GESTÃO & PRODUÇÃO

ISSN 0104-530X (Print)
ISSN 1806-9649 (Online)

ORIGINAL ARTICLE

Assessment of sustainable performance of the top five Brazilian steel industries using the TOPSIS technique with Gaussian AHP

Avaliação do desempenho sustentável das cinco maiores siderúrgicas brasileiras utilizando a técnica TOPSIS com AHP-Gaussiano

Carlos Alberto Soares Cunha[1], Igor Macedo de Lima[1], Gabriel Brito Caldas[1], Julio Vieira Neto[1], Luís Alberto Duncan Rangel[1], Gilson Brito Alves Lima[1]

[1]Universidade Federal Fluminense – UFF, Niterói, RJ, Brasil. E-mail: carloscunha@id.uff.br; igorml@id.uff.br; gabriel_caldas@id.uff.br; julion@id.uff.br; luisduncan@id.uff.br; glima@id.uff.br

How to cite: Cunha, C. A. S., Lima, I. M., Caldas, G. B., Vieira Neto, J., Rangel, L. A. D., & Lima, G. B. A. (2024). Assessment of sustainable performance of the top five Brazilian steel industries using the TOPSIS technique with Gaussian AHP. *Gestão & Produção*, 31, e9823. https://doi.org/10.1590/1806-9649-2024v31e9823

Abstract: The Brazilian steel industry holds enormous economic significance, as it produced approximately 32 million steel products in 2022 and exported around 12 million tons to over 100 countries. Based on a 2021 study conducted by the Institute for Applied Economic Research (IPEA), the steel industry contributed 1.9% to the overall national Gross Domestic Product (GDP). Although the steel industry plays a significant role in Brazil's trade balance, it has direct implications on economic, environmental, and social aspects, thereby intersecting with the three fundamental principles of sustainability. This study aims to assess the sustainable performance of the five primary companies by integrating the TOPSIS method with the Gaussian AHP method. The evaluation will be based on indicators derived from the Sustainable Development Goals (GRI) and will utilize sustainability reports from 2019 to 2021. The study demonstrated the feasibility of employing the suggested approach as a means of evaluating the sustainable performance of the five organizations in the steel sector, thus positioning it as a prospective tool for stakeholder analysis.

Keywords: sustainable performance; Brazilian steel companies; TOPSIS; AHP-Gaussian.

Resumo: A indústria siderúrgica brasileira possui importância ímpar para a economia, uma vez que sua produção, em 2022, girou na ordem de 32 milhões de produtos siderúrgicos e suas exportações, para mais de cem países, chegou ao montante de aproximadamente 12 milhões de toneladas. Segundo estudo de 2021 do Instituto de Pesquisa Econômica Aplicada (IPEA), a siderurgia representou 1,9% do PIB Nacional. Apesar da contribuição para a balança comercial brasileira, a siderurgia afeta diretamente as questões ligadas à economia, ao meio ambiente e ao social interagindo, desta forma, com os três pilares da sustentabilidade. Em razão dessa interconexão, o presente estudo tem por objetivo avaliar o desempenho sustentável das cinco principais empresas através da combinação do método TOPSIS com o método AHP-Gaussiano utilizando indicadores estabelecidos pelo *Sustainable Development Goals* (GRI), oriundo dos relatórios de sustentabilidade dos anos de 2019 a 2021. O estudo demonstrou a possibilidade de utilização do método proposto

Received Jan. 23, 2024 - Accepted Feb. 1, 2024
Financial support: None.Financial support: None.

como forma de avaliar o desempenho sustentável das cinco organizações do setor siderúrgico tornando-se potencial ferramenta de análise por partes interessadas.

Palavras-chave: desempenho sustentável; siderúrgicas brasileiras; TOPSIS; AHP-Gaussiano.

1 Introduction

According to the Brazilian Steel Institute (2023), the country had, in 2022, a producer park with 31 steel mills, being administered by 11 business groups. For production, its installed capacity is around 51 million tons/year of crude steel. Given this potential, the park produced 31.5 million tons of steel products, 11.9 million tons exported to more than 100 countries.

Still in relation to 2022, according to Comex Stat Portal (Brasil, 2023), the export of cast iron, iron and steel registered approximately 16.7 billion dollars. In terms of participation in exports, the Brazilian steel industry generated 5% of the value traded externally. As a result, the sector occupied the fifth position among all Brazilian products intended to other countries and, in addition, according to the IPEA (2021) study, the steel industry represented 1.9% of the National GDP.

Since the export of products is responsible for a significant portion of the revenues generated externally, the Brazilian trade balance is favored by this sector. With this, it is noted that the national steel industry guarantees a prominent role in commodity exports contributing to the economic development of the country.

However, although the economic axis (revenue generation) is paramount for the development of a country, it can no longer dissociate itself from the other pillars of the Triple Bottom Line (TBL). This is due to the fact that a linear model of production and consumption is unsustainable and leads to resource depletion, waste production and environmental degradation, all of which pose serious risks to people's health and the environment (Hegab et al., 2023).

For example, considering the environmental pillar, steel production generates waste and greenhouse gas (GHG) emissions that directly impact the environment. According to the Climate Observatory (2023), GHG emissions have been increasing over fifty years. In 2019, production of 32.6 million tons of steel generated approximately 42 million tons of CO_2 Another important point noted was that, in a decade (2009-2019), steel production varied by 27.69% while gas emission varied by 49.21%.

Thus, the fact that GHG emissions are characteristic of the sector in terms of environmental impact and in the face of the problems that the steel industry entails, the concern with waste generation has become the current agenda of several scientific research in responses to environmental impacts (Rossoni et al., 2021).

Another concern occurs in the social field, whose theme lies mainly in the health care of the people who inhabit the surroundings where the steel mills are located. As an example of the need for a social look, one has the specific case of Taranto – a city in southern Italy, where one of the largest steel mills in Europe is located. Due to the activities of the plant, a higher risk of mortality from lung cancer, respiratory diseases and pleural mesothelioma was reported. In addition, the record of excess incidence of cancer appeared among the younger population (Gianicolo et al., 2021). Therefore, one cannot forget to worry about what is outside the organization.

In addition, social issues go beyond simple concern for community health. They can also be embraced internally by the company through gender and race diversity and the empowerment of the workforce, the promotion of the development of local suppliers, as well as improving relationships with the community. All this, in the organization, cannot be executed alone. In the literature, new research and practices in sustainability propose an integrated concept in which “social issues” are indistinguishable and inseparable from economic or environmental issues (Peterson, 2016).

Since the pillars must be interconnected, knowing *the status* quo of the three dimensions of sustainability of an organization is the first step to propose strategies and actions that stimulate sustainable development in the search for competitive advantage (Falsarella & Jannuzzi, 2020).

One of the ways to know *the status quo* of an organization is through sustainability reports, because these arise as a tool for promoting performance (Guedes et al., 2020) and as a means of dissemination of sustainable actions (Souza et al., 2023). The main report model, adopted by several organizations, is the one provided by the Global Reporting Initiative (GRI) (Oliveira et al., 2022).

Created in 1997 in Amsterdam (Netherlands). GRI is a non-profit organization, the result of a joint effort by the Coalition for Environmentally Responsible Economies (CERES) and the United Nations Environmental Program (UNEP), it aims to help governments and organizations understand the impacts of business on sustainable development (Campos et al., 2013). The first version of the GRI guidelines was published in 2000 (Vieira et al., 2020) and, in 2015, the version adapted to Sustainable Development Goals (GRI, 2021) appears.

Since the 2015 GRI version presents guidelines that dialogue with the 17 Sustainable Development Goals (SDGs), established by the United Nations (UN), these have become the voluntary communication structure of environmental and social performance of the best known companies worldwide (Caiado et al., 2017).

However, considering the amount of information presented in the sustainability reports of steel organizations addressed in this study, which translate into numerous indicators (criteria) of sustainability (economic, environmental and social), it is necessary to use a multicriteria model to support the decision that orders organizations from the best to the worst performance.

According to the literature, the quantities of available Multi-Criteria Decision Making (MCDM) tools that support techniques to help decision makers are numerous. The best known are AHP, TOPSIS, ELECTRE, PROMETHEE, VIKOR and others. However, in order to seek the best alternative for each criterion through a simple mathematical formulation, as well as the ease of its computational process and the characteristic that the best alternative is through the ordering of criteria, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Hamurcu & Eren, 2023) will be adopted.

The TOPSIS method will aim to prioritize and select the organization that had the best sustainable performance considering the various indicators contained in the company reports. However, instead of using the traditional Analytic Hierachy Process (AHP) method to define the criteria weights, the AHP-Gaussian will be used in view of the fact that it stands out for its ability to save the cognitive effort of the decision-maker in assigning weights to the criteria (Pereira et al., 2023), eliminating the subjectivity of the analyses.

Given the presented, the objective of this article is to evaluate the sustainable performance of the five largest Brazilian steel companies, through the application of the TOPSIS method for sorting combined with the AHP-Gaussian method for assigning the weights of the criteria. To achieve the objective, the criteria for sustainability evaluation were identified – the common criteria selected in the GRI reports of the years 2019 and 2021; the construction of the spreadsheets with the values of the criteria; the performance decision matrices were constructed; standardized performance decision matrices; Calculated weights by standardized Gaussian factor; Calculated best (PIS) and worst solution for each year; Calculated distances to PIS and NIS; Calculated relative distances and nearby per year; and finally, obtained the classifications of companies per year. As a result of the evaluation, the relevance of the research lies in the practical application of these methods, providing valuable information that can contribute to the improvement of sustainability in the steel industry. In addition, it is noteworthy that the approach of this study meets the growing demands of society for sustainable practices.

In addition to this introduction, the article includes a theoretical framework where sustainable development is presented – which contains the concept and importance of this theme nowadays; the TOPSIS method, whose technique has as characteristic to evaluate the performance of the alternatives through the similarity with the ideal solution, thus ordering from the best to the worst solution; the AHP-Gaussian method, whose main characteristic is to obtain the weights of the criteria by means of quantitative criteria; the materials and methods adopted in the study related to the development of the work; analysis and discussion of the results; and conclusion.

2 Theoretical framework

2.1 Sustainable development

The concept of sustainable development, which aims to balance economic progress, environmental preservation and social well-being, is crucial in the current context. The concept has been widely discussed and analyzed in several academic papers that present the importance of sustainable development in the balance between economic progress, environmental preservation and social well-being, in addition to the concepts, definitions and elements of sustainability and optimization (Sadollah et al., 2020).

Industry plays a significant role in this equation, as it is a major engine of economic transformation, but also a significant generator of environmental and social impacts. The work of Luken & Castellanos-Silveria (2011) examined the relationship between industrial transformation and the positive and negative impacts of industry on sustainable development in developing countries, providing information on the dual role of the industry in promoting economic progress, while generating environmental and social impacts.

According to Usman & Hammar (2021), in order to achieve sustainable development, it is necessary to understand the driving factors of economic growth, such as technological progress, trade openness and financial development. The challenges to achieving sustainability in the steel industry are substantial due to the various environmental impacts associated with steel production. These impacts include greenhouse gas emissions, natural resource consumption and waste generation (Milford et al., 2013).

Schoeman et al. (2020) claim that the sustainability of the steel industry is undermined by the negative consequences of waste generation, such as environmental degradation and economic spending to mitigate environmental impacts. In addition, the sustainability of the steel industry is challenged by the need to adopt principles of sustainable development and ensure that performance is aligned with these principles (Bucur et al., 2017).

The environmental impacts generated by the steel industry are really significant (Toktarova et al., 2020). He & Wang (2017) concluded that substantial consumption of natural resources, such as water and energy, and the generation of solid waste by industry present urgent challenges that require immediate attention and action from the sector. In the social context, the presence of steel mills has been associated with public health and well-being issues. Studies in areas close to these industries have pointed out health problems related to air and water pollution, directly impacting the quality of life of local communities (Touzi & Horchani-Naifer, 2023).

Understanding these impacts is essential to promote effective actions toward sustainability in the steel industry. Strategies that address both environmental and social issues are necessary to mitigate these adverse effects. The steel industry has responded to environmental challenges by adopting strategies and initiatives to promote sustainability. Investments in cleaner technologies, emission reduction policies and environmental management practices have been implemented to mitigate adverse impacts (Duan et al., 2021).

These efforts demonstrate the industry's commitment to addressing environmental challenges and promoting sustainable practices. In a competitive market it is necessary to carry out such actions to measure sustainable performance. The sustainable performance of organizations can be measured with different techniques and approaches. Multiple criteria decision making is an important technique that presents a systematic approach to help decision-makers in this field (Stojčić et al., 2019). An example of multi-criteria decision methodology is TOPSIS, and with this technique it is possible to eliminate subjectivity in the analysis and provide a more objective and accurate evaluation of the sustainable performance of steel companies (Azimifard et al., 2018).

2.2 The TOPSIS method

The Technique Method to evaluate the Performance of Alternatives through similarity with the ideal solution (TOPSIS) was developed by Hwang & Yoon (1981). In this method, the Decision Matrix is composed of alternatives and criteria, according to Equation 1.

$$A = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}, \text{ where } i = 1, \ldots, m; j = 1, \ldots, n \quad (1)$$

The alternatives A_1, A_2, ... A_m are viable alternatives and C_1, C_2, ... C_m are the respective criteria. Also, in Matrix A, x_{ij} indicates the performance of the *Alternative* A_{ij} according *to* C_j (criterion j). Moreover, according to Hwang & Yoon (1981), considering that Matrix A has several dimensions (unit of measurement), it is necessary to normalize it, that is, transform all x_{ij} values into dimensionless values that allow the comparison. As a first step to construct the normalized decision matrix, Equations 2 and 3 (Behzadian et al., 2012) are used.

$$r_{ij} = \frac{x_{ij}}{\sqrt{(\sum x_{ij}^2)}}, \text{ with } i = 1, \ldots, m \text{ and } j = 1, \ldots, n \quad (2)$$

$$V_{ij} = w_j \times r_{ij}, \text{ where } w_j \text{ is the weight for each criterion } j \quad (3)$$

For the calculation of weights for each criterion, TOPSIS uses an objective method based on entropy (Pegden et al., 1995). Entropy, in turn, aims to describe the amount of information of the decision matrix. However, as it will be described later, the weights will be calculated using the Gaussian AHP method.

Continuing the characteristic mathematical model of TOPSIS (Pegden et al., 1995), the ideal solutions are calculated according to Equations 4 and 5.

$$A^{+} = (v_1^{+}, \dots, v_m^{+}), \text{ in which } v_j^{+} = \{max(v_{ij}) \text{ if } j \in J_1;\ min(v_{ij}), \text{if } j \in J_2\} \quad (4)$$

$$A^{-} = (v_1^{-}, \dots, v_m^{-}), \text{ in which } v_j^{-} = \{min(v_{ij}) \text{ if } j \in J_1;\ max(v_{ij}), \text{if } j \in J_2\} \quad (5)$$

Where A^+ are the ideal positive solutions and A^- are the ideal negative solutions, with J_1 and J_2 being, respectively, the best option and the worst option for the established alternatives.

The next step is to calculate Euclidean distances between A^+ *and* A^- through Equations 6 and 7.

$$d^{+} = \sqrt{\sum_{j=1}^{n} w_j\,(d_{ij}^{+})^2}, \text{ with } d_{ij}^{+} = p_j^{+} - p_{ij}, \text{ being } i = 1, \dots, m \quad (6)$$

$$d^{-} = \sqrt{\sum_{j=1}^{n} w_j\,(d_{ij}^{-})^2}, \text{ with } d_{ij}^{-} = p_j^{-} - p_{ij}, \text{ being } i = 1, \dots, m \quad (7)$$

Calculated the distances, the next step is to calculate the relative proximity x_i for *Each* A_i with respect to the ideal solution positive A^+, according to Equation 8.

$$\xi_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \quad (8)$$

Finally, through relative proximity, the alternatives are classified (ranked). With this, the best alternatives are those that have the highest value of x_i and, thus they should be chosen and ordered from the best to the worst performance.

2.3 The Gaussian AHP method

The Analytic Hierarchy Process (AHP) method was developed in the 70 by Saaty (1980) and its objective is to analyze the criteria through the opinion and feelings of experts, considering the comparison peer to peer. In this comparison, values of judgment are used to represent a scale (Souza et al., 2023) and this is done through the fundamental Saaty scale, where the criteria receive the value of 1, considered equally important, to the value of 9, for extremely important (Paz et al., 2022).

Thus, the AHP is a method that synthesizes knowledge, experience and point of view of the specialist (Souza et al., 2023), through peer comparisons, where the priorities evaluated capture subjective and objective measures that demonstrate the intensity of one domain from one alternative over another (Saaty & Vargas, 2012 apud Souza et al., 2023). Thus, it is evident that the AHP method requires a cognitive effort from experts to analyze the degree of importance of criteria (Paz et al., 2022).

To avoid the use of the expert "resource", the AHP-Gaussian method emerged, whose main characteristic is to obtain the weights of the criteria from the decision matrix by means of quantitative criteria. Thus, the peer-to-peer evaluation of the degree of importance of the criteria will no longer be carried out by specialists used in the traditional AHP method, being the weights of the criteria obtained through the decision matrix (Santos & Costa, 2021).

Thus, according to Santos & Costa (2021), for the calculation of weights (Gaussian factor), the sequence of Figure 1 should be respected:

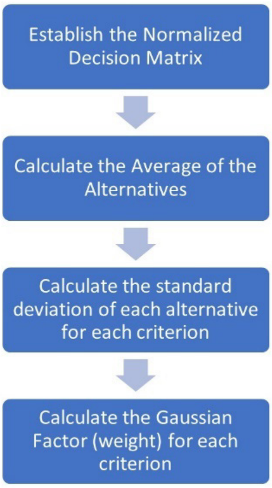

Figure 1. Sequence for calculating the Gaussian Factor (adapted from Santos & Costa (2021).

Turning the steps into equations, the first step will be to establish the Normalized Decision Matrix. As seen before, this will be done through Equations 1 to 3. The other stages can then be represented mathematically according to Equations 9, 10 and 11.

$$y_i = average_{altern.in\ which\ criterion} = \frac{\sum alternatives\ of\ each\ criterion}{number\ of\ alternatives}, where\ i = 1, \dots, m \quad (9)$$

$$\sigma_i = \sqrt{\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{n-1}} \quad (10)$$

$$Gaussian\ Factor\ (GF_i) = \frac{\sigma_i}{y_i} \quad (11)$$

3 Materials and methods

The methodology adopted in this research focused on a quantitative approach to evaluate the sustainable performance of the five largest steel mills in Brazil. The collection of information was carried out through documentary research, using data from statistical yearbook, and sustainability reports aligned to the GRI standard to obtain the criteria for analysis.

The population considered in the analysis covered the main steel companies operating in Brazil and the sample was selected based on the representativeness of these organizations in terms of crude steel production. The five companies chosen, classified in terms of decreasing production in 2022, were responsible for 82.26% of the national production, standing out as representative in the sector (according to Instituto Aço Brasil). Table 1 shows the total volume produced by company.

Table 1. Steel production by steel mill.

Steel mill	Gross Steel Production (10^3t)
S1	10,694
S2	6,496
S3	4,424
S4	3,773
S5	2,655

Applied what can be considered the first filter for the evaluation of this study, the next step consisted in the collection of indicators (criteria) contained in the sustainability reports linked to the GRI. The additional requirement was that these publications share common indicators to allow the comparison of the materials raised. Although the reports of the companies analyzed for this study were related to the years 2019, 2020 and 2021, those absent in the GRI were collected directly from the companies' websites.

In possession of the reports obtained from the Global Reporting Initiative (GRI), the next step included the meeting of the indicators (criteria) that can be compared, using an electronic spreadsheet developed in Microsoft Excel, Office 365 package. The spreadsheet, having the data collected by company, is of great value since the GRI criteria serve as a basis, according to some studies, to examine the sustainability practices in companies (Vallet-Bellmunt et al., 2023). Thus, with the use of indicators that enable quantitative and qualitative measurement, it is possible to compare the organizations (Feil et al., 2023).

In addition, the notion of corporate sustainability is referred to as a Triple Bottom Line, where the three pillars of sustainability are highlighted: Economic, social and environmental (Politis & Grigoroudis, 2022). Thus, due to indicators common to companies and in order to contemplate the analysis under the prism of the TBL, four criteria for the economic dimension were selected, four for the social dimension and three for the environmental dimension, as presented in Table 2.

Table 2. Sustainability Criteria Common to Reports.

Dimension	Criterion	Measures	Unit
Economic	CE1	EBITDA	R$ (BILLION)
	CE2	Net Revenue	R$ (BILLION)
	CE3	Net Profit	R$ (BILLION)
	CE4	Steel Sale Volume	TON (MILLION)
Social	CS1	Frequency rate of accidents with loss of time	%
	CS2	Number of direct jobs generated	THOUSAND
	CS3	Number of women employed	THOUSAND
	CS4	Investment in social	R$ (MILLION)
Environmental	CA1	Total direct energy consumption	GJ (MILLION)
	CA2	Direct and indirect emissions of greenhouse gases	tCO2 (MILLION)
	CA3	Water consumption	THOUSAND MEGALITERS

Finally, with the common indicators (criteria) contained in the sustainability reports for the years researched, the creation of performance decision matrices (standard and normalized), the calculation of criteria weights (standardized Gaussian Factor), the calculations of PIS (best solution) and NIS (worst solution), the distances to PIS and NIS, the calculation of distances per year/company, the calculation of relative vicinity per year/company and, finally, the classification of companies per year, using the formulas presented in the Theoretical Reference.

Figure 2 shows the sequence used to achieve the purpose of the research and also to facilitate the understanding by other researchers and scholars who are interested in the subject or for the development of studies not contemplated due to the limitations of the research.

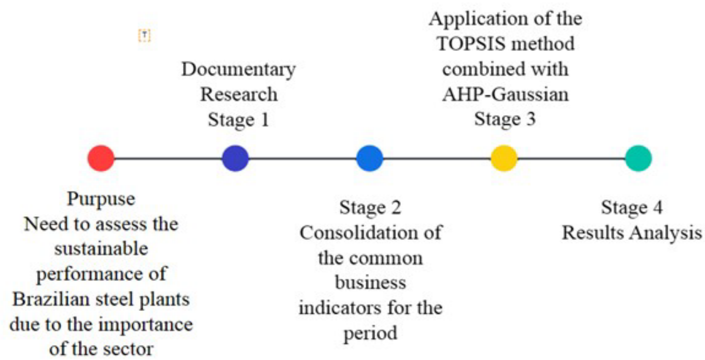

Figure 2. Flow Materials and Methods.

4 Analysis and discussion of results

In this topic, the results will be analyzed and discussed resulting from the use of the established in the topic Materials and Methods of the present research. The following sequence of tables and information, as previously stated, were obtained using the Microsoft Excel 365 program.

In possession of the criteria in common in the reports of the five companies for the years researched, the performance decision matrices presented in Tables 3, 4 and 5 were reached.

Table 3. 2019 Performance Decision Matrix.

2019	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3
S1	4.006	32.455	1.230	10.000	0.360	16.594	1.778	22.697	209.143	15.809	410.820
S2	7.251	30.064	2.245	5.100	3.010	24.869	3.433	30.730	103.982	11.180	108.435
S3	5.710	39.640	1.300	12.090	5.830	17.276	2.213	1.770	151.202	13.839	80.938
S4	1.973	14.949	0.377	4.105	1.260	15.852	1.131	13.500	65.820	7.790	62.480
S5	6.019	40.212	2.485	12.511	0.840	19.863	1.589	26.038	276.500	18.700	198.600

Analyzing the economic dimension criteria in Table 3, it is noticed that the company that presented the highest EBITDA (CE1) was the company S2. The one that presented the highest Net Revenue (CE2) was the company S5. Regarding the criteria CE3 (Net Income) and CE4 (Steel Sales Volume), it is noticed that the company S2 obtained a net profit close to the company S5, despite having a sales volume of less than half (5.1). In addition, comparing S2 to S1, it is noticed that its sales volume was almost half of S1 and its net profit was almost double (2.245). Thus, it cannot be said that there is a causal relationship of net profit with the Steel Sales Volume, that is, other variables must have influenced the results.

Regarding the social criteria, the company S1 had the lowest CS1 (frequency rate of accidents with loss of time) and the S3 with the highest rate. Regarding criteria CS2, CS3 and CS4, the company S2 obtained the highest values. This may mean that the company has a more engaged policy of action in the social field, because the variables dialogue directly with specific parts of society: direct jobs generated, women employed (gender equality policy) and investment in social.

In the environmental pillar, the company S4 presented more efficient performance in all metrics, with lower total direct energy consumption, lower direct and indirect greenhouse gas (GHG) emissions and lower water consumption. On the other hand, companies S1 and S5 were the ones that consumed the most electric energy, emitted GHG and consumed water.

Table 4. 2020 Performance Decision Matrix.

2020	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3
S1	5.083	33.070	1.235	9.300	0.180	19.915	2.048	28.278	187.765	13.414	351.123
S2	11.500	25.436	4.290	4.651	2.460	23.577	3.380	52.400	100.500	11.301	99.396
S3	7.690	43.815	2.400	11.461	0.860	17.122	2.294	3.321	146.365	13.019	51.429
S4	3.194	16.088	1.292	3.723	1.160	12.109	0.982	23.955	69.100	6.470	58.840
S5	7.860	45.038	4.475	11.360	0.820	15.059	1.355	57.229	249.909	17.300	178.600

In 2020, S5 stood out with higher values for EBITDA, Net Revenue, Net Income and Steel Sales Volume, consolidating its position as a highlight in financial terms. S4, however, was the one that presented, almost entirely, lower values for these criteria. Relating the criteria CE3 and CE4, S2 presented a net profit close to that of S5, although its Steel Sales Volume was almost a third lower. On the other hand, S3 recorded a Steel Sales Volume higher than that of S5, but its net profit was below than the one achieved by S2 and S5. Therefore, once again, it cannot be said that there is a causal relationship between Net Profit and Steel Sales Volume, that is, other internal variables influenced the results.

Regarding the social aspects, the company S1 was the one that obtained the lowest frequency rate of accidents with time-wasting (CS1) and the S2 was that with the highest value for this criterion. The company S2, in 2020, remained a leader in the criteria of number of direct jobs generated (CS2) and number of women employed (CS3), losing only the leadership to S5 in the criterion of social investment (CS4).

In the environmental dimension, the steel mill S4 maintained a more efficient performance, with lower total direct energy consumption (CA1) and lower GHG emissions (CA2). However, comparing its data with those of the previous year, the company fell to the second best value regarding water consumption.

Table 5. 2021 Performance Decision Matrix.

2021	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3
S1	20.189	69.002	12.841	12.500	0.195	16.816	2.051	133.170	217.743	17.158	384.016
S2	22.000	47.900	13.600	4.603	1.968	26.161	4.425	105.000	112.333	13.770	98.476
S3	23.222	78.345	15.600	12.722	0.900	21.695	3.710	12.698	152.011	11.970	49.915
S4	12.830	33.737	10.060	4.765	2.130	14.125	1.283	75.400	76.270	7.312	65.120
S5	31.630	86.809	23.561	12.065	0.790	14.927	1.493	93.334	288.354	19.200	157.000

For the year 2021, in the economic context, the company S2, despite having the lowest Steel Sales Volume (CE4), obtained the third highest net profit (CE3). Again, comparing the sales volumes with the net profits of steel mills, it cannot be said that there was a causal relationship between the criteria, that is, other variables should have influenced the results.

In the social criteria of 2021, the company S1 was the one that again obtained the lowest rate of accidents with time-wasting (CS1) and the S4 was that with the highest value for the criterion. The company S2 also remained a leader in the criteria of number of direct jobs generated (CS2) and number of women employed (CS3), losing only the leadership to S1 in the criterion of social investment (CS4), when compared to the previous year.

In the environmental pillar, in 2021, the steel mill S4 maintained a more efficient profile, with the lowest total consumption of direct energy (CA1) and the lowest value for direct GHG emissions (CA2). Only in terms of water consumption, the company was second.

After establishing the analysis of the three decision matrices corresponding to the years 2019 to 2021, where the alternatives (steel mills) and the criteria were crossed, the next step was to normalize the matrices. The normalization of the criteria is necessary to enable the comparison between them (Chakraborty, 2022) in search of the ideal solution, because otherwise, vectors with incomparable units would have been obtained (Yoon & Kim, 2017). As a result of standardization, the Normalized Performance Decision Matrices were obtained for each year.

Table 6. 2019 Performance Decision Matrix (Normalized).

2019	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3
S1	0.337	0.443	0.322	0.474	0.053	0.387	0.366	0.471	0.526	0.506	0.856
S2	0.610	0.410	0.588	0.242	0.446	0.580	0.706	0.638	0.261	0.358	0.226
S3	0.480	0.541	0.341	0.573	0.865	0.403	0.455	0.037	0.380	0.443	0.169
S4	0.166	0.204	0.099	0.194	0.187	0.370	0.233	0.280	0.165	0.249	0.130
S5	0.506	0.549	0.651	0.593	0.125	0.463	0.327	0.540	0.695	0.598	0.414

Analyzing the economic dimension normalized in 2019 in Table 6, more specifically in relation to criteria CE3 (Net Income) and CE4 (Steel Sales Volume), the company S2 continues to perform higher in terms of Net Income and Steel Sales Volume.

Based on the standardized data on social criteria, a number of observations can be made. Regarding the accident frequency rate (CS1), the S1 performed relatively well, while the S3 scored the highest – which translates into high frequency. As for the number of direct jobs generated (CS2), S2 led with the highest score, followed by S5. In the criterion of number of women employed (CS3), S2 obtained the highest score, indicating the highest proportion of women employed. Finally, in relation to social investment (CS4), S2 also led with the highest score, while S4 presented the worst normalized performance. On the environmental side, the company S4 presented very efficient performance in all criteria, with the lowest values for total direct energy consumption, the lowest direct and indirect GHG emissions and the lowest water consumption. On the other hand, companies S5 and S1 were the ones that consumed the most direct energy, emitted GHG and consumed water.

Table 7. 2020 Performance Decision Matrix (Normalized).

2020	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3
S1	0.299	0.429	0.179	0.476	0.061	0.495	0.421	0.329	0.513	0.469	0.849
S2	0.676	0.330	0.623	0.238	0.827	0.586	0.695	0.609	0.275	0.395	0.240
S3	0.452	0.568	0.349	0.586	0.289	0.426	0.471	0.039	0.400	0.455	0.124
S4	0.188	0.209	0.188	0.190	0.390	0.301	0.202	0.278	0.189	0.226	0.142
S5	0.462	0.584	0.650	0.581	0.276	0.374	0.279	0.665	0.683	0.605	0.432

For the analysis under the economic perspective of 2020 – Table 7, when comparing the criteria CE3 and CE4, the steel mill S2 presented the second best value in net profit (CE3) with a high score of 0.623 despite the fourth best normalized value for Steel Sales Volume (CE4), with a score of 0.238. Analyzing the values of the steel mill S5, it had the best normalized value of CE3 and second best for Steel Sales Volume (CE4), with 0.581. On the other hand, the S3 company that had the best CE4 did not have the best CE3. Thus, this analysis suggests once again that a higher Steel Sales Volume (CE4) may not directly translate into a higher net profit (CE3), and vice versa.

In the social pillar, the company S1 had the lowest rate of frequency of accidents normalized (CS1). The company S2 was the one that obtained the worst normalized value, separating considerably from the others. Regarding the criterion of number of direct jobs generated (CS2), the steel mill S2 was the one that had the best performance normalized and the S4 was the one with the worst performance. In the criterion related to the number of women employed (CS3), S2 played a prominent role and S4 presented the worst scenario. Finally, for Social Investment (CS4), the company S5 led with the best value and S3 performed the worst.

As for the environmental aspect, the steelmaker that consumed the most direct energy and the one that emitted the most GEEs was the organization S5. The company that consumed the most water was S1. In the opposite direction, the company that consumed less energy and issued GEEs was S4 and the one that consumed less water was S3.

Table 8. 2021 Performance Decision Matrix (Normalized).

2021	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3
S1	0.396	0.467	0.363	0.555	0.062	0.390	0.319	0.640	0.525	0.530	0.884
S2	0.432	0.324	0.385	0.204	0.626	0.607	0.688	0.504	0.271	0.425	0.227
S3	0.456	0.530	0.441	0.565	0.286	0.503	0.576	0.061	0.366	0.370	0.115
S4	0.252	0.228	0.285	0.212	0.678	0.327	0.199	0.362	0.184	0.226	0.150
S5	0.621	0.587	0.667	0.536	0.251	0.346	0.232	0.448	0.695	0.593	0.362

Analyzing part of the economic aspect of Table 8, the organization S5 had the best performance in the Net Profit criterion (CE3), despite the third best value for Steel Sales Volume (CE4). The company S2, despite having the worst value normalized for CE4, obtained the third best value for CE3. Again, a higher volume of steel sales does not directly translate to higher net profit.

Continuing the analysis, Tables 9 to 11 will present the values resulting from the calculation of the weights using the Gaussian Factor in order to meet one of the premises of this study, that is, to replace the subjectivity of the comparison pair, when the use of specialists in determining the weights of the criteria.

Thus, through Equation 11, it was possible to calculate the weights for each year and for each criterion, as shown in Tables 9 to 11.

Table 9. Weight calculation (normalized Gaussian factor) for 2019.

Gaussian	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3
Mean	0.420	0.429	0.400	0.415	0.335	0.441	0.417	0.393	0.406	0.431	0.359
Standard Deviation	0.172	0.140	0.223	0.186	0.331	0.086	0.180	0.238	0.211	0.134	0.298
Gaussian Factor	0.410	0.325	0.557	0.449	0.988	0.194	0.432	0.606	0.519	0.312	0.832
Normalized Gaussian Factor	0.073	0.058	0.099	0.080	0.176	0.035	0.077	0.108	0.092	0.055	0.148

Table 10. Weight calculation (normalized Gaussian factor) for 2020.

Gaussian	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3
Mean	0.415	0.424	0.398	0.414	0.369	0.436	0.413	0.384	0.412	0.430	0.357
Standard Deviation	0.185	0.159	0.228	0.189	0.283	0.110	0.191	0.256	0.195	0.137	0.301
Gaussian Factor	0.445	0.376	0.574	0.455	0.768	0.251	0.461	0.668	0.474	0.319	0.841
Normalized Gaussian Factor	0.079	0.067	0.102	0.081	0.136	0.045	0.082	0.119	0.084	0.057	0.149

Table 11. Weight calculation (normalized Gaussian factor) for 2021.

Gaussian	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3
Mean	0.431	0.427	0.428	0.414	0.381	0.435	0.403	0.403	0.408	0.429	0.348
Standard Deviation	0.132	0.148	0.145	0.189	0.262	0.118	0.217	0.216	0.204	0.143	0.315
Gaussian Factor	0.307	0.347	0.338	0.455	0.689	0.271	0.540	0.536	0.500	0.334	0.905
Normalized Gaussian Factor	0.059	0.066	0.065	0.087	0.132	0.052	0.103	0.103	0.096	0.064	0.173

For Tables 9 to 11, the mean of the alternatives were calculated in each criterion, the standard deviation, the Gaussian Factor and the normalized Gaussian Factor. The mean was calculated by calculating the sum of each criterion on the number of alternatives, according to Equation 9. The standard deviation of each table followed the Equation 10. Consequently, the Gaussian Factor for each criterion was calculated according to Equation 11. Finally, each Gaussian Factor relative to the criteria was normalized.

After the calculations are performed in the tables, the next step is to multiply the weights found for each year with their respective standardized performance decision matrices.

In the sequence, considering the characteristic theory of TOPSIS, we now calculate the best performance (Positive Ideal Solution – PIS) and the worst performance (Negative Ideal Solution – NIS) for each year and for the five companies. However, before determining the values, it is necessary to adjust the impacts of the criteria. For example, for social (CS1), the better the lower the frequency Rate of time-wasting accidents for organizations will be. In the environmental field, all criteria will be better the lower their values. Thus, lower values for Direct Energy consumption, GHG emissions and water consumption affect the environment less. Tables, 12, 13 and 14 present the PIS and NIS for the years 2019 to 2021.

Table 12. PIS and NIS 2019.

Impacts	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(-)	(-)	(-)
2019	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3
PIS	0.044	0.032	0.065	0.047	0.009	0.020	0.054	0.069	0.015	0.014	0.019
NIS	0.012	0.012	0.010	0.016	0.152	0.013	0.018	0.004	0.064	0.033	0.127

Table 13. PIS and NIS 2020.

Impacts	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(-)	(-)	(-)
2020	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3
PIS	0.053	0.039	0.066	0.047	0.008	0.026	0.057	0.079	0.016	0.013	0.019
NIS	0.015	0.014	0.018	0.015	0.113	0.013	0.017	0.005	0.057	0.034	0.127

Table 14. PIS and NIS 2021.

Impacts	(+)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(-)	(-)	(-)
2021	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3
PIS	0.036	0.039	0.043	0.049	0.008	0.031	0.071	0.066	0.018	0.014	0.020
NIS	0.015	0.015	0.018	0.018	0.089	0.017	0.021	0.006	0.067	0.038	0.153

In Tables 12 to 14, the calculation of PIS and NIS resulted from the use of Formulas 4 combined with Formulas 3 and Formulas 5 with Formulas 3, respectively. However, for the Environmental Criteria (CAs) and for the Social Criterion (CS1), there was a need to reverse the use of formulas, because the lower the total consumption of direct energy, emission of GEEs and water consumption, the better the solution will be. Consequently, for the PIS we used the Equation 5 combined with Equation 3 and for NIS, Equation 4 with Equation 3.

Once the PIS and NIS are determined, the next step is now taken, according to TOPSIS, which refers to the calculation of the PIS and NIS distances.

Table 15. Distance to PIS 2019.

Company	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3	SUM
S1	0.00040	0.00004	0.00106	0.00009	0.00000	0.00004	0.00068	0.00032	0.00111	0.00020	0.01151	0.01546
S2	0.00000	0.00006	0.00004	0.00078	0.00477	0.00000	0.00000	0.00000	0.00008	0.00004	0.00020	0.00597
S3	0.00009	0.00000	0.00095	0.00000	0.02030	0.00004	0.00037	0.00420	0.00039	0.00012	0.00003	0.02649
S4	0.00105	0.00040	0.00300	0.00101	0.00055	0.00005	0.00132	0.00149	0.00000	0.00000	0.00000	0.00886
S5	0.00006	0.00000	0.00000	0.00000	0.00016	0.00002	0.00085	0.00011	0.00239	0.00037	0.00176	0.00571

Table 16. Distance to NIS 2019.

Company	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3	SUM
S1	0.00016	0.00019	0.00049	0.00050	0.02030	0.00000	0.00010	0.00219	0.00024	0.00003	0.00000	0.02420
S2	0.00105	0.00014	0.00235	0.00001	0.00540	0.00005	0.00132	0.00420	0.00160	0.00018	0.00868	0.02498
S3	0.00053	0.00038	0.00057	0.00091	0.00000	0.00000	0.00029	0.00000	0.00085	0.00007	0.01033	0.01393
S4	0.00000	0.00000	0.00000	0.00000	0.01417	0.00000	0.00000	0.00069	0.00239	0.00037	0.01151	0.02914
S5	0.00062	0.00040	0.00300	0.00101	0.01690	0.00001	0.00005	0.00295	0.00000	0.00000	0.00427	0.02920

Table 17. Distance to PIS 2020.

Company	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3	SUM
S1	0.00089	0.00011	0.00230	0.00008	0.00000	0.00002	0.00050	0.00159	0.00074	0.00019	0.01169	0.01811
S2	0.00000	0.00029	0.00001	0.00079	0.01093	0.00000	0.00000	0.00004	0.00005	0.00009	0.00030	0.01251
S3	0.00031	0.00000	0.00094	0.00000	0.00097	0.00005	0.00033	0.00552	0.00032	0.00017	0.00000	0.00862
S4	0.00149	0.00063	0.00222	0.00102	0.00202	0.00016	0.00163	0.00210	0.00000	0.00000	0.00001	0.01128
S5	0.00029	0.00000	0.00000	0.00000	0.00086	0.00009	0.00116	0.00000	0.00173	0.00046	0.00210	0.00669

Table 18. Distance to NIS 2020.

Company	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3	SUM
S1	0.00008	0.00022	0.00000	0.00053	0.01093	0.00007	0.00032	0.00118	0.00020	0.00006	0.00000	0.01360
S2	0.00149	0.00007	0.00205	0.00001	0.00000	0.00016	0.00163	0.00457	0.00118	0.00014	0.00824	0.01954
S3	0.00044	0.00058	0.00030	0.00102	0.00538	0.00003	0.00049	0.00000	0.00057	0.00007	0.01169	0.02056
S4	0.00000	0.00000	0.00000	0.00000	0.00355	0.00000	0.00000	0.00081	0.00173	0.00046	0.01111	0.01766
S5	0.00047	0.00063	0.00230	0.00100	0.00566	0.00001	0.00004	0.00552	0.00000	0.00000	0.00387	0.01949

Table 19. Distance to PIS 2021.

Company	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3	SUM
S1	0.00017	0.00006	0.00038	0.00000	0.00000	0.00013	0.00145	0.00000	0.00107	0.00038	0.01779	0.02144
S2	0.00012	0.00031	0.00033	0.00099	0.00554	0.00000	0.00000	0.00019	0.00007	0.00016	0.00038	0.00809
S3	0.00009	0.00001	0.00021	0.00000	0.00088	0.00003	0.00013	0.00353	0.00031	0.00008	0.00000	0.00528
S4	0.00047	0.00057	0.00061	0.00095	0.00660	0.00021	0.00254	0.00081	0.00000	0.00000	0.00004	0.01280
S5	0.00000	0.00000	0.00000	0.00001	0.00062	0.00018	0.00221	0.00039	0.00240	0.00055	0.00183	0.00819

Table 20. Distance to NIS 2021.

Company	CE1	CE2	CE3	CE4	CS1	CS2	CS3	CS4	CA1	CA2	CA3	SUM
S1	0.00007	0.00025	0.00003	0.00093	0.00660	0.00001	0.00015	0.00353	0.00027	0.00002	0.00000	0.01186
S2	0.00011	0.00004	0.00004	0.00000	0.00005	0.00021	0.00254	0.00207	0.00165	0.00011	0.01300	0.01983
S3	0.00014	0.00040	0.00010	0.00099	0.00267	0.00008	0.00152	0.00000	0.00099	0.00020	0.01779	0.02489
S4	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00096	0.00240	0.00055	0.01621	0.02012
S5	0.00047	0.00057	0.00061	0.00083	0.00317	0.00000	0.00001	0.00158	0.00000	0.00000	0.00821	0.01546

As previously reported, PIS and NIS distances mean, respectively, how much a certain value is close to the best performance and how much it moves away from the worst performance.

In Table 15, for example, the company S2, for criterion CE1 (EBITDA), had the “value 0” for distance to PIS, that is, it was the closest to the best solution. In the same year, the company S4 had the “value 0” for distance to NIS, that is, it was closer to the worst solution, as shown in Table 16. As expected, analyzing the data presented in Table 1, the best performance for CE1 was for the company S2 and the worst performance was for the company S4.

Analyzing now Table 17, more specifically the social criterion that translates Investment in Social (CS4), the steel mill that presented the lowest distance to the PIS was S5. Regarding distance to NIS, Table 18, the company that presented the lowest distance to NIS was S3. Comparing these results with the data in Table 2, again a coincidence in terms of performance is observed.

Finally, analyzing the environmental aspect related to criterion CA2 in Tables 19 and 20, also for PIS and NIS distances, the organization S4 had the lowest distance to PIS and S5 to NIS.

Following the analysis, the Euclidean distance for each ideal point (D^+) and ideal ante (D^-) is now calculated according to the Equations 6 and 7 for the years included in the research.

Table 21. Calculation of Distances per Year.

Company	D^+ (2019)	D^- (2019)	D^+ (2020)	D^- (2020)	D^+ (2021)	D^- (2021)
S1	0.12434	0.15557	0.13456	0.11661	0.14642	0.10892
S2	0.07725	0.15806	0.11183	0.13980	0.08996	0.14082
S3	0.16275	0.11803	0.09283	0.14338	0.07267	0.15777
S4	0.09412	0.17071	0.10621	0.13291	0.11314	0.14183
S5	0.07558	0.17088	0.08178	0.13961	0.09050	0.12433

Table 21 shows the distances between the normalized score of each steel mill and the ideal positive solution (+) and the ideal negative solution (-) per year. Considering the distance D+, in 2019, for example, the company S5 presented the lowest value. For distance D-, in the same year, the company S5 presented the highest value. Thus, for that year, the steel mill S5 was closer to the ideal solution in terms of PIS and further away from the ideal solution of NIS.

The other step refers to the calculation of relative proximity per year, according to Equation 8, whose values are shown in Table 22. Table 22, therefore, presents the values that will be used for ordering according to TOPSIS methodology, combined with the AHP-Gaussian method for calculating weights.

Table 22. Calculation of Relative Vicinity by Year.

Company	R2019	R2020	R2021
S1	0.55580	0.46427	0.42656
S2	0.67171	0.55557	0.61020
S3	0.42035	0.60701	0.68464
S4	0.64459	0.55583	0.55626
S5	0.69334	0.63060	0.57874

According to Yoon & Kim (2017), TOPSIS chooses the alternative that has the maximum value according to Equation 8. Thus, when analyzing Table 22, where the calculations of the relative nearby for the years 2019 to 2021 are presented, the company S3 presents the lowest value in 2019 and the highest value in 2021. The company S1, with its values for the period analyzed in the research, is the one that stands out the least. The S5 organization guarantees the highest values in 2019 and 2020, but in 2021 it is below companies S2 and S3. Companies S2 and S4 exhibited variations over the period.

Finally, it is performed the ordering of the alternatives according to TOPSIS, where the results are presented in Table 23.

Table 23. Classification of companies by year.

Classification	2019	2020	2021
1st	S5	S5	S3
2nd	S2	S3	S2
3rd	S4	S4	S5
4th	S1	S2	S4
5th	S3	S1	S1

As previously reported, the calculation of the vicinity of Table 22 leads to the classification of companies based on the model considered. Thus, as presented in Table 23, the company S5 took the first place in the first years and, in the end, fell to third place. In 2021, the company S3 obtained the highest value, coming from an upward trajectory. Finally, the companies S2 and S4 had a position alternation behavior over the period covered in the research.

The analyzes were carried out considering the comparisons between non-standard and standardized criteria, the discussion of the results from the perspective of the Triple Bottom Line (TBL) concept. This concept allows to evaluate business performance beyond financial performance, as well as change corporate behavior through institutional pressure and self-regulation (Sridhar & Jones, 2013), because it includes the three pillars of sustainability: Economic, social and environmental. In addition, organizations must undertake a TBL sustainable development strategy to ensure that they integrate the economic, social and environmental context in strategic decision-making (Moosa & He, 2023).

Considering the data presented in Table 23, it can be seen that the company S3 left last place in 2019 to first place in 2021, passing by second place in 2020. In terms of sustainable performance, this company was the one that stood out most based on the criteria chosen in the application of the TOPSIS method with AHP-Gaussian. On the other hand, the S5 organization was the one that lost prominence despite occupying the first place in 2019 and 2020. The other companies have oscillated their sustainable performance for the period researched.

Detailing the data of the tables, in 2019, the steel company S3 held the second best value for Net Revenue (CE2) and the third for Net Income (CE3) for an expressive Steel

Sales Volume (CE4) – second place. In the social field, the company had the second best value for the number of women employed (CS3) and the third place for the criterion number of direct jobs generated (CS2). However, it had the highest value for the frequency rate of time-wasting accidents (CS1) and the lowest value for Social Investment (CS4). Finally, on the environmental side, the company held the third parties the highest values for total direct energy consumption (CA1) and for direct and indirect emissions of GEEs (CA2). For the criterion water consumption (CA3), the company was the fourth that consumed the most this input. Thus, in general, despite being well-positioned in the economic and environmental criteria, the high accident rate and the tiny participation in social investment, when compared to the others, positioned the company last in terms of sustainable performance in 2019.

In 2020, the steel company S3 maintained the second best value for Net Revenue (CE2) and the third for Net Income (CE3) for a higher Steel Sales Volume (CE4). Thus, an improvement in its economic performance is already seen in relation to the others, because when leaving the second best value of CE4 in 2019 to the largest in 2020, it maintained the positions for CE2 and CE3. In the same year, in social terms, the company maintained the second best value for the number of women employed (CS3) and the third place for the criterion number of direct jobs generated (CS2). However, the company ceased to have the worst position for criterion CS1 that it occupied in 2019. The steel company started to have the third highest value the frequency rate of accidents with waste of time, improving its performance by reducing this indicator. Finally, the company maintained the worst value for Social Investment (CS4), once again occupying the last place in 2020. Finishing with the environmental side, the company maintained the third parties higher values for total direct energy consumption (CA1) and for direct and indirect emissions of GEEs (CA2). For the criterion water consumption (CA3), the company was the one that consumed the least this input. The fact that it held several positions in 2020 on various criteria and improved its position on criteria CE4, CS1 and CA3, the company became the second best place in sustainable performance in 2020.

In 2021, the steel company S3 maintained the second best value for Net Revenue (CE2). As for net income (CE3), the company went from third party (2020) to the second best value in 2021. Regarding the Steel Sales Volume (CE4), the company maintained a prominent role with the highest value in 2021. In social terms, the company maintained the second best value for the number of women employed (CS3) and moved from third place in 2020 to second place in 2021, regarding the criterion number of direct jobs generated (CS2). For criterion CS1, the company maintained the third position, maintaining its performance in this indicator. Finally, again, the company maintained the worst value for Social Investment (CS4), occupying the last place. On the environmental side, the company kept the third parties higher values for total direct energy consumption (CA1) and for direct and indirect emissions of GEEs (CA2). For the criterion water consumption (CA3), the company was the one that least consumed this input, once again. The fact that it maintained and improved some values of economic, social and environmental criteria throughout 2019 and 2020, as well as improved the values of CE3 and CS2, in 2021, was crucial for the company to have, this year, the best sustainable performance among the five largest Brazilian steel mills. Its improvement and maintenance of values in various indicators have boosted its trajectory as the one with better sustainable performance over the years.

Now analyzing the steel mill S5, it was evident that it was left from the first place in 2019 and 2020 to third place in 2021. In the economic criteria, the company maintained the highest values for CE2 and CE3 in the three years surveyed. However, its performance in terms of Steel Sales Volume (CE4) fell in position. This went from higher value in 2019 to the third highest value. As for EBITDA (CE1), it went from the second best value of the years 2019 and 2020 to better value 2021. Despite the jump in CE1 and having maintained the highest values for CE2 and CE3, the loss of significant position in CE4 contributed to its decline in the planning in 2021. As for social criteria, the company registered the fourth lowest value for the accident frequency rate (CS1), the second highest value for the number of direct jobs (CS2), the fourth highest value for the number of women employed (CS3) and the second best value for Social Investment (CS4) in 2019. In 2020, the company keeps the fourth lowest value for CS1, falls to fourth best value for CS2, maintains the fourth highest value for CS3 and finally holds the best value for CS4. In 2021, the company maintains the fourth lowest value for CS1 and maintains the fourth largest for CS4, but worsens its values for CS2 (fourth largest) and CS3 (third largest). With this, it is noticed its worsening of performance in social criteria throughout the period researched, because there was a decrease in the number of direct jobs generated and in social investment. Concluding with regard to the environmental criteria, the company S5 was the one that consumed the most water and emitted GEEs and the second that consumed the most water, among the five, in the years 2019 to 2021. Thus, the company over the three years has maintained its leadership in two of the three environmental criteria that cause the most damage. With this, the fact that the company S5 lost space in the economic and social pillar in 2021, as well as maintained poor performance for the environmental aspect over the three years, contributed to the loss of the first place occupied in 2019 and 2020.

Considering all the analysis and discussion presented, it can be stated that the use of the TOPSIS method, combined with the AHP-Gaussian method for assigning the weights to the criteria, it is a useful tool to compare and evaluate sustainable performance based on the three pillars present in the TBL for the criteria listed in this article.

5 Conclusion

In 2022, Brazil consolidated itself as one of the main players in the global steel market, exporting 11.9 million tons to more than one hundred countries, resulting in a significant contribution of 16.7 billion dollars in the economy. The relevance of this exported volume puts steel products in fifth place in terms of importance to the country. The magnitude of installed capacity and the economic impact of these values highlight the Brazilian steel industry as a crucial engine for economic development. In parallel, the five main companies in the sector produced approximately 28 million tons of crude steel in 2022, an amount that undoubtedly resonates with the three pillars of sustainability: Economic, environmental and social.

This massive production, although vital to the economy, also raises challenges and implications in terms of sustainability. In the economic sphere, the sector not only generates substantial currencies and revenues, but also makes investments essential to the country's progress. However, in the environmental context, steel production demands a considerable amount of direct energy, resulting in the generation of waste that influences climate change, among other impacts. Finally, in the social scenario, steel mills exert a direct influence on the health and well-being of the communities that reside in their vicinity.

In this context, it is imperative to recognize more and more that economic aspects are not the guiding principles of the objectives of the companies. It must be understood that organizations must seek their perpetuation by integrating actions aimed not only at the financial aspect, but should also cover the social and environmental domains. This paradigm reflects an approach that meets the principles of the Triple Bottom Line (TBL). In this article, as a way to evaluate the sustainable performance of the main Brazilian steel mills, four economic indicators, four social and three environmental indicators were used, totaling eleven criteria. The use of these indicators, conducted through the TOPSIS method for ordering companies, combined with the AHP-Gaussian method for assigning weights, culminated in the achievement of the objective of this research. It was possible, through the research, to promote the evaluation of the sustainable performance of the five largest Brazilian steel mills. Consequently, it was also possible to understand the behavior of the five organizations of the Brazilian steel sector.

However, it is essential to observe the limitations inherent to the scope and methodology of the study. Focusing on the five largest companies can restrict the generalization of results for the sector as a whole, suggesting the need for more comprehensive and representative research. In addition, the study was limited to analyzing data from reports belonging to the three-year period. For future studies, it is recommended that the research explore and consider a broader spectrum of companies in the Brazilian steel sector or be applied in other important sectors of the Brazilian economy, as well as be replicated using a more comprehensive time cut. Finally, it is also expected that future studies can demonstrate the sustainable panorama of organizations in a given sector and thus become useful as a tool for stakeholders to analyze business actions and allocate resources and investments.

Acknowledgements

Author Gilson B A Lima would like to thank CNPq (Grant PQ 311484/2020-4) for their financial support.

Statement on Data Availability

The authors assert that all pertinent data are included within the manuscript.

References

Azimifard, A., Moosavirad, S. H., & Ariafar, S. (2018). Selecting sustainable supplier countries for Iran's steel industry at three levels by using AHP and TOPSIS methods. *Resources Policy*, 57, 30-44. http://dx.doi.org/10.1016/j.resourpol.2018.01.002.

Behzadian, M., Khanmohammadi Otaghsara, S., Yazdani, M., & Ignatius, J. (2012). A state-of the-art survey of TOPSIS applications. *Expert Systems with Applications*, 39(17), 13051-13069. http://dx.doi.org/10.1016/j.eswa.2012.05.056.

Brasil. Ministry of Industry, Foreign Trade and Services. (2023). *Comex Stat Portal, 2023*. Retrieved in 2023, September 23, from http://comexstat.mdic.gov.br/pt/geral/105563

Brazilian Steel Institute. (2023). *Brazil Steel Databook 2023*. Rio de Janeiro: Brazilian Steel Institute. Retrieved in 2023, September 23, from https://acobrasil.org.br/site/wp-content/uploads/2023/07/AcoBrasil_Anuario_2023.pdf

Bucur, A., Dobrotă, G., Oprean-Stan, C., & Tănăsescu, C. (2017). Economic and qualitative determinants of the world steel production. *Metals*, 7(5), 9. http://dx.doi.org/10.3390/met7050163

Caiado, R. G. G., Lima, G. B. A., Gaviáo, L. O., Quelhas, O. L. G., & Paschoalino, F. F. (2017). Sustainability analysis in electrical energy companies by similarity technique to ideal solution. *Revista IEEE América Latina*, 15(4), 675-681. http://dx.doi.org/10.1109/TLA.2017.7896394

Campos, L. M. D. S., Sehnem, S., Oliveira, M. D. A. S., Rossetto, A. M., Coelho, A. L. D. A. L., & Dalfovo, M. S. (2013). Relatório de sustentabilidade: perfil das organizações brasileiras e estrangeiras segundo o padrão da Global Reporting Initiative. *Gestão & Produção*, 20(4), 913-926. http://dx.doi.org/10.1590/S0104-530X2013005000013.

Chakraborty, S. (2022). TOPSIS and Modified TOPSIS: a comparative analysis. *Decision Analytics Journal*, 2, 100021. https://doi.org/10.1016/j.dajour.2021.100021.

Climate Observatory. (2023). *The Greenhouse Gas Emissions and Removals Estimation System (SEEG) Portal, 2023*. Retrieved in 2023, September 23, from https://plataforma.seeg.eco.br/?_gl=1*1u92vj1*_ga*OTU4MTIzMTYxLjE3MTA4ODE5NTk.*_ga_XZWSWEJDWQ*MTcxMDg4MTk1OC4xLjEuMTcxMDg4MjM2OC4wLjAuMA

Duan, Y., Han, Z., Zhang, H., & Wang, H. (2021). Research on the applicability and impact of CO2 emission reduction policies on China's steel industry. *International Journal of Climate Change Strategies and Management*, 13(3), 352-374. http://dx.doi.org/10.1108/IJCCSM-02-2021-0020

Falsarella, O. M., & Jannuzzi, C. S. C. (2020). Organizational and competitive intelligence and big data: a systemic vision for the organizations'sustainable management. *Perspectivas em Ciência da Informação*, 25(1), 179-204. http://dx.doi.org/10.1590/1981-5344/3497

Feil, A. A., Amaral, C. C., Walter, E., Bagatini, C. A., Schreiber, D., & Maehler, A. E. (2023). Set of sustainability indicators for the dairy industry. *Environmental Science and Pollution Research International*, 30(18), 52982-52996. http://dx.doi.org/10.1007/s11356-023-26023-3. PMid:36847943.

Gianicolo, E. A. L., Cervino, M., Russo, A., Singer, S., Blettner, M., & Mangia, C. (2021). Environmental assessment of interventions to restrain the impact of industrial pollution using a quasi-experimental design: limitations of the interventions and recommendations for public health policy. *BMC Public Health*, 21(1), 1856. http://dx.doi.org/10.1186/s12889-021-11832-3 PMid:34649551.

Global Reporting Initiative - GRI. (2021). *News Center of GRI, 2021. All eyes on a sustainable COVID recovery*. Retrieved in 2023, September 23, from https://www.globalreporting.org/news/news-center/all-eyes-on-a-sustainable-covid-recovery/

Guedes, É. C., Ribeiro, R. R., & Jeunon, E. E. (2020). Análise da utilização dos indicadores do Global Reporting Initiative (GRI) nos relatórios de sustentabilidade de empresas com atuação em Minas Gerais. *Revista Sinapse Múltipla*, 9(2), 150-151.

Hamurcu, M., & Eren, T. (2023). Multicriteria decision making and goal programming for determination of electric automobile aimed at sustainable green environment: a case study. *Environment Systems & Decisions*, 43(2), 211-231. http://dx.doi.org/10.1007/s10669-022-09878-8. PMid:36118127.

He, K., & Wang, L. (2017). A review of energy use and energy-efficient technologies for the iron and steel industry. *Renewable & Sustainable Energy Reviews*, 70, 1022-1039. http://dx.doi.org/10.1016/j.rser.2016.12.007

Hegab, H., Shaban, I., Jamil, M., & Khanna, N. (2023). Toward sustainable future: Strategies, indicators, and challenges for implementing sustainable production systems. *Sustainable Materials and Technologies*, 36, e00617. http://dx.doi.org/10.1016/j.susmat.2023.e00617.

Hwang, C.-L., & Yoon, K. (1981). *Multiple attribute decision making*. Berlin, Heidelberg: Springer Berlin Heidelberg. http://dx.doi.org/10.1007/978-3-642-48318-9.

Institute for Applied Economic Research – IPEA. (2021). *IPEAdata*. Retrieved in 2023, September 23, from http://www.ipeadata.gov.br/Default.aspx

Luken, R., & Castellanos-Silveria, F. (2011). Industrial transformation and sustainable development in developing countries. *Sustainable Development (Bradford)*, 19(3), 167-175. http://dx.doi.org/10.1002/sd.434

Milford, R. L., Pauliuk, S., Allwood, J. M., & Müller, D. B. (2013). The roles of energy and material efficiency in meeting steel industry CO2 targets. *Environmental Science & Technology*, 47(7), 3455-3462. http://dx.doi.org/10.1021/es3031424 PMid:23470090.

Moosa, A., & He, F. (2023). Impact of environmental management practices on corporate sustainability: evidence from the Maldives hospitality industry. *International Journal of Emerging Markets*, 18(9), 2869-2889. http://dx.doi.org/10.1108/IJOEM-06-2020-0700

Oliveira, R. S. G., Forapani, G., & Pereira, P. D. S. (2022). Responsabilidade Social Universitária: analisando organizações educacionais no contexto de capitalismo neoliberal a partir dos relatórios de sustentabilidade da Global Reporting Initiative. In *XI Encontro de Estudos Organizacionais da ANPAD* (pp. 1-11). Maringá: Associação Nacional de Pós-Graduação e Pesquisa em Administração – ANPAD.

Paz, T. D. S. R., Santos, M., & Gomes, C. F. S. (2022). Performance sustentável das empresas do setor de saúde: análise a partir da abordagem VFT e dos métodos AHP-Gaussiano e WASPAS. In *XLII Encontro Nacional de Engenharia de Produção* (pp. 1-12). Foz do Iguaçu: ENEGEP. http://dx.doi.org/10.14488/ENEGEP2022_TN_ST_390_1938_45066.

Pegden, C. D., Shannon, R. E., & Sadowski, R. P. (1995). *Introduction to simulation using SIMAN*. New York: McGraw-Hill.

Pereira, R. C. A., Silva, O. S. Jr, Mello Bandeira, R. A., Santos, M., Souza Rocha, C. Jr, Castillo, C. D. S., Gomes, C. F. S., Moura Pereira, D. A., & Muradas, F. M. (2023). Evaluation of smart sensors for subway electric motor escalators through AHP-Gaussian method. *Sensors (Basel)*, 23(8), 1. http://dx.doi.org/10.3390/s23084131 PMid:37112474.

Peterson, N. (2016). Introduction to the special issue on social sustainability: Integration, context, and governance. *Sustainability*, 12(1), 3-7. http://dx.doi.org/10.1080/15487733.2016.11908148

Politis, Y., & Grigoroudis, E. (2022). Incorporating the sustainability concept in the major business excellence models. *Sustainability (Basel)*, 14(13), 1. http://dx.doi.org/10.3390/su14138175

Rossoni, A., Rossoni, H. A. V., & Rodrigues, A. B. (2021). Potencial reutilização dos resíduos provenientes da indústria de ferrossílicio: revisão sistemática e aprofundada da literatura. *Revista Ibero-Americana de Ciências Ambientais*, 12(10), 385-398. http://dx.doi.org/10.6008/CBPC2179-6858.2021.010.0031.

Saaty, T. L. (1980). *The Analytic Hierarchy Process (AHP): Planning, Priority Setting, Resource Allocation*. New York: McGraw-Hill International Book Co.

Sadollah, A., Nasir, M., & Geem, Z. W. (2020). Sustainability and optimization: from conceptual fundamentals to applications. *Sustainability (Basel)*, 12(5), 1. http://dx.doi.org/10.3390/su12052027

Santos, M., & Costa, I. P. (2021). Multicriteria decision-making in the selection of warships: a new approach to the ahp method. *International Journal of the Analytic Hierarchy Process*, 13(1), 147-169. http://dx.doi.org/10.13033/ijahp.v13i1.833

Schoeman, Y., Oberholster, P., & Somerset, V. (2020). Value stream mapping as a supporting management tool to identify the flow of industrial waste: a case study. *Sustainability (Basel)*, 13(1), 91. http://dx.doi.org/10.3390/su13010091

Souza, M. M., Oliveira, A. L. R., & Souza, M. F. (2023). Location of agricultural warehouses based on spatial multicriteria analysis. *Revista de Economia e Sociologia Rural*, 62(1), e268622. http://dx.doi.org/10.1590/1806-9479.2022.268622

Sridhar, K., & Jones, G. (2013). The three fundamental criticisms of the Triple Bottom Line approach: an empirical study to link sustainability reports in companies based in the Asia-Pacific region and TBL shortcomings. *Asian Journal of Business Ethics*, 2(1), 91-111. http://dx.doi.org/10.1007/s13520-012-0019-3.

Stojčić, M., Zavadskas, E., Pamučar, D., Stević, Ž., & Mardani, A. (2019). Application of MCDM methods in sustainability engineering: a literature review 2008-2018. *Symmetry*, 1(3), 350. http://dx.doi.org/10.3390/sym11030350

Toktarova, A., Karlsson, I., Rootzén, J., Göransson, L., Odenberger, M., & Johnsson, F. (2020). Pathways for low-carbon transition of the steel industry: a swedish case study. *Energies*, 13(15), 1. http://dx.doi.org/10.3390/en13153840

Touzi, N., & Horchani-Naifer, K. (2023). A study on the preparation and characterization of pigment quality from iron-containing waste materials. *Environmental Science and Pollution Research*. (Preprint).

Usman, M., & Hammar, N. (2021). Dynamic relationship between technological innovations, financial development, renewable energy, and ecological footprint: fresh insights based on the STIRPAT model for Asia Pacific Economic Cooperation countries. *Environmental Science and Pollution Research International*, 28(12), 15519-15536. http://dx.doi.org/10.1007/s11356-020-11640-z PMid:33241498.

Vallet-Bellmunt, T., Fuertes-Fuertes, I., & Flor, M. L. (2023). Reporting Sustainable Development Goal 12 in the Spanish food retail industry. An analysis based on Global Reporting Initiative performance indicators. *Corporate Social Responsibility and Environmental Management*, 30(2), 695-707. http://dx.doi.org/10.1002/csr.2382

Vieira, I. L., Silva, E. R., Martini, L. C. Jr, & Mattos, U. A. O. (2020). Pontos positivos e negativos dos relatórios de sustentabilidade no modelo global reporting initiative: revisão da literatura nacional e internacional. *Revista Gestão Industrial*, 16(2), 21-46. http://dx.doi.org/10.3895/gi.v16n2.10549.

Yoon, K. P., Kim, W. K. (2017). The behavioral TOPSIS. *Expert Systems with Applications*, 89, 266-272. https://doi.org/10.1016/j.eswa.2017.07.045.

Authors contribution

Carlos Alberto Soares Cunha contributed to the conceptualization and development of the theoretical and methodological approach. The author Carlos Alberto Soares Cunha conducted the theoretical review with the assistance of Igor Macedo de Lima. Author Carlos Alberto Soares Cunha conducted data collection and processing, under the guidance of Professor Dr. Gilson Brito Alves Lima. Furthermore, Carlos Alberto Soares Cunha oversaw the project, utilized the required resources for its execution, and authored the essay. Carlos Alberto Soares Cunha, Igor Macedo de Lima, and Gabriel Brito Caldas were involved in the data analysis, under the supervision of Professor Dr. Gilson Brito Alves Lima. Professor Dr. Julio Vieira Neto assisted with the effort to prepare and finalize the essay. Professor Dr. Luís Alberto Duncan Rangel assisted with the formal analysis. Each of the authors contributed to the process of revising and making final edits to the manuscript.