development, they cannot serve as a comprehensive expression of sustainable development (Parris and Kates, 2003; Pearce, 2014). Therefore, grouping the indices within their respective scopes is expected to offer advantages to both policymakers focusing on specific dimensions and researchers aiming to develop a comprehensive sustainability index by obtaining more accurate information from each dimension.

To create robust sustainable development indices, it is essential to carefully select indicators that accurately represent the economic, social, and environmental aspects. Within this section, we will initially present studies that analyze sustainable development indices, emphasizing both their advantages and limitations. Next, we will examine analytical studies that, similar to the approach that is to be employed in this study, entail choosing between indices, categorizing countries, or concentrating on comparable aspects of indices.

In their study, Kwatra et al. (2020) mention that the United Nations Commission on Sustainable Development has introduced the 'institutional dimension' as a fourth fundamental dimension, in addition to the three primary dimensions of sustainable development. They outline the steps to be followed in creating a composite sustainable development index. At this juncture, they emphasize that specific indices developed for different dimensions of sustainable development are crucial for decision-makers, providing insights into their proximity to the desired targets in specific dimensions.

In their study, Mair et al. (2017) emphasize the fact that the Sustainable Development Goals (SDGs) unify controversial concepts. They argue that indicators measuring these goals, due to their reductive nature, may pose challenges when attempting to simplify and organize subjective issues. Expanding on these criticisms, they also suggest that SDG indicators can provide new insights through quantitative analysis, such as modeling, and can contribute to a better understanding of sustainability. Thus, indicators that are more appropriately interpreted may be more successful in revealing both weaknesses and strengths.

In summary, theoretical studies on sustainable development emphasize the complex nature of this concept and argue that it is not feasible to determine a single measurement for its evaluation (Parris and Kates, 2003; Kwatra et al.,2020; Ruggerio, 2021). Instead, indices measuring sub-dimensions should be developed to obtain stronger and more comprehensive results. Additionally, if a single index is still deemed necessary, it is suggested that combining these reconstructed indices with different quantitative analyses would be more appropriate. In analytical studies, various methods have been developed to create sustainability indices for countries, enabling the assessment of their success in achieving sustainable development goals on time and the evaluation of the similarities and differences among countries for a particular sub-dimension index. The most prominent of these methods include PCA, input-output analysis with PCA, and data envelopment analysis (Zhao, 2015; Park et al., 2015; Dong et al. 2016). The analytical studies discussed in this context will be limited to those that use PCA, which is also the method employed in this study.

In their study, Strezov et al. (2017) emphasize the importance of identifying indicators that best represent each sub-dimension, considering them to be of equal significance and constructing an overall index based on these indicators. They assess the capability of nine sustainable development indices for three key dimensions through cluster analysis. The findings reveal that only two of these nine indices (the Real Savings Rate and the Sustainable Society Index) effectively represent all three core dimensions of sustainable development. Moreover, only two indices (the Prosperity Change Index and Ecological Footprint) focus solely on the economic or environmental sub-dimension. Upon comparing the Normalized Average Sustainability Index (NASI) created in the study with other indices, it is evident that the Global Well-being Index and the Human Development Index exhibit the least divergence from NASI, respectively.

Mathrani et al. (2023) utilized the Ward Method in their study, where they conducted a cluster analysis on sustainable development indicators for Asian countries. They categorized the 45 Asian countries into groups based on the indicators they defined for each development goal and compared their performances. According to the findings, Southeast, Central, and Western Asian nations are comparatively stronger in the economic dimension, whereas East and Central Asian nations are stronger in the social dimension, and West and South Asian nations are stronger in the environmental dimension.

Using an unsupervised clustering framework, Kanmani et al. (2020) examined the global level of environmental sustainability. In this context, they explain that their primary focus on environmental sustainability is due to the existence of numerous indices developed using different methods within each sub-dimension. These indices have faced criticism for issues such as bias, indicator weighting, and interindicator dependency. Consequently, they aim to address these criticisms by proposing a new data-based framework for the Environmental Performance Index indicators, utilizing the principles of unsupervised learning theory. This approach is intended to facilitate more objective evaluations, particularly within the dimension of environmental sustainability.

Hierarchical cluster analysis and principal component analysis were utilized by Drastichova and Filzmoser (2019) to examine 28 EU countries' 12 sustainable development indicators for the period 2012–2018. The analysis revealed that among the countries divided into four clusters, Ireland, Slovakia, and Hungary transitioned to clusters representing better performance in sustainability in 2013. Consequently, the findings of the analysis allow us to observe the trajectory of countries' sustainability performance over the years.

Lamichhane et al. (2021) used over 90 indicators to assess the performance of 35 OECD countries in achieving sustainable development goals. To address the correlation problem arising from the use of a high number of similar indicators, they employed Goal-Specific Principal Component Analysis (GS-PCA). The new performance scores indicate that group averages have improved for selected indicators related to certain targets, but there are significant differences in the rankings of countries with average and poor performance.

In their study, Megyesiova and Lieskovska (2018) applied PCA and cluster analysis to 15 sustainable development indicators that were specifically chosen for OECD countries. The results of the comparative analysis for the years 2000 and 2015 reveal changes in the clusters of countries in terms of their success in achieving sustainable development goals.

Furthermore, hierarchical clustering analysis and PCA have been applied not only to sustainable development indices or sub-indicators but also to specific indices for each of the sub-dimensions used in policy analysis. For example, Mekonnen et al. (2023) utilize hierarchical clustering analysis and PCA for waste management, whereas Karangoda and Nanayakkara (2023) specifically examine water quality. They employed indices specifically calculated for these issues to observe similarities among countries and seized the opportunity to comparatively analyze the policies of countries in these fields.

It is evident from the literature review that PCA and other data analysis techniques are crucial for examining complex data structures.In this respect, this study will analyze various indices used to measure the complexity of sustainable development for a large number of countries together, unlike the studies in the literature. It will use the PCA method to reveal the main dimensions that each index addresses and its relationship with overall sustainability. This will provide a better understanding of how the data and variables used to construct the indices are aggregated, how they are related, and which factors affect the results and how.

3. METHODOLOGY

3.1. Data Set

The concept of sustainable development, despite its definitional ambiguities, has become a major focus of attention worldwide. Extensive studies have been conducted to identify and measure quantitative indicators of sustainable development. Hundreds of different indicators have been proposed in the literature that can be used to assess various dimensions of sustainable development. The number of studies in this area has exceeded 500 (Parris and Kates, 2003). These efforts reflect the global effort to achieve sustainable development goals and evaluate progress. However, challenges exist in the process of determining and applying these indicators. There is no standard or consensus among the indices regarding the indicators used to measure the three dimensions of sustainable development. Each index uses specific indicators according to its measurement methodology and priorities. The selection of indicators evaluated under the economic, environmental, and social dimensions may vary depending on the purpose, objectives, and focus of the index (Strazov et al., 2017). In this study, 12 sustainable development indices calculated by various institutions and organizations were examined and, as in the study of Strezov et al. (2017), the total number of indicators used in the calculation of these indices and the percentages of indicators falling into economic, environmental, and social dimensions were determined. Considering their sub-indicators, the indices are discussed in the dimension that they focus on among the three main dimensions of sustainable development. These indices and their sub-indicators are briefly discussed below.

Human Development Index (HDI): The HDI, calculated by the United Nations Development Programme (UNDP), is obtained from indicators determined for sub-dimensions of countries' human development such as income, education, and health. For the study, data for 2021 were taken from UNDP's database.

Environmental Performance Index (EPI): EPI, calculated for the first time in 2002 by the Yale University Centre for Environmental Law and Policy, is an index that assesses the environmental sustainability performance of countries (EPI, 2023). It is calculated from 24 sub-indicators included in two main headings: environmental health and ecosystem vitality (Wolf et al., 2022). For the study, data for 2022 were taken from Yale University's database.

Social Progress Index (SPI): SPI is a measure that assesses the social progress of a country based on social and environmental factors. It includes social factors such as education, health, basic human rights, and environmental sustainability. For the study, data from the World Population Review database for the year 2022 were taken. 57

Global Peace Index (GPI): GPI is an index prepared by the Institute for Economics and Peace to evaluate the peace level of countries based on factors such as internal peace, external peace, war potential, and military expenditures. Data for 2022 were taken from the Economics and Peace database.

World Happiness Index (WHI): It is published by the United Nations to evaluate the happiness level of countries. Factors that make up the index include income, social support, freedom, and health. Data for 2022 were taken from The World Happiness Report database.

Global Food Security Index (GFSI): This index is an annual assessment measuring countries' food security through food supply, safe food production, and nutritional status. In other words, it focuses on factors related to sustainable food production. It is prepared by the Economist Intelligence Unit (EIU). Data for 2022 were taken from the report published by Economist Impact.

Ecological Footprint (EF): It measures the rate at which an individual or a country consumes natural resources and compares it with the reproductive capacity of these resources. Data for 2022 were taken from the Footprint Network database.

Global Competitiveness Index (GCI): It is an index prepared by the World Economic Forum. The index assesses the factors that determine the level of economic competitiveness of countries, such as economic performance, infrastructure, innovation, and institutional factors Data for 2020 were taken from the World Economic Forum's database.

Global Hunger Index (GHI): Published jointly by Concern Worldwide and Welthungerhilfe, it is an index designed to comprehensively measure and track hunger at the global, regional, and country levels. The GHI aims to promote actions to reduce hunger worldwide, taking into account factors such as malnutrition, child mortality rates, and policy effectiveness in combating hunger. Data for 2022 is taken from the Global Hunger Index database.

Legatum Prosperity Index (LPI): It is an index prepared by the Legatum Institute to measure a country's level of prosperity by evaluating factors such as economic performance, education, health, and safety. Data for 2022 were taken from the Prosperity database.

Global Innovation Index (GII): Published by Cornell University, INSEAD, and the World Intellectual Property Organisation (WIPO), the GII is an index that assesses the innovation capacity of countries and their knowledge economies about sustainable development. The index, which is calculated from two main indicators: the innovation input index and the innovation output index, includes factors such as research and development, patents, and creative industries (WIPO, 2023). For the study, data for 2022 were taken from the Global Innovation Index database.

Sustainable Development Index (SSI): The SSI, calculated by the Institute of Technology, Cologne University of Applied Sciences, is an overall sustainability index calculated from 21 indicators for the three main dimensions of sustainable development. For the study, the data for 2022 were taken from the SSIndex database.

A common data set has been created for all of the above indices to be used within the scope of the research and considering that some indices are not calculated for all countries, the research is limited to 86 countries. The indices described above focus on different dimensions of sustainable development such as economic development, environmental sustainability, and social equity. Table 1 lists the total number of indicators used to calculate each index and the percentage of indicators that fall into economic, environmental, or social dimensions.

Table 1. The Total Number of Indicators and the Percentage of Indicators That Fall into Economic, Environmental, Or Social Dimensions

Index	Num. of Indicator	Economic	Environmental	Social
HDI	3	33.3%		66.7%
EPI	17		88.2%	11.8%
SPI	57		8.78%	91.2%
GPI*	23	8.7%		91.3%
WHI	8	12.5%		87.5%
GFSI	68	4.4%	29.4%	66.2%
EF	6		100%	
GCI	103	49.5%	3%	47.5%
GHI*	4			100%
LPI	300	6.3%	9%	85.7%
GII	80	31.3%	3.7%	65%
SSI	21	19%	43%	33%

***** In these indices, a high score represents poor performance and a low score represents good performance. For this reason, the scoring was reversed by subtracting the values from 100 in order to be consistent with the other indices in the analysis.
Note: Strezov et al. (2017) 's method was used to calculate the indices' percentages.

LPI stands out as the index with the largest set of indicators with 300 indicators in total. The indices with the widest distribution of indicators among the three dimensions is SSI. GHI and HDI are the indices with the lowest number of indicators. While EF is an indicator that only addresses the environmental dimension of sustainable development, GHI includes only the social dimension of sustainable development. Among the 12 indices selected, there is not a single indicator devoted entirely to the economic dimension; however, the GCI is the indicator that gives the most weight to the economic dimension of sustainable development. The majority of the indicators used in these indices measure the social dimension (62.15 %), followed by the environmental dimension (23.75%). The proportion of indicators assessing the economic dimension of sustainable development is the lowest at 13.75%.

These indices are divided into economic, environmental, and social categories according to the percentage of indicators they contain. As seen in Table 2, this categorization is based on the dimension with the highest weight.

Table 2. Indices Used for Economic, Environmental, and Social Dimensions

Economic Dimension	Environmental Dimension	Social Dimension
GCI	EPI	HDI
	EF	SPI
	SSI	GPI
		WHI
		GFSI
		GHI
		LPI
		GII

A comprehensive analysis of 12 different indices, each addressing particular aspects of sustainable development, has been presented above. These indices also include specialized indicators about sub-dimensions of sustainable development. However, unlike these indices, the Sustainable Development Goals Index (SDGI) addresses the multidimensional and complex nature of sustainable development from a holistic perspective. The SDGI is a thorough tool that assesses how closely nations are getting to the 17 Sustainable Development Goals (SDGs) that the United Nations has set.Indicators for each SDG assess the performance of countries in achieving the relevant targets. The SDGI emphasizes that development is a multidimensional process that includes not only economic growth but also social justice and environmental sustainability. This perspective emphasizes the complex nature of sustainable development and the intertwined relationships between economic, social, and environmental dimensions. The point of this study is to compare the 12 indices that look at different dimensions of sustainable development with the SDGI by breaking them down into their main components based on the three main dimensions they are assigned to and seeing how they differ in terms of where they are found in different countries (Sachs et al., 2023).

3.2. Principal Component Analysis (PCA)

Within the scope of the study, PCA will first be applied to 12 different index values to evaluate the determining factors of sustainable development. PCA is a mathematical procedure generally used for variable or data reduction. Essentially, it transforms the set of variables with possible relationships into a smaller number of uncorrelated variables. The first principal component explains as much of the largest possible variability in the data as possible. Subsequent components are not related to the first component but still explain as much of the remaining variability as possible. All principal components together account for the maximum variability in the original variables. PCA has been explained with two different approaches in the historical process. The first of these is the Pearson approach, which, when it first emerged, was rooted in regression thinking and emphasized the modeling feature. Later, the Hotelling approach, which emphasizes the idea of taking linear combinations of variables, emerged.

Although the Hotelling approach is a multivariate statistical approach, the most important difference between the two approaches is that in the Hotelling approach, the principal components define new axes called principal axes, while in the Pearson approach, subspaces are taken into account (Bro and Smilde, 2014).

PCA is highly sensitive to unit of measurement differences in the original data. For this reason, the method should start by standardizing the data according to different measurement units (Vyas and Kumaranayake, 2006). In this regard, the steps of PCA are listed as follows:

- The data matrix of p variables in n measurements is standardized,
- The correlation matrix of the standardized data matrix is calculated,
- Eigenvalues and standardized eigenvectors of the correlation matrix are calculated,
- From the eigenvalues, the explanation ratio of the principal components to the total variance is found,
- The principal component values are found by multiplying the standardized data matrix with the transpose of each eigenvector (Ersungur et al., 2007; 60).

Dimensional reduction, especially in high-dimensional data, is to 'simplify' the existing data by expressing similar data in close components to purify related data from their relationships. Within the scope of learning paradigms of machine learning, PCA is one of the important examples of unsupervised learning. For this reason, it is seen that PCA is also used in studies conducted within the scope of unsupervised machine learning and unsupervised dimensionality reduction (Howley et al. 2005; Kanchan and Kishor, 2016; Lasisi and Attoh-Okine, 2018). In their study, Ding and He (2004) show that dimensionality reduction based on PCA provides the best low-dimensional linear combination of data and provides evidence for the observed effectiveness of PCA-based data reduction. Unsupervised dimension reduction via PCA is frequently used in areas with multidimensional data such as meteorology, image processing, and genomic analysis (Ding and He, 2004). In many of these studies, PCA is used to project the data into a lower dimensional subspace and look at the spatial distribution (Esmaili et al., 2023; Zhang et al., 2023; Roshan et al.,2022).

4. FINDINGS

In the first step of the study, 12 different sustainability indices that are assumed to measure sustainable development levels for 86 selected countries were analyzed. For each of these indices, the sub-indicators were classified as economic, environmental, and social, and the percentages represented by the indices according to the sub-dimensions were determined by calculating the ratios to the total number of indicators according to this classification. This approach reveals which dimension of sustainable development each of the analyzed indices emphasizes more, thereby enabling a more detailed analysis of the sustainable development levels of the selected countries. This methodological step aims to better understand the multidimensional nature of sustainable development and the relationships between these dimensions.

In the next step, the indices listed in the sub-dimensions they represent were reduced to a single component using the PCA method. However, since there is only one index in the economic dimension, PCA was not applied for this dimension. Initially, the Kaiser-Meyer-Olkin (KMO) and Bartlett's Sphericity Test were applied to assess the significance of the relationships among the indices, classified according to the sub-dimensions they represent, and to evaluate the data's suitability for PCA.

Table 3. Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity Results

	KMO Measure of Sampling Adequacy	Approx. Chi-Square	Sig.
Environmental Dimension	,695	182,600	,000
Social Dimension	,866	1137,793	,000

The KMO test for the environmental dimension is equal to 69.5% and the KMO test for the social dimension is equal to 85.8% and the results for all dimensions are within the acceptable range (greater than 0.50). Bartlett's test result was significant for all dimensions (for environmental dimension; $\chi2(6) = 112,513$; $p<0,000$, for social dimension; $\chi2(28) = 1162,704$; $p<0,000$). These findings indicate that the correlation matrix is significant, suggesting a strong correlation between the indices. Therefore, the dataset is considered appropriate for PCA.

Table 4. Total Variance Explained

	Components	Initial Eigenvalues		
		Total	% of Variance	Cumulative %
Environmental Dimension	1	**2,607**	74,735	74,735
	2	0,654	16,803	91,538
	3	0,254	8,462	100,000
Social Dimension	1	**6,689**	83,609	83,609
	2	,631	7,888	91,497
	3	,255	3,192	94,690
	4	,217	2,712	97,402
	5	,081	1,010	98,412
	6	,074	,920	99,331
	7	,043	,535	99,866
	8	,011	,134	100,000

Since the dataset comprises 12 indices, the analysis is based on standardized data. Therefore, the correlation matrix was utilized. Table 4 presents the initial eigenvalues for two dimensions. When determining the number of components, we accepted the number of eigenvalues greater than 1. Based on Table 4, one component was used for the environmental dimension. The first eigenvalue explains 74.735% of the total variance, meaning that the environmental dimension, consisting of three indices, can be explained by a single variable. Thus, by obtaining a single uncorrelated variable from 3 correlated indices, the dependency structure was eliminated and dimension reduction, which is the purpose of PCA, was achieved. The number of components was taken as 1 for the social dimension. The first eigenvalue explains 83,609% of the total variance. In other words, it is possible to explain the social dimension consisting of 8 indices with a single variable. Thus, by obtaining an uncorrelated variable from 8 correlated indices, the dependency structure was eliminated, and dimension reduction was achieved. The analysed component matrices are presented in Table 5.

Table 5. Component Matrices for Economic, Environmental and Social Dimensions

Environmental Dimension Indices	Component 1
EPI	,919
EF	,826
SSI	,752

Social Dimension Indices	Component 1
HDI	,962
SPI	,977
GPI	,676
GHI	,921
WHI	,884
LPI	,983
GFSI	,959
GII	,915

For the quantile classification of countries, the value of the economic dimension is taken as the GCI value that constitutes the dimension. In addition, the quantile classification of the social and environmental dimensions used the factor loadings generated by PCA. Countries were classified into four groups (Q_1, Q_2, Q_3, and Q_4) by the quantiles of all dimensions. Table 6 shows the quantile groups of countries according to the economic dimension.

Table 6. Countries according to the Economic Dimensions Quantiles

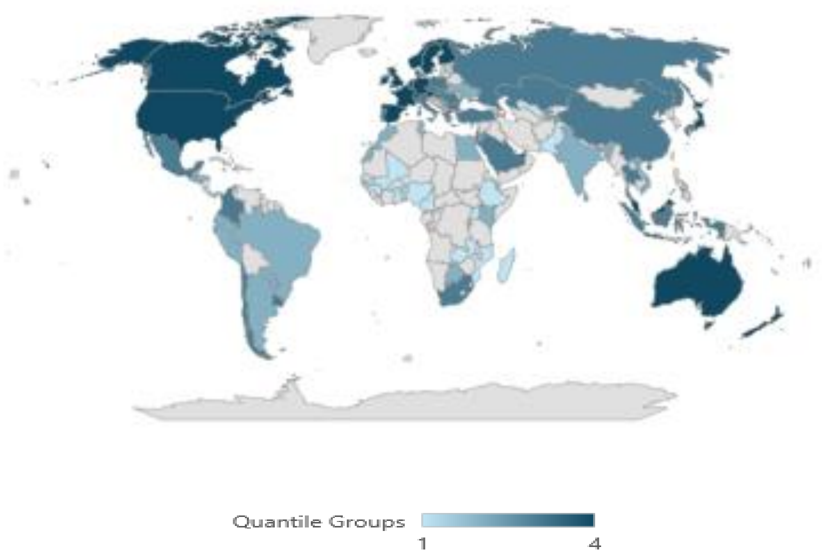
Quantile	Countries
Q_1	Mozambique, Uzbekistan, Madagascar, Burkina Faso, Mali, Ethiopia, Benin, Cameroon, Guinea, Zambia, Tanzania (United Republic of), Nigeria, Uganda, Senegal, Lao People's Democratic Republic, Ghana, Pakistan, Nicaragua, Nepal, Bolivia (Plurinational State of), Bangladesh, Cambodia
Q_2	Tajikistan, El Salvador, Honduras, Guatemala, Paraguay, Kenya, Egypt, Botswana, Ecuador, Tunisia, Ukraine, Sri Lanka, Argentina, Morocco, Brazil, Jordan, Serbia, India, Viet Nam, Panama, Peru
Q_3	Türkiye, South Africa, Greece, Colombia, Kazakhstan, Uruguay, Romania, Indonesia, Bulgaria, Mexico, Hungary, Russian Federation, Slovakia, Thailand, Poland, Saudi Arabia, Portugal, Chile, Czechia, Italy, China

Q_4	Malaysia, United Arab Emirates, Ireland, Spain, Belgium, Austria, Israel, New Zealand, Norway, Australia, France, Canada, Finland, Denmark, Sweden, United Kingdom, Germany, Japan, Switzerland, Netherlands, United States, Singapore

When Table 6 is examined, as the economic dimension progresses from Q_1 to Q_4, a significant improvement is observed in factors such as economic performance, infrastructure and innovation. Countries in Q_1 such as Mozambique, Uzbekistan, Madagascar, Burkina Faso are generally low-income countries with low economic competitiveness. Their economic fragility poses significant obstacles to achieving the sustainable development goals of these countries. Countries such as Tajikistan, El Salvador, Honduras, and Guatemala in Q_2 have better economic competitiveness than countries in Q_1,but still face many economic challenges. Countries such as Turkey, Indonesia, Mexico and Russian Federation in Q_3 are economically more stable and developed compared to Q_1 and Q_2 and are in a better position in economic competition. Countries such as Finland, Denmark, Sweden, United Kingdom, Germany, United States and Japan in Q_4 are considered economic power centers around the world. Their high income levels, advanced industrial and technological sectors, and strong institutions make them leaders in economic competition. In summary, developed countries are generally in a better position in the economic dimension, while developing and underdeveloped countries need to make more efforts to achieve their economic development and sustainability goals.

Figure 1 presents a quantile map illustrating the spatial distribution of countries based on the economic dimension across the world.

Figure 1. Quantile Map of Countries by Economic Dimension



In Figure 1, the values of countries according to economic dimension are shown in different colors on the map as four quantiles. Countries shown in gray are those without data. As the colors become darker on the map, the performance of the countries in economic development increases and decreases as the colors become lighter. The economic dimension index values of the 22 countries with the highest ranking values and shown in the darkest color are in the range of 0.746-0.848. The index values of the 22 countries with the lowest economic development performance, shown in the lightest color on the map, are in the range of 0.381-0.521. It can also be seen in the quantile map that countries differ according to economic dimension. This differentiation demonstrates the diversity of the challenges and opportunities faced by countries in terms of economic sustainability.

Countries are ranked from smallest to largest according to the factor loadings of the environmental dimension. Table 7 shows the quantile groups of countries according to the environmental dimension.

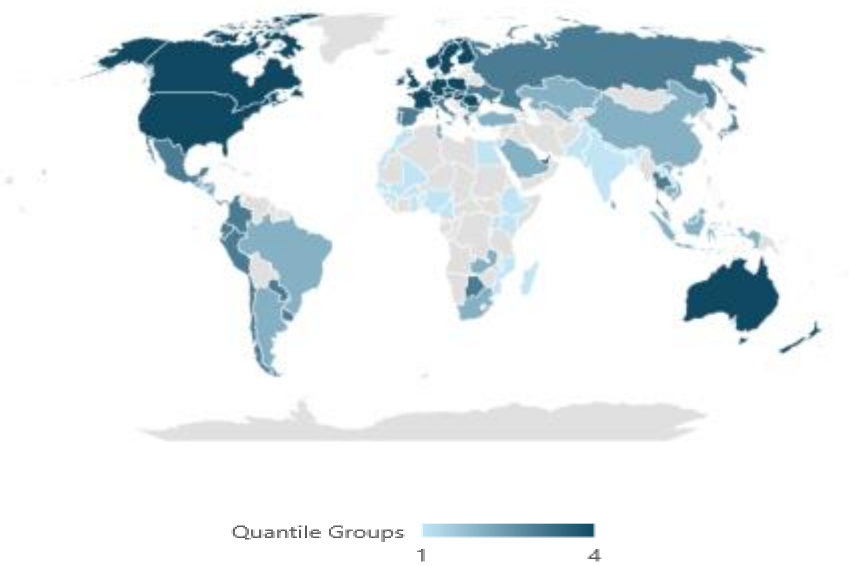
Table 7. Countries According to the Environmental Dimensions Quantiles

Quantile	Countries
Q_1	Guinea, India, Pakistan, Madagascar, Mali, Senegal, Bangladesh, Ethiopia, Kenya, Benin, Burkina Faso, Mozambique, Ghana, Uganda, Nepal, Morocco, Jordan, Tajikistan, Lao People's Democratic Republic, Cameroon, Nigeria, Egypt
Q_2	Viet Nam, South Africa, Zambia, Indonesia, China, Tunisia, Uzbekistan, Cambodia, Tanzania (United Republic of), Türkiye, Honduras, El Salvador, Sri Lanka, Guatemala, Bolivia (Plurinational State of), Malaysia, Brazil, Argentina, Nicaragua, Saudi Arabia, Kazakhstan
Q_3	Peru, Colombia, Thailand, Mexico, Ukraine, Botswana, Serbia, Panama, Ecuador, Japan, Paraguay, Russian Federation, Uruguay, Chile, Israel, Greece, Singapore, Portugal, Spain, Italy, Bulgaria
Q_4	United States, Hungary, Romania, Canada, Ireland, Poland, France, Belgium, New Zealand, United Kingdom, Slovakia, Australia, Germany, United Arab Emirates, Netherlands, Austria, Czechia, Norway, Switzerland, Finland, Sweden, Denmark

Table 7, which represents the environmental dimension, shows the differences among countries' approaches to the environment within the framework of sustainable development. In the environmental dimension, as we move from Quartile 1 to Quartile 4, there is an improvement in the environmental sustainability performance of countries.The Countries in Q_1, such as Guinea, India, Pakistan, and Madagascar, generally face significant challenges in tackling environmental problems and perform poorly in terms of environmental sustainability. Countries in Q_2, such as Vietnam, China, Turkey, Malaysia, Malaysia, Brazil, and Argentina, may have a better environmental performance than those in

Q_1. However, these countries have made progress in environmental protection and sustainable natural resource management, they still face significant environmental challenges. Countries in Q_3 (e.g. Peru, Colombia, Thailand, Mexico, Japan, Russian Federation, Israel, Greece, Singapore, Portugal, Spain, and Italy) are among the developing countries that perform better in environmental sustainability than the countries in Q_1 and Q_2, but are still developing. Countries in the Q_4 group (e.g. United States, Hungary, Romania, Canada, Ireland, Poland, Netherlands, Austria, Czechia, Norway, Switzerland, Finland, Sweden, Denmark, Poland, Netherlands, Austria, Czechia, Norway, Switzerland, Finland, Sweden, and Denmark) ranked the highest in terms of environmental performance. These countries often demonstrate advanced efforts in environmental protection, pollution prevention, investing in green technologies and implementing sustainable development policies. This makes them leaders in the field of environmental sustainability.

Figure 2. Quantile Map of Countries by Environmental Dimension



In Figure 2, the values of countries according to the environmental dimension are shown as four quantiles in different colors on the map. Countries shown in gray are countries with no data. As the colors get darker on the map, the environmental sustainability performance of the countries increases and decreases as the colors get lighter. This differentiation shows that countries make different efforts to achieve environmental sustainability in areas such as environmental management, pollution reduction, protection of natural resources, and combating climate change.

Countries are ranked from smallest to largest according to the factor loadings of the social dimension obtained as a result of PCA analysis and Table 8 shows the quantile groups of countries according to this dimension.

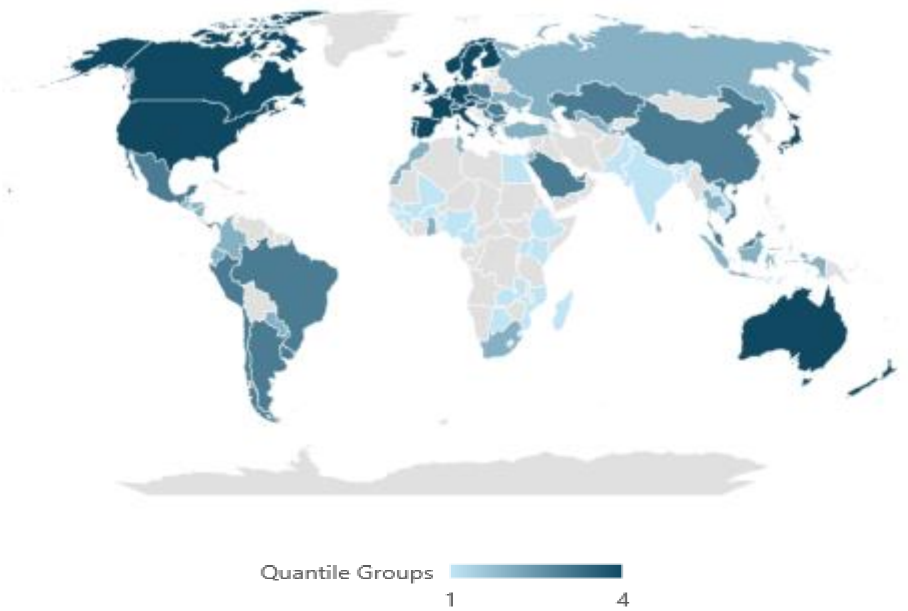
Table 8. Countries According to the Social Dimensions Quantiles

Quantile	Countries
Q_1	Madagascar, Mali, Ethiopia, Mozambique, Guinea, Burkina Faso, Nigeria, Zambia, Pakistan, Uganda, Cameroon, Benin, Tanzania (United Republic of), Kenya, Bangladesh, India, Cambodia, Lao People's Democratic Republic, Senegal, Egypt, Botswana, Nepal
Q_2	Tajikistan, Nicaragua, Ghana, Honduras, Guatemala, Sri Lanka, Jordan, Bolivia (Plurinational State of), Morocco, Tunisia, El Salvador, Indonesia, Colombia, Ukraine, Ecuador, Uzbekistan, Türkiye, South Africa, Paraguay, Russian Federation, Thailand
Q_3	Viet Nam, Brazil, Mexico, Peru, Saudi Arabia, Kazakhstan, Argentina, Panama, Serbia, China, Malaysia, Bulgaria, Uruguay, United Arab Emirates, Romania, Chile, Hungary, Greece, Slovakia, Poland, Israel
Q_4	Italy, Portugal, Spain, Czechia, United States, France, Belgium, Japan, Singapore, Australia, United Kingdom, New Zealand, Austria, Canada, Germany, Ireland, Norway, Netherlands, Sweden, Denmark, Switzerland, Finland

Indices gathered under the social dimension of sustainable development mostly include indicators such as health, education, equality, social justice, and social participation. When Table 8, which includes the classification of countries according to this dimension, is analyzed, countries such as Madagascar, Mali, Ethiopia, and Mozambique, which are in the Q_1 group, generally have low scores in social sustainability performance indicators such as education quality, healthcare, gender equality, and access to social services. Countries in Q_2, such as Morocco, Tunisia, El Salvador, Indonesia, Turkey, South Africa, the Russian Federation, and Thailand, are still struggling with significant social problems, even though they are trying to improve themselves in the areas of social sustainability. Countries such as Viet Nam, Brazil, Mexico, China, Malaysia, Greece, Poland, and Israel are in Q_3. These countries are among the developing countries that perform better in terms of social sustainability. Countries in Q_4 (e.g., Italy, Spain, Czechia, the United States, France, Japan, New Zealand, Canada, Germany, Norway, the Netherlands, and Sweden) generally have high living standards, comprehensive social services, a high quality of education and health care, gender equality, and social justice, and rank highest in terms of social sustainability.

Figure 3 shows the quantile map, which is utilized to determine the spatial distribution of countries according to their social dimension.

Figure 3. Quantile Map of Countries by Social Dimension



The quantile map presented in Figure 3 illustrates the differences in the social sustainability performance of countries. This differentiation shows the diversity of social policies, investments, and social values across countries. This shows that social sustainability is a complex and multidimensional goal and that each country needs to develop policies appropriate to its own circumstances to achieve social sustainability.

In summary, it has been analyzed so far that 12 different indices represent different sub-dimensions of sustainable development and their distribution according to these dimensions. In particular, when the quantile maps created for each dimension are analyzed, the ranking of countries, which are predominantly located in quantiles Q_2 and Q_3, varies. At this point, there is a need to make inferences about the level of success of countries in key dimensions by comparing the change in the distribution of quantile maps for economic, social, and environmental dimensions with the distribution of quantile maps according to a general sustainability index. In this context, in the next step of the analysis, the countries will be divided into 4 quantile groups, and a quantile map will be created by taking into account the SDGI values, which are claimed to reflect the complex nature of sustainable development by taking a holistic approach in all key dimensions. In Table 9, countries are divided into quantiles according to SDGI values.

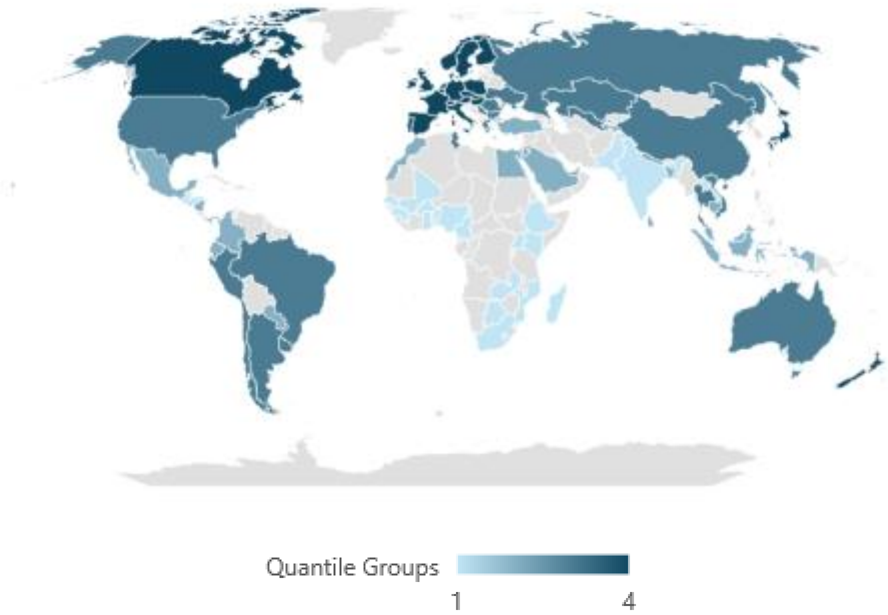
Table 9. Countries According to the SDGI Quantiles

Quantile	Countries
Q_1	South Africa, Madagascar, Burkina Faso, Mozambique, Nigeria, Zambia, Ethiopia, Guinea, Uganda, Benin, Cameroon, Tanzania (United Republic of), Mali, Pakistan, Guatemala, Kenya, Ghana, Senegal, Botswana, Honduras, Lao People's Democratic Republic, India
Q_2	Nicaragua, Cambodia, Bangladesh, Nepal, Panama, Saudi Arabia, Paraguay, Bolivia (Plurinational State of), Tajikistan, Sri Lanka, Egypt, Mexico, United Arab Emirates, Malaysia, Jordan, Colombia, Indonesia, Ecuador, El Salvador, Türkiye, Morocco
Q_3	Uzbekistan, Kazakhstan, Peru, Singapore, China, Tunisia, Viet Nam, Argentina, Brazil, Russian Federation, Israel, Bulgaria, Thailand, Australia, United States, Ukraine, Serbia, Romania, Uruguay, Chile, Greece
Q_4	New Zealand, Canada, Italy, Slovakia, Hungary, Japan, Netherlands, Belgium, Portugal, Ireland, Spain, Switzerland, United Kingdom, Poland, Czechia, Norway, France, Austria, Germany, Denmark, Sweden, Finland

When analyzing Table 9, it becomes apparent that countries falling within Q_1, such as South Africa, Madagascar, Burkina Faso, Mozambique, etc., generally encounter challenges in adopting a holistic approach to economic development, environmental protection, and social welfare. Countries in Q_2, such as Indonesia, Ecuador, El Salvador, Turkey, and Morocco, exhibit slightly better performance in terms of holistic sustainable development. This suggests that they may have made progress towards achieving a more balanced integration of economic development, environmental sustainability, and social justice, yet further efforts are required to fully realize their objectives in these dimensions. Countries in Q_3—Brazil, the Russian Federation, Israel, Bulgaria, Thailand, Australia, and the United States—have demonstrated greater success compared to those in Q_1 and Q_2 in advancing all three dimensions of sustainable development in a harmonized manner. Meanwhile, countries in Q_4 (e.g., New Zealand, Canada, Italy, Slovakia, Hungary, Japan, and the Netherlands) are exemplary in achieving comprehensive success across the economic, environmental, and social dimensions of sustainable development, demonstrating adeptness in applying a holistic approach. These nations have formulated and executed comprehensive strategies aimed at accomplishing sustainable development goals.

In order to visually represent the spatial distribution of countries based on their SDGI scores, the quantile map depicted in Figure 4 was generated.

Figure 4. Quantile Map of Countries by SDGI



As depicted in Figure 4, the quantile map based on SDGI values exhibits distinct variations from the quantile maps representing other key dimensions. In summary, the holistic consideration of sustainable development assumes paramount importance in formulating strategies to address the challenges encountered by countries in their sustainability endeavors. However, as evidenced by the aforementioned findings, the prioritization of sustainable development sub-dimensions varies among countries. While some countries may demonstrate economic robustness, others may exhibit weaknesses in environmental or social dimensions. Hence, it is imperative to evaluate each dimension in alignment with specific circumstances and requirements to comprehensively assess the sustainability performance of individual countries.

5. CONCLUSION

This study aimed to address an important gap in the field of sustainable development by examining the tendency of existing indices to focus on different dimensions. Specifically, this study focused on identifying the limitations and deficiencies of these indices in the context of sustainable development. Given the diversity, dependency, and abundance of sub-dimensions arising from the multidimensional nature of sustainable development, it is evident that most indices in the literature cannot adequately represent this complexity. Many indices place excessive weight on certain sub-dimensions while neglecting others. In light of these issues, this study aims to compare indices that assign different weights to different dimensions of sustainable development in 86 countries with the SDGI, which is a more balanced index that includes all sustainable development goals. For this purpose, 12 different indices used to measure sustainable development in the literature were utilized. Considering the indicators they contain, these indices represent the three dimensions of sustainable development, namely the economic, environmental, and social dimensions, by focusing on them at different rates. Therefore, in the first step of the study, these indices were assigned to environmental, social, and economic dimensions, considering that they focus on different subdimensions of sustainable development in varying proportions. Thus, the economic dimension consisted of a single index, the environmental dimension consisted of three indices, and the social dimension consisted of eight indices. This approach is important for evaluating the scope and effectiveness of sustainable development indices. Dimension reduction was achieved by applying PCA to dimensions other than the economic dimension, and indices that were highly correlated with each other were uncorrelated. The spatial distribution of the countries according to the components obtained as a result of principal component analysis and the economic dimension index were examined, and these distributions were compared with the spatial distribution of the countries according to the SDGI. Based on the claim that SDGI offers a comprehensive approach in terms of the way it is calculated and can comprehensively reflect the multidimensional nature of sustainable development, it has been seen that it can better reflect the current situation of countries when compared to the spatial distributions of other indices. This study aims to help policymakers, researchers, and interested parties in sustainable development to understand both the specialized sub-dimensions and the holistic nature of development. Thus, it can contribute to the development and implementation of more effective and localized sustainable development strategies.

The results of the analysis showed that the quantile rankings of countries in different dimensions of sustainable development varied. In general, countries in the Q_1 and Q_2 quantiles showed poor performance in a certain dimension of sustainable development, while countries in the Q_3 and Q_4 quantiles showed higher performance. When examining how differentiation is distributed according to dimensions, it was seen that some countries in Q_1 in the economic dimension were not in Q_1 in the environmental or social dimension. This suggests that some countries perform better in certain dimensions while performing worse in others. In other words, a country with poor economic performance may perform better in terms of environmental or social performance and therefore be included in different quantiles. The quantiles with the most differentiation are generally Q_2 and Q_3 quantiles. This shows that countries with low and medium performance across the different dimensions of sustainable development have greater variation. Among these countries, some may show improvement in a certain dimension and move on to other quantiles, while others may show regression in certain areas. Countries in the Q_4 quantile group show more consistent performance. The difference between these quantiles with respect to size is less clear. The reason for this may be that the countries in this group have a high level of development and generally have high performance in all three dimensions of sustainable development. The variation in quantile distributions highlights the important differences between countries' performances in different dimensions of sustainable development. This difference provides important insights for policymakers and researchers on which areas should be focused on to achieve sustainable development goals. It also shows that while some countries make improvements in certain dimensions, they may lag behind others, so policy interventions and resource allocation should be shaped by taking these imbalances into consideration.

On the other hand, in the second step of the analysis, in addition to the spatial distributions obtained for each dimension, the spatial distributions of SDGI, which are thought to provide a more comprehensive perspective on sustainable development and determine a general sustainability level due to the way it is calculated in the literature, were determined. This distribution enables a comparison of economic, social, and environmental dimensions. When the spatial distributions were compared, it was seen as a natural result that the spatial distribution of the SDGI differed across all sub-dimensions. In particular, it can be seen that countries in the same quantile in all three main dimensions are also in the same quantile in SDGI. However, when examined in more detail, the locations of countries such as the United States, Mexico, Australia, Uzbekistan, and South Africa are seen to be different in all three main dimensions in the quantiles made according to the SDGI. All these countries, except Uzbekistan, have shifted to the less successful quantile group in the SDGI. The shift of these countries to the less successful quantile in the quantile ranking based on the SDGI, which is believed to be a more consistent measure of sustainability, is a remarkable finding for policymakers. In addition, it can be seen that the quantile in which countries such as Russia, Turkey, Kazakhstan, China, India, Romania, Paraguay, Peru, Spain, and Morocco are included in the SDGI is the same as the quantile in which they are included in two main dimensions. Moreover, it has been observed that the quantile of countries such as Brazil, Argentina, Colombia, Saudi Arabia, Ukraine, and Egypt in the SDGI overlaps with the quantile of only one main dimension. At this point, most of the countries whose quantile in the SDGI is the same as the quantile in two main dimensions are in the less successful quantile group in the SDGI, while most of the countries whose quantile in one main dimension is the same as the quantile in two main dimensions are in the more successful quantile group in the SDGI.

Finally, from a more general perspective, almost all of the countries in Q_1 in all three main dimensions have Q_1 quantiles in the SDGI, and the countries in Q_4 in all three main dimensions have almost all of them in the SDGI, except for the above-mentioned exceptional countries. It can be said that the quantile is also Q_4, and the biggest difference between the SDGI quantiles and the quantile ranking of the main dimensions is observed in the environmental dimension.

Successful sustainable development is possible by combining economic, environmental, and social dimensions and addressing these factors in a balanced manner. The findings of the study revealed that sustainable development indices have some limitations in comprehensively measuring the performance of countries in economic, social, and environmental dimensions. Principal components analysis has shown that these indices generally focus on the sub-dimensions of sustainable development, thus highlighting performance in specific areas rather than providing a holistic assessment. This emphasizes the importance of developing new methodological approaches and indicators to comprehensively evaluate sustainable development and consider these interdimensional relationships in policymaking processes. Analyzing the variation in quantile distributions of countries allowed us to better understand the multidimensional nature of sustainable development performance and revealed the dynamics underlying performance differences between countries. This information can be used to develop sustainable development strategies and policies that consider factors such as economic growth, social welfare, and environmental protection in a balanced manner by understanding the strengths and weaknesses of each group of countries. Therefore, the study suggests that future studies should focus on methodologies for measuring sustainable development performance in a more comprehensive and integrated manner, which can fill the gaps in this field and provide more effective solutions to the challenges faced by policymakers.

One of the limitations of this study is that the process of assigning indices to certain dimensions is based on the researchers' own judgment, although it is supported by the literature. This shows that the content and dimensions of the indices may vary depending on the researcher’s personal perspective. In addition, the lack of a generally accepted sustainable development index in the literature, which may affect the validity and generalizability of the research, is another limitation.

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