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RANKING OF GEOGRAPHICAL REGIONS ACCORDING TO CEMENT INDUSTRY SUSTAINABILITY PERFORMANCE CRITERIA WITH MULTI-CRITERIA DECISION MAKING METHODS

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Keywords

Cement industry, Sustainability, Multi-Criteria Decision Making, Entropy, ARAS.

Abstract

The cement production process uses non-renewable resources to convert large amounts of raw materials into finished products. In this process, high energy use causes high CO_2 emissions. The aim of this study is to rank geographical regions according to selected sustainability performance indicators regarding gray and white cement production, using Getting Numbers Right (GNR) 2018 data. Eleven different geographical regions are included in the reports published by GNR. In the ranking of these countries, total cement production volume, total gross CO_2 emission amount, gross CO_2 emission amount excluding CO_2 resulting from on-site electricity production, total net CO_2 emission amount excluding CO_2 resulting from on-site electricity production, total external power consumption for cement production, total alternative fossil fuels, and the sustainability performance criteria of the mixed fuel consumption amount and the total biomass fuel amount were taken into account. In this problem, Multi-Criteria Decision Making (MCDM) methods were used since the geographical regions would be ranked according to the determined performance criteria. In the proposed integrated approach, entropy was used to determine the weights of the performance criteria, and the

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Additive Ratio Assessment (ARAS) method was used to rank the geographical regions. As a result of the study, the first three places were Brazil, the Commonwealth of Independent States (CIS), and North America, and the resulting ranking was discussed. It has been determined that the proposed integrated approach is an easy-to-implement and effective method to obtain the sustainability performance ranking of geographical regions.

ÇİMENTO ENDÜSTRİSİ SÜRDÜRÜLEBİLİRLİK PERFORMANS KRİTERLERİNE GÖRE COĞRAFİ BÖLGELERİN ÇOK KRİTERLİ KARAR VERME YÖNTEMLERİYLE SIRALANMASI

Anahtar Kelimeler

Çimento endüstrisi, Sürdürülebilirlik, Performans göstergeleri, Çok kriterli karar verme, Entropi, ARAS.

Öz

Çimento üretim süreci, büyük miktarda ham maddeyi bitmiş ürünlere dönüştürmek için yenilenemeyen kaynakları kullanır. Bu süreçte yüksek enerji kullanımı yüksek CO_2 emisyonlarına neden olur. Bu çalışmada, Getting Numbers Right (GNR) 2018 verilerine göre coğrafi bölgelerin gri ve beyaz çimento üretimine ait seçilen performans göstergelerine sıralanması amaçlanmıştır. Bu sıralama için göz önünde bulundurulan sürdürülebilirlik performans kriterleri şunlardır: Toplam çimento üretim hacmi, toplam brüt CO_2 salınımı miktarı, yerinde elektrik üretiminden kaynaklanan CO_2 hariç brüt CO_2 salınımı miktarı, yerinde elektrik üretiminden kaynaklanan CO_2 hariç toplam net CO_2 salınımı miktarı, çimento üretimi için toplam harici güç tüketimi, toplam alternatif fosil yakıtlar ve karışık yakıt tüketimi miktarı ve toplam biokütle yakıt miktarı. GNR'ın yayınladığı raporlarda, Afrika, Asya, Brezilya, Orta Amerika, Çin – Kore – Japonya, CIS, Avrupa, Hindistan, Orta Doğu, Kuzey Amerika ve Güney Amerika olmak üzere 11 farklı coğrafi bölge ele alınmıştır. Bu problemde, belirlenen performans kriterlerine göre coğrafi bölgelerin sıralaması yapılacağından Çok Kriterli Karar Verme (ÇKKV) yöntemlerinden yararlanılmıştır. Önerilen bütünleşik yaklaşımda, performans kriterlerinin ağırlıklarını belirlemek için Entropy yönteminden, coğrafi bölgelerin sıralaması için de Additive Ratio Assessment (ARAS) yönteminden kullanılmıştır. Çalışmanın sonucunda, ilk üç sırada Brezilya, Bağımsız Devletler Topluluğu (BDT) ve Kuzey Amerika yer almış ve elde edilen sıralama tartışılmıştır. Önerilen bütünleşik yaklaşımın, coğrafi bölgelerin sürdürülebilirlik performans sıralamasının elde edilmesi için uygulaması kolay ve etkili bir yöntem olduğu tespit edilmiştir.

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1. Introduction

Cement production is a process by which enormous amounts of materials are converted into commercial products using non-renewable resources. This process requires high energy, resulting in high CO_2 emissions. Leading members of the cement industry have sought various solutions to increase environmental performance and improve cost competitiveness. For this purpose, they applied to the World Business Council for Sustainable Development (WBCSD) in 1999 and asked them to make an independent assessment and manage the sustainable development problems facing the industry today. Thus, it was aimed to build an understanding of sustainable development, its implications for the cement industry, and the changes in business practices it may require.

Later, in 1999, the Cement Sustainability Initiative (CSI), a global volunteer-based program, was established within the WBCSD. CSI members, ranging in size from very large multinational companies to small local producers, report their energy consumption and CO_2 emissions in accordance with CSI's CO_2 and Energy Accounting and Reporting Standard for the Cement Industry (Cement CO_2 and Energy Protocol). With this reporting, the sector-specific and public Getting Numbers Right (GNR) database was developed. GNR provides a solid and validated analytical basis for total CO_2 emissions and energy consumption data, allowing the industry to monitor and compare performance across geographical regions year on year.

This study aims to rank geographical regions based on sustainability performance indicators related to gray and white cement production. Reports published by GNR cover eleven different geographical regions (Africa, Asia, Brazil, Central America, China, Korea, Japan, Commonwealth of Independent States (CIS), Europe, India, Middle East, North America and South America). Using GNR 2018 data in the ranking of these countries, the total volume of cement produced, total gross CO_2 emissions, gross CO_2 emissions excluding CO_2 from on-site electricity production, total net CO_2 emissions excluding CO_2 from on-site electricity production, total amount of external energy used for cement production from alternative fossil fuels. Sustainability performance criteria such as total amount, amount of mixed fuel consumed, and amount of biomass fuel consumed were considered (GNR Project Reporting CO_2, 2018).

The rest of the study is organized as follows. A brief literature review about ranking countries according to sustainability criteria with Multi-Criteria Decision Making (MCDM) and studies using Entropy and Additive Ratio Assessment (ARAS) hybridization in the second section. In the third section of the study, Entropy and ARAS methods used in ranking countries/regions according to sustainability performance criteria are introduced. Application of the proposed approach is given in the fourth section. The findings of the sensitivity analysis are presented in the fifth section. The findings and proposed future studies are discussed in the last sections.

2. Literature Review

This study will offer flexibility in evaluation studies by using MCDM methodologies to rank countries/regions based on the importance levels of these criteria, considering the sustainability performance factors that are significant in cement production. The Entropy method is often recommended as it is objective and easy to apply for calculating the criteria weights, and the ARAS method for the ranking of countries/regions. The reasons why entropy and the ARAS methods are preferred are as follows: Both approaches do not require decision makers. Effectively, the actual values disclosed by the initial decision matrix serve as the basis for all computations. The ARAS method, introduced by Zavadskas and Turskis in 2010, ranks countries/regions according to their utility function value according to their sustainability criteria. The results obtained from the literature review show that the cement industry does not use integrated Entropy-ARAS approaches when ranking countries/regions according to sustainability performance criteria (Zavadskas and Turskis, 2010).

There are many studies in the literature that rank countries according to sustainability criteria with MCDM methods. Some of recent studies are summarized in Table 1.

In the literature, it is seen that the Entropy method is frequently used in criteria weighting and the ARAS method is frequently used in alternative ranking in MCDM problems. For this reason, studies in which Entropy and ARAS methods are used together are included in resource research.

In a study conducted by Karadağ, Hazar and Babuşcu in 2022, the weighting of the financial indicators selected to determine the performance of Turkish development and investment banks was done with the Entropy method, while the banks were ranked with the ARAS method.

Goswami and Behera (2021a) analyzed which of the seven materials is most suitable for engineering applications based on six critical criteria such as bending fatigue limit, core hardness, cost, surface hardness, ultimate tensile strength and surface fatigue limit. Here, the criteria weights were calculated using the Entropy method, and the materials were ranked using the ARAS method. According to the analysis, it was determined that hardened alloy steel was the worst option among the alternatives, while cast alloy steel was the best option.

In another study by Goswami and Behera (2021b), in the material handling equipment selection problem, the rankings obtained by making the criteria weights with the Entropy method and the equipment rankings with the ARAS and COmplex PRoportional Assessing (COPRAS) methods were compared.

Table 1.

Studies that Rank Countries According to Sustainability Criteria with MCDM

Authors	Ranking	MCDM methods
Burhan, 2024.	Ranking of EU countries and Turkey according to industry, innovation and infrastructure, which is the number 9 sustainability development goal.	VIKOR and MAIRCA.
Brodny and Tutak, 2023.	Ranking of EU-27 countries according to 17 selected criteria for assessing sustainable energy and climate development.	CODAS, EDAS, TOPSIS, VIKOR, and WASPAS.
Kaya, 2020.	Ranking of OECD countries according to the impact of COVID-19 on sustainable development performance.	MAIRCA, MABAC, and WASPAS.
Martín and Carnero, 2019.	Analysis of sustainability of EU countries.	AHP.
Alptekin, 2015.	Ranking of EU countries and Turkey according to sustainable development indicators.	Entropi ve TOPSIS.
Ecer, Pamucar, Zolfani and Eshkalag, 2019.	Sustainability assessment of OPEC countries.	CoCoSo, WASPAS, MABAC, CODAS, and VIKOR.
Göker, Karsak and Dursun, 2022.	Performance Ranking of Countries.	Integrated QFD and Joint Weighted Data Envelopment Analysis Based Fuzzy MCDM.
Brodny and Tutak, 2021.	Assessment of the level of sustainable energy development of Central and Eastern European countries.	TOPSIS, VIKOR, MOORA, and COPRAS.
Tutak, Brodny and Bindzár 2021.	Evaluation of sustainable economic development in the field of energy and climate in EU countries.	COPRAS.
Liu, 2007.	Environmental sustainability assessment of 146 countries	Fuzzy MCDM.

Gök-Kısa, Celik and Peker evaluated the performance of privatized ports with the MCDM approach in their study in 2022. In the study, Mersin, Samsun, Bandırma, İskenderun and Derince Ports were listed according to the criteria of dry cargo, liquid bulk cargo, general cargo, container, RO-RO capacity, total port area, total dock, total dock length and depth. The weights of the criteria were determined according to the Entropy method and the ports were ranked according to the ARAS and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods. Mersin port was identified as the port with highest performance, and these results showed that "container" was the most significant criterion.

In the study conducted by Mishra and Rani in 2023, the sustainable recycling partner selection problem was discussed. In criteria weighting, the q-rung orthopair fuzzy set (q-ROFS) method based on Entropy and discriminant measure was proposed, and the partners were ranked by combining it with the ARAS method

According to Goswami et al. (2022) electrical discharge machining parameters may be optimized in an eco-friendly manufacturing setting. This study's primary goal is to create a new hybrid MCDM model that combines ARAS and COPRAS to determine the ideal input electrical discharge machining parameters for cutting high carbon chrome tool steel plates. The parameters employed to carry out the selection procedure were dielectric level, peak current, flushing pressure, and pulse length at three distinct magnitudes. Then, the values of the five output parameters obtained as a result of the experiment were obtained. Entropy method was used to determine the weights of these five criteria and COPRAS-ARAS hybrid model was used to select the most suitable alternative experiment.

In the study conducted by Eti et al. (2024), the financial and technical obstacles associated with alternative renewable energy project options were evaluated using a new model. Sine Trigonometric Pythagorean Fuzzy (ST-PFN) DEMATEL was used to calculate the weights of the determined criteria. In the next stage, six renewable energy alternatives were ranked with the interval valued Spherical fuzzy multicriteria analysis with ratio and categorical data (SF MAIRCA) approach. Entropy and ARAS methodology were also considered to make a comparative evaluation.

In the study of Azizi and Ardakani in 2023, they used the MCDM approach to evaluate the factors affecting the growth of coastal tourism in Iran. Therefore, literature review, expert opinions and fuzzy Delphi method were used to determine the effective factors that cause the development of coastal tourism in Iran. It used survey and sampling techniques to collect data. Professionals in Iran's coastal tourism industry were selected as participants in the research. Judgmental sampling technique was used, and after the data was collected, the Entropy method was used to determine the weight and importance of each factor. Then, the factors were ranked and evaluated using the ARAS method.

Jamshidi, Karamidehkordi, Karbasioun and Layani (2023) aimed to identify and classify priority areas of rural ecotourism in Chaharmahal and Bakhtiari provinces. Fuzzy Entropy method was used to determine the importance and weight of the determined indicators. The fuzzy Aras method was also used to determine the priorities of the regions. Finally, the indicators determined using the kriging interpolation method in ARC GIS software were interpreted.

3. Methods and Material

The steps of the proposed combined Entropy-ARAS technique are described in this section. In the first stage of the proposed technique is to determine the weights of the criteria by the Entropy method. The steps of ARAS method for ranking the alternatives are provided in the second stage.

In this study, research and publication ethics were followed. This study does not require Ethics committee approval.

Stage 1: Criteria Weight Determination: The Entropy Method

Step 1.1. Determine the criteria and alternatives, then get the initial decision matrix.

In this step, after the alternatives $(A_i, i = 1,2,\dots,I)$ and criteria $(K_j, j = 1,2,\dots,J)$ to be used in the selection problem are determined, the initial decision matrix (B) is obtained as in Equation (1).

$$B = \begin{bmatrix} x_{(1,1)} & x_{(1,2)} & \cdots & x_{(1,J)} \\ x_{(2,1)} & x_{(2,2)} & & x_{(2,J)} \\ \vdots & & \ddots & \vdots \\ x_{(I,1)} & x_{(I,2)} & \cdots & x_{(I,J)} \end{bmatrix} \quad (1)$$

In Equation (1), the elements of matrix B denoted by $x_{(i,j)}, i = 1,2,\dots,I; j = 1,2,\dots,J$ and show the value of ith alternative for the jth criterion.

Step 1.2. Normalize the initial decision matrix.

The alternatives for each criterion in the problem may have varying values in different structures and units. Equation (2) is used to transfer all the values in the original decision matrix to the [0,1] range.

$$n_{(i,j)} = \frac{x_{(i,j)}}{\sum_{i=1}^{I} x_{(i,j)}}, i = 1,2,\dots,I;\ j = 1,2,\dots,J \quad (2)$$

Step 1.3. Find the Entropy value for every criterion.

Equation (3) shows the calculation of Entropy value.

$$e_j = -k \sum_{i=1}^{I} n_{(i,j)} l\,n\left(n_{(i,j)}\right), j = 1,2,\dots,J \quad (3)$$

Equation (3) uses the formula $k = 1\ /\ (ln(I))$ where I shows the number of alternatives. The range of values for entropy is $0 \leq e_j \leq 1$.

Step 1.4. Determine each criterion's degrees of divergence.

Equation (4) provides degrees of differentiation based on the entropy values determined for each criterion.

$$d_j = 1 - e_j, \qquad j = 1,2,\dots,J \quad (4)$$

Step 1.5. Compute the criteria's Entropy weights.

Entropy criteria weights are determined using Equation (5):

$$w_j = \frac{d_j}{\sum_{j=1}^{J} d_j}, \qquad j = 1,2,\dots,J \quad (5)$$

Stage 2: Alternatives Ranking: The ARAS Method

Step 2.1. Convert all criteria to benefit type.

If a criterion is preferred to have low values, it is defined as “cost type criterion”. On the other hand, if a criterion is preferred to have high values, it is called as "benefit type criterion". This step involves converting the cost type criterion values from the original decision matrix into benefit type using the formula $x^*_{(i,j)} = 1 / x_{(i,j)}$. Then, the optimal value is determined by the largest alternative value of each criterion.

Step 2.2. Obtain the normalized initial decision matrix converted to benefit type.

As in Stage 1, the values of the criteria converted to the benefit type of the alternatives are normalized using Equation (6).

$$n^*_{(i,j)} = \frac{x^*_{(i,j)}}{\sum_{i=1}^{11} x^*_{(i,j)}}, \quad i = 1,2,\dots,I;\ j = 1,2,\dots,J \tag{6}$$

Step 2.3. Obtain the weighted normalized matrix.

In this step, the weights of the criteria obtained by the Entropy method in Stage 1 are multiplied by the normalized initial decision matrix. The weighted normalization process is shown in Equation (7).

$$\hat{n}^*_{(i,j)} = n^*_{(i,j)}.w_j, \quad i = 1,2,\dots,I; j = 1,2,\dots,J \tag{7}$$

Step 2.4. Finalize ranking by calculating the optimality function and utility degrees.

Optimality function values for each alternative are calculated with Equation (8):

$$S_i = \sum_{j=1}^{J} \hat{n}^*_{(i,j)}, \quad i = 1,2,\dots,I \tag{8}$$

Then, using Equation (9), the utility degree is found for each alternative.

$$C_i = \frac{S_i}{S_0}, \quad i = 1,2,\dots,I \tag{9}$$

In Equation (9), the S_0 value is obtained by the sum of the optimal values for each criterion. The utility degrees ($C_i{}'$s) obtained for the alternatives are ranked from largest to smallest, and the alternative with the greatest utility value is determined as the best alternative.

4. Application of the Proposed Approach

The proposed method was used to rank the regions/countries that are dominant in cement production in the world according to the determined sustainability performance criteria.

Application of Stage 1: Criteria Weight Determination: The Entropy Method

Step 1.1. Identify alternatives and criteria, create the initial decision matrix.

According to GNR 2018 data, the geographical regions where cement production in the world is concentrated have been determined as alternatives ($A_i, i = 1,2,\dots,11$): Africa (A_1), Asia (A_2), Brazil (A_3), Central America (A_4), China – Korea – Japan (A_5), CIS (A_6), Europe (A_7), India (A_8), Middle East (A_9), North America (A_{10}), South America (A_{11}). The sustainability performance criteria determined for gray and white cement production in these geographical regions. The definitions and types of these criteria are given in Table 2.

Table 2.

Sustainability Performance Criteria; Definitions and Types of These Criteria

Criteria	Definitions of Criteria	Criteria Type
K_1	Total production volumes of cement | Grey and white cement (t cement)	Benefit
K_2	Total gross CO_2 emissions | excluding CO_2 from on-site power generation	Cost
K_3	Gross CO_2 emissions - Weighted average | excluding CO_2 from on-site	Cost
K_4	Total net CO_2 emissions | excluding CO_2 from on-site power generation - Grey and white cement (t CO_2)	Cost
K_5	Total external power consumption for cement manufacturing | Grey and white cement (MWh / $year$)	Cost
K_6	Total alternative fossil fuels and mixed fuels consumption | Grey and white cement (t alternative fossil fuels)	Cost
K_7	Total biomass fuels | Grey and white cement (t biomass)	Cost

The initial decision matrix obtained according to the determined sustainability criteria and alternatives is given in Table 3.

Table 3.

The Initial Decision Matrix

	K_1	K_2	K_3	K_4	K_5	K_6	K_7
A_1	176052385.3	114945138.9	634.2	101811317.6	6926790.0	10958618.3	1972094.8
A_2	84411446.8	62507162.3	650.3	59991405.5	8839621.2	1783248.0	283838.0
A_3	23435888.8	16490755.9	588.8	16412896.3	4002497.2	75456.7	57741.1
A_4	50054669.1	30891074.5	631.6	29348971.5	5244815.7	1130343.2	119290.5
A_5	37991283.1	22432608.0	673.3	21346352.3	2074887.0	778390.8	638374.7
A_6	37228885.1	21702124.5	691.1	21395147.1	2750499.5	175006.8	181786.7
A_7	185815303.7	109962966.5	620.7	108714895.4	19620960.9	743819.1	222718.9
A_8	116337720.2	75885221.7	576.1	74468458.5	4374632.7	997504.3	857255.6
A_9	74316400.6	44497929.5	718.6	43821168.2	3161993.5	637303.8	589790.9
A_{10}	33640344.9	24419559.0	739.5	23800815.5	11130043.4	408737.1	74396.9
A_{11}	39687545.6	27510797.9	588.8	26562270.5	3091333.9	1138259.8	195789.1

Step 1.2. Normalize the initial decision matrix.

All elements in the initial decision matrix are normalized using Equation (2). In this way, all elements are ensured to take values in the range [0,1]. Table 4 gives the normalized initial decision matrix.

Table 4.

The Normalized Initial Decision Matrix

	K_1	K_2	K_3	K_4	K_5	K_6	K_7
A_1	0.205	0.209	0.089	0.193	0.097	0.582	0.380
A_2	0.098	0.113	0.091	0.114	0.124	0.095	0.055
A_3	0.027	0.030	0.083	0.031	0.056	0.004	0.011
A_4	0.058	0.056	0.089	0.056	0.074	0.060	0.023
A_5	0.044	0.041	0.095	0.040	0.029	0.041	0.123
A_6	0.043	0.039	0.097	0.041	0.039	0.009	0.035
A_7	0.216	0.199	0.087	0.206	0.276	0.040	0.043
A_8	0.135	0.138	0.081	0.141	0.061	0.053	0.165
A_9	0.087	0.081	0.101	0.083	0.044	0.034	0.114
A_{10}	0.039	0.044	0.104	0.045	0.156	0.022	0.014
A_{11}	0.046	0.050	0.083	0.050	0.043	0.060	0.038

For example, the normalized value for Brazil (A_3) according to total net CO_2 emissions (K_4) is calculated as in Equation (10):

$$n_{(3,4)} = \frac{x_{(3,4)}}{\sum_{i=1}^{11} x_{(i,4)}} = \frac{16412896.3}{527673698.5} = 0.031 \tag{10}$$

Step 1.3. Find the Entropy value for every criterion.

Each criterion's Entropy value was determined using Equation (3). For example, the entropy value for gross CO_2 emissions (K_3) was obtained as in Equation (11) where $k = 1/ln(I) = 1/ln(11) = 0.417$.

$$e_3 = -k\sum_{i=1}^{7} n_{(i,3)}ln\left(n_{(i,3)}\right) = -0.417[0,089ln(0.089) + \cdots + 0.083ln(0.083)] \\ = 0.999 \tag{11}$$

Table 5 shows the Entropy values for all criteria.

Table 5.

The Entropy Values For All Sustainability Criteria

	K_1	K_2	K_3	K_4	K_5	K_6	K_7
e_j	0.906	0.910	0.999	0.914	0.900	0.649	0.793

Step 1.4. Determine each criterion's degree of divergence.

The degrees of differentiation for each criterion in Table 6 are calculated by subtracting the entropy values listed in Table 5 from 1. For example, the degree of differentiation value for the first criterion is calculated as $d_1 = 1 - e_1 = 1 - 0.906 = 0.094$.

Table 6.

The Degrees of Differentiation of Sustainability Criteria

	K_1	K_2	K_3	K_4	K_5	K_6	K_7
d_j	0.094	0.090	0.001	0.086	0.100	0.351	0.207

Step 1.5. Compute the criteria's Entropy weights.

Equation (5) was used to determine the criteria's Entropy weights and importance rankings, which are shown in Table 7.

Table 7.

The Weights of Sustainability Criteria

	K_1	K_2	K_3	K_4	K_5	K_6	K_7
w_j	0.1019	0.0965	0.0014	0.0926	0.1072	0.3787	0.2227
Rank	4	5	7	6	3	1	2

The Entropy weight of the fifth criterion is given in Equation (12), as an example.

$$w_5 = \frac{d_5}{\sum_{j=1}^{7} d_j} = \frac{0.100}{0.094 + 0.090 + \cdots + 0.207} = \frac{0.100}{0.928} = 0.1072 \tag{12}$$

Application of Stage 2: Alternatives Ranking: The ARAS Method

Step 2.1. Convert all criteria to benefit type.

When the sustainability performance criteria determined in Table 1 are examined, it is seen that all criteria are cost types except for the first criterion (total cement production volumes). Criteria that are cost types are converted to benefit types by inverting them in the initial decision matrix. Then, the largest alternative value for each criterion is determined as the optimal value. The initial decision matrix converted to benefit type and the optimal values of the criteria are given in Table 8.

Table 8.

Initial Decision Matrix Converted to Benefit Type and Optimal Values of Sustainability Criteria

	K_1	K_2	$\cdots$	K_7
A_1	176052385.3	8.70×10^{-9}	$\cdots$	5.07×10^{-7}
A_2	84411446.8	1.60×10^{-8}	$\cdots$	3.52×10^{-6}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
A_{11}	39687545.6	3.63×10^{-8}	$\cdots$	5.11×10^{-6}
Optimal value	185815303.7	6.06×10^{-8}	$\cdots$	1.73×10^{-5}

The benefit type value of the second criterion of the second alternative is calculated as $x^*_{(2,2)} = 1 / x_{(2,2)} = 1 / 62507162.3 = 1.60 \times 10^{-8}$ as an example.

Step 2.2. Obtain the normalized initial decision matrix converted to benefit type.

The values of the criteria converted to benefit type in Step 2.1 are normalized using Equation (6). The normalized initial decision matrix is given in Table 9.

Table 9.
The Normalized Benefit Type Initial Decision Matrix

$n^*_{(i,j)}$	K_1	K_2	K_3	K_4	K_5	K_6	K_7
A_1	0.205	0.026	0.092	0.029	0.057	0.003	0.008
A_2	0.098	0.048	0.090	0.049	0.044	0.019	0.056
A_3	0.027	0.184	0.099	0.179	0.098	0.457	0.276
A_4	0.058	0.098	0.092	0.100	0.075	0.030	0.134
A_5	0.044	0.135	0.087	0.138	0.189	0.044	0.025
A_6	0.043	0.139	0.085	0.137	0.142	0.197	0.088
A_7	0.216	0.028	0.094	0.027	0.020	0.046	0.072
A_8	0.135	0.040	0.101	0.039	0.090	0.035	0.019
A_9	0.087	0.068	0.081	0.067	0.124	0.054	0.027
A_{10}	0.039	0.124	0.079	0.124	0.035	0.084	0.214
A_{11}	0.046	0.110	0.099	0.111	0.127	0.030	0.081
Optimal value	0.216	0.184	0.101	0.179	0.189	0.457	0.276

To demonstrate the normalization procedure at this stage, the third criterion value of the seventh alternative was calculated as in Equation (13).

$$n^*_{(7,3)} = \frac{x^*_{(7,3)}}{\sum_{i=1}^{11} x^*_{(i,3)}} = \frac{0.001611}{0.001577 + 0.001538 + \cdots + 0.001698} = 0.094 \qquad (13)$$

Step 2.3. Obtain the weighted normalized matrix.

The criteria weights obtained using the Entropy method given in Table 7 are multiplied by the normalized initial decision matrix. The weighted normalized matrix is as in Table 10.

Table 10.

The Weighted Normalized Matrix.

w_i	0.101	0.096	0.001	0.093	0.107	0.379	0.223
	K_1	K_2	K_3	K_4	K_5	K_6	K_7
A_1	0.021	0.003	0.000	0.003	0.006	0.001	0.002
A_2	0.010	0.005	0.000	0.005	0.005	0.007	0.013
A_3	0.003	0.018	0.000	0.017	0.010	0.173	0.062
A_4	0.006	0.009	0.000	0.009	0.008	0.012	0.030
A_5	0.004	0.013	0.000	0.013	0.020	0.017	0.006
A_6	0.004	0.013	0.000	0.013	0.015	0.075	0.020
A_7	0.022	0.003	0.000	0.003	0.002	0.018	0.016
A_8	0.014	0.004	0.000	0.004	0.010	0.013	0.004
A_9	0.009	0.007	0.000	0.006	0.013	0.020	0.006
A_{10}	0.004	0.012	0.000	0.011	0.004	0.032	0.048
A_{11}	0.005	0.011	0.000	0.010	0.014	0.011	0.018
Optimal value	0.022	0.018	0.000	0.017	0.020	0.173	0.062

For example, the weighted normalized value for the first criterion of the first alternative is calculated as in Equation (14).

$$\begin{aligned} \hat{n}^*_{(1,1)} = n^*_{(1,1)}.w_1 &= 0.205 \times 0.101 \\ &= 0.021 \end{aligned} \tag{14}$$

Step 2.4. Obtain the final ranking by calculating the optimality function and the utility degrees.

Optimality function values (S_i) and utility degrees (C_i) for each alternative are given in Table 11. Sample calculations for the second alternative are as in Equations (15) and (16), respectively.

$$\begin{aligned} S_2 = \sum_{j=1}^{7} \hat{n}^*_{(2,j)} &= 0.010 + 0.005 + \cdots + 0.013 \\ &= 0.044 \end{aligned} \tag{15}$$

$$\begin{aligned} C_2 = \frac{S_2}{S_0} &= \frac{0.044}{0.022 + 0.018 + \cdots + 0.062} \\ &= 0.141 \end{aligned} \tag{16}$$

Table 11.

Optimality Function Values, Utility Values and Final Rankings of Countries/Regions

Country/Region	S_i	C_i	Rank
Africa	0.035	0.113	11
Asia	0.044	0.141	10
Brazil	0.282	0.907	1
Central America	0.074	0.238	4
China- Korea – Japan	0.073	0.235	5
CIS	0.140	0.450	2
Europe	0.063	0.202	7
India	0.048	0.155	9
Middle East	0.061	0.197	8
North America	0.111	0.357	3
South America	0.069	0.221	6
S_0	0.311		

When the utility degrees (C_i's) are listed from largest to smallest in Table 11, the alternative with the largest utility degree value is determined to be Brazil. Secondly, it was observed that the CIS (Commonwealth of Independent States) and North America were in third place.

5. Sensitivity Analysis

In this section, a sensitivity analysis was conducted to show the accuracy and bias of the ranking results obtained. In sensitivity analysis, the effect of small changes made in the proposed method on the results is observed. The sensitivity study deals with how the geographical region rankings were affected by the objective criterion weighting techniques of the CRITIC and Equal Weight (EA) methods, as well as the criterion weighting technique of Entropy. Criteria weights and rankings are given in Table 12. Calculation steps of the CRITIC method are given in the study conducted in 1995 by Diakoulaki et al.

Table 12.

Comparison of Criteria Weights Using Entropy, CRITIC, and EW Methods

	Entropy		CRITIC		EW	
	w_j	Rank	w_j	Rank	w_j	Rank
K_1	0.1019	4	0.2572	1	0.1429	1
K_2	0.0965	5	0.1191	4	0.1429	1
K_3	0.0014	7	0.1655	2	0.1429	1
K_4	0.0926	6	0.1231	3	0.1429	1
K_5	0.1072	3	0.1166	5	0.1429	1
K_6	0.3787	1	0.1059	7	0.1429	1
K_7	0.2227	2	0.1126	6	0.1429	1

The criteria rankings varied when the Entropy, CRITIC, and EW methods were applied, as shown in Table 12. The following is a list of the justifications for the various criterion weights and rankings. The objective techniques of Entropy and CRITIC reveal criteria weights based on the initial decision matrix's actual values. In a different way, each approach seeks to accomplish effective criterion weighting. The data group with higher values in the entropy method has more uncertainty (Hwang and Yoon, 2012). According to Diakoulaki et al, the CRITIC method uses both the criteria's standard deviations and their correlation with one another (Diakoulaki et al., 1995). Since the data in this study did not fit the normal distribution, Spearman correlation was used. Every criterion is given equal weight in the EW method.

In the subsequent analysis, the ARAS method was applied using the criterion weights listed in Table 12, and Table 13 presents the comparative rankings of the geographical regions. Table 13 demonstrates that the top two countries/regions continue to rank similarly across all criterion weighting techniques. These findings demonstrate that the ARAS approach is a reliable and successful alternative ranking technique.

Table 13.

Rankings of Countries/Regions According to Different Objective Criteria Weighting Methods

	Entropy		CRITIC		EW	
	C_i	Rank	C_i	Rank	C_i	Rank
Africa	0.113	11	0.379	6	0.262	10
Asia	0.141	10	0.301	11	0.253	11
Brazil	0.907	1	0.726	1	0.824	1
Central America	0.238	4	0.373	8	0.367	6
China- Korea – Japan	0.235	5	0.405	5	0.413	4
CIS	0.450	2	0.487	2	0.519	2
Europe	0.202	7	0.428	3	0.314	8
India	0.155	9	0.355	9	0.286	9
Middle East	0.197	8	0.346	10	0.317	7
North America	0.357	3	0.415	4	0.437	3
South America	0.221	6	0.377	7	0.377	5

The graph showing the ranking comparisons of countries/regions is given in Figure 1.

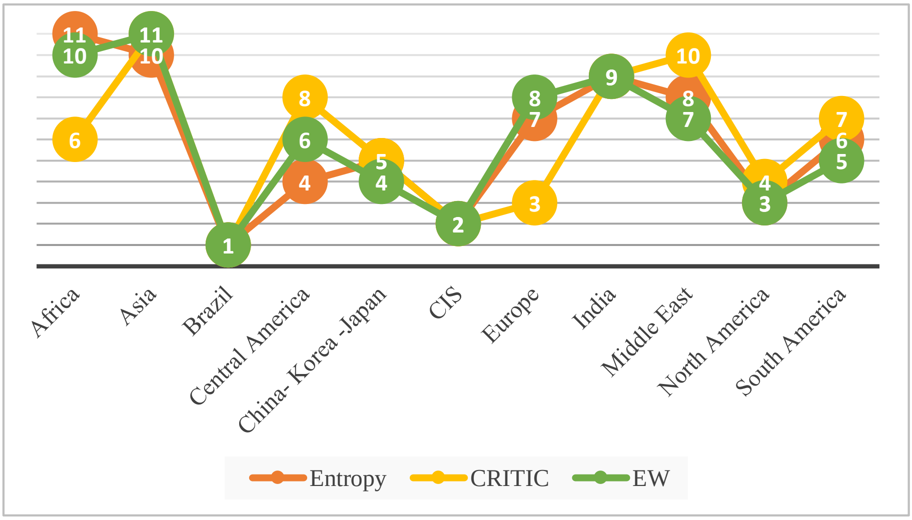

Figure 1. Comparison For Rankings of Countries/Regions Based on Different Criteria Weighting Methods

6. Results and Discussion

In this study, the countries/regions that have a say in gray and white cement production in the world are ranked according to the sustainability performance criteria given in Table 1, using GNR 2018 data.

Entropy method, one of the objective decision-making methods, was used in criterion weighting. This method is easy to apply without the need for subjective evaluation. According to the criteria weights obtained, total alternative fossil fuels and mixed fuel consumption (K_6) ranked first, total biomass fuels (K_7) ranked second, and total external power consumption for cement production (K_5) ranked third. According to this ranking, the importance of using options such as hydroelectric energy, wind energy, solar energy and biomass energy, which are the most reliable energy sources, instead of coal, oil and gas to stop the climate crisis, is emphasized. These alternative sources are renewable and clean energy sources. The largest energy source in the world is the sun. The use of solar energy is increasing day by day.

The ARAS method was used to rank the countries/regions according to their utility degrees according to the determined criteria. This reveals the proportional similarity of each country/region to the ideal alternative. The utility degree used to calculate the relative efficiency of countries/regions is directly proportional to the relative effects of the weights and values of the determined criteria. When the final ranking of Countries/Regions in Table 10 is examined, Brazil (A_3) ranks first in terms of sustainability performance, CIS (A_6) ranks second, and North America (A_{10}) ranks third. According to the initial decision matrix in Table 3, it is seen that the countries/regions in the first three ranks are the countries with the least cement production volume and the resulting CO_2 emission amounts and power consumption have the lowest values. In the ranking, it is seen that as the cement production volume increases, the CO_2 emission amounts, and power consumption of countries/regions increase.

Sensitivity analysis was used to see how minor changes to the suggested approach affected the outcomes. In this study, the effect of the Entropy method, which is recommended to be used for criteria weighting, and the criteria obtained by the CRITIC and EW methods, on the rankings of countries/regions was observed. As a result, although different rankings were observed due to the characteristics of the selected methods, the fact that the countries/regions in the first two ranks did not change shows that the chosen alternative ranking method, the ARAS method, is a robust method.

7. Conclusion

In this study, using GNR 2018 data, the countries/regions with global influence over the production of gray and white cement are ranked based on the sustainability performance criteria listed in Table 1. While the Entropy method was used for criteria weighting, the ARAS method was used to obtain the final ranking of countries/regions. Brazil ranked first in terms of sustainability performance. Different weighting methods were used to demonstrate the robustness of the proposed method, and it was observed that the ranking of the first two countries/regions did not change.

In future studies, different sustainability criteria may be considered when ranking countries/regions. Decision makers can also participate in the decision-making process by choosing subjective multi-criteria decision-making methods instead of objective multi-criteria decision-making methods. The results can be compared with those presented in this study.

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Conflict of Interest

There is no financial conflict of interest with any institution, organization or person regarding this article. I did not have a conflict of interest with anyone.

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