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Oil and gas industry analysis with multicriteria decision making: the last eighteen years

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Introdução
Across the globe, companies are faced with the responsibility not to cause damage to the environment, or at least minimize it. In industrialized nations, more companies are including sustainability in their business; they believe being capable of reducing pollution and increasing profits simultaneously (Hart, 1996). In third world countries, the demands for effective implementation of sustainability have also experienced considerable increase in face of the global view of economic development (Kumah, 2006).
Problema de Pesquisa e Objetivo
It focuses on the important case of the oil and gas industry worldwide, comparing the five largest companies in the period 2005 until 2022. It also analyzes the year-by-year evolution for each company.
Fundamentação Teórica
In third world countries, the demands for effective implementation of sustainability have also experienced considerable increase in face of the global view of economic development (Kumah, 2006). In this context, the number of reports on sustainability performance of companies presented to stakeholders and shareholders has increased in the recent years. One of the key purposes of this report, according to the Global Reporting Initiative (GRI), is to allow a comparison among companies and a performance evaluation for every year (GRI, 2012). This article aims at checking for this possibility.
Metodologia
The multicriteria approaches propose ways to model the decision-making processes, including items such as type of decision to be made, unknown events that may affect the results, possible courses of action and the results themselves. The multicriteria are also used to measuring the sustainability (Tosicey al., 2015; Castellini et al., 2012) and others scientific areas. Among the most robust multicriteria methods, the specific methodology of ELECTRE Family stands out (Roy, 1985).
Análise dos Resultados
The company E1 got the worse evolution according to the criteria analyzed. This got the last position every year, being indifferent to companies E2 (E1 I E2) and E5 (E5 I E1) in 2007,E3 (E1 I E3) and E5 (E5 I E1) in 2008, only the company E5 (E1 I E5) in 2009, and in 2010 to 2013 this companywas the worst. In 2014 until 2022, the company E2 and E4 were the better, therefore the companies E1 and E3 were the worst. In order to analyze the robustness of results, the sensitivity analysis was performed, whose weighted values, thresholds and criteria arrangements were varied.
Conclusão
The system application provided the ranking of companies, which proved to be little susceptible to the variation of criteria weights, as well as in changing the arrangement of some other criteria. The application of the method ELECTRE III promoted working on the objective (criteria values) and subjective (weights and criteria thresholds) variables in combination, characteristic that directs a hierarchy process understood as more sensitive to the complexity of decisions.
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Palavras Chave
Multicriteria Analysis, Oil and Gas Industry, Sustainability

OIL AND GAS INDUSTRY ANALYSIS WITH MULTICRITERIA DECISION MAKING: THE LAST EIGHTEEN YEARS

1. INTRODUCTION

Across the globe, companies are faced with the responsibility not to cause damage to the environment, or at least minimize it. In industrialized nations, more companies are including sustainability in their business; they believe being capable of reducing pollution and increasing profits simultaneously (Hart, 1996). In third world countries, the demands for effective implementation of sustainability have also experienced considerable increase in face of the global view of economic development (Kumah, 2006).

In this context, the number of reports on sustainability performance of companies presented to stakeholders and shareholders has increased in the recent years. One of the key purposes of this report, according to the Global Reporting Initiative (GRI), is to allow a comparison among companies and a performance evaluation for every year (GRI, 2012). This article aims at checking for this possibility, through the use of reports for benchmarking and comparison. It focuses on the important case of the oil and gas industry worldwide, comparing the five largest companies in the period 2005 until 2022. It also analyzes the year-by-year evolution for each company.

The Multicriteria Decision Analysis (MCDA) was used to obtain the ranking of companies. The MCDA term refers to various methods developed to help decision makers achieve robust and promising results (Loken, 2007; Lepoldino et al, 2019), and can be used in various areas, e.g., solid waste management (Karmperis et al., 2013) and assessment of biodiversity conservation (Bottero et al., 2013). Among the existing methods, the ELECTRE III was chosen for reasons that will bedetailed in Section 3.

The paper is organized as follows. The first part consists of this introduction, Section 1, followed by detailing the data analyzed, Section 2. In Sections 3 and 4 there is the method description and thereupon the results. Finally, Section 5 shows the conclusion synthesizing the study and results.

2. DATA

The top five companies in the oil and gas sector worldwide were analyzed. They account for over 50% of the world oil industry investment (Passuello et al., 2012).

These companies were compared by means of their sustainability reports, all prepared according to the GRI guidelines, version 3 (G3). Aggregate data from reports between 2005 and 2022 were used, i.e. in the eighteen years preceding the important Macondo accident in 2010. This accident caused major repercussions in the international media and directly impacted oneof the selected companies. This company affected by Macondo accident was BP British Petroleum.

The GRI sustainability reports consist of two parts: general information and information on economic, environmental and social indicators. This article made use of the latter one. In G3, the total number of indicators is seventy-nine, but not all companies are obliged to report all of them.

For data selection and comparison of companies, the following steps were followed:

a) The five companies selected were defined according to their market value. Table 1 shows the five largest companies in the oil and gas sector, with their nomenclature and market value.

Table 1 - List of the selected companies

Companies	Nomenclature	Market value (billions USD - 2023)
Exxon Mobil Coporation	E4	USD 457,70
Royal Dutch Shell	E3	USD 166,38
Petrobrás S.A	E1	USD 102,80
Chevron Corporation	E5	USD 314,50
British Petroleum – BP	E2	USD 111,50

The indicators of environmental performance, economic and social reports of all companies were collected and analyzed regarding the sustainable performance improvement. An important contribution can also be seen in Lang et al. (2007). It is noteworthy that as GRI signatories, they apply the GRI G3 Guidelines for preparing their sustainability reports.
It was sought to compare the evolution of these companies' activities over eighteen years, i.e. 2005-2022.

b) The indicators were selected from the following criteria (Worrall et al., 2009):
    i. Relevance to the sector under study;
    ii. Contribution to the Triple Bottom Line analysis; and
    iii. Reporting and full disclosure by all companies selected.

An important observation can be made for the criterion EC8. This criterion has a qualitative scale as standardization measure, since its weights assigned were given by the scale described in Frame 1.

c) The standardization of measures for each criterion followed a logic that can be seen in Frame 3. The economic and environmental criteria were normalized to the amount produced, i.e. the total annual production, which encourages the company's economic expansion and establishes a magnitude comparison between them. The social criteria were normalized according to the total number of employees in the particular year, company, since these criteria are of major impact on life quality of workers and families.
d) The purpose of each criterion can be observed bellow. These objectives are of paramount importance for the correct application of the ELECTRE III method.

3. METHOD

The multicriteria approaches propose ways to model the decision-making processes, including items such as type of decision to be made, unknown events that may affect the results, possible courses of action and the results themselves. The multicriteria are also used to measuring the sustainability (Tosicey al., 2015; Castellini et al., 2012) and others scientific areas. Among the most robust multicriteria methods, the specific methodology of ELECTRE Family stands out (Roy, 1985).

3.1 ELECTRE III

Within the ELECTRE family, the method chosen was ELECTRE III that allows the use of inaccurate, indefinite and uncertain criteria, inherent to complex processes in human decision, based on the use of pseudo-criteria and thresholds of preference and indifference. Moreover, the "very bad" performance in one criterion that cannot be offset by good results in other criteria depending on the veto threshold. ELECTRE III has been widely used. In order to exemplify it, some practices are applied: in classification problems, for example, in the ranking of actions for investments selection (Huck, 2009), the choice for a strategic sustainable management of demolition waste (Roussat et al., 2009), energy systems selection (Tosic, et al., 2015; Cavallaro, 2010), housing evaluation (Natividade-Jesus et al., 2007), environment and management of water consumption (Mushtaq Khan, et al., 2015;Giner-Santonja et al., 2012; Hanandeh and El-Zein, 2010), finance (Zhelev, 2014; Li and Sun,

2010), decision analysis (Infante, et al., 2013;Montazer et al., 2009), education (Giannoulism and Ishizaka, 2010) and others (Bana e Costa and Oliveira, 2012; Durbach and Stewart, 2012; Frini et al., 2012). However, it has not been applied to the ordination and performance evolution analysis of the greatest oil and gas industries worldwide.

The ELECTRE III depends on the construction and exploitation of some relationships. Its phases are depicted in Fig. 1.

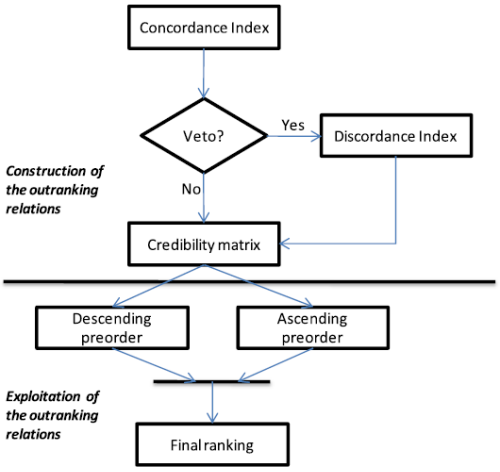

Fig 1 - Electre III flow

- Construction of the outranking relationship: the performance alternatives (the five companies under study) are pairwise compared (A, B). Each pairwise is characterized by an overcome relationship. Establish that "the alternative A outperforms alternative B" means "alternative A is at least as good as alternative B". There are three overcome relationships: "indifferent," "weakly preferred" or "strictly preferred", according to the difference between the performance alternatives and thresholds given by the decision maker.
- Exploitation of the outranking relationship: two preclassifications are then constructed with two antagonist procedures (upward and downward distillation). The combination of the two pre-classifications provides the final classification.

3.2 Constructing the outranking relationships

3.2.1 Pseudo-criteria

The simplest and most traditional criterion is called 'true criteria'. These have no defined limits. Only the difference among criteria scores is used to determine which option is the preferred one. Pseudo-criteria are used in order to take into account the inaccuracy and uncertainty in indeterminacy in complex decision problems. The indifference q and preference p thresholds allow the construction of a pseudo-criterion. Thus, three alternative relationships between alternatives A and B can be considered:

a) A and B are indifferent if the difference between the performance of two alternatives issmaller than the threshold indifference. The indifference between alternatives is denoted as A **I** B.

A **I** B if; and only if; $z(A) - z(B) \leq q$ (1)

where, z(X): alternative X performance; q: indifference threshold.

b) Alternative A has weak preference compared to alternative B if the difference between their performances is between the thresholds of indifference and preference. The notation for weak preference is A **Q** B.

A Q B if; and only if; $q < z(A) - z(B) \leq p$ (2)

where, z(X): alternative X performance; q: indifference threshold; p: preference threshold.

c) Alternative A is strictly preferred to alternative B if the difference between the alternative performances is greater than the threshold preference. The notation is strictly preferential A **P** B.

A P B if; and only if; $z(A) - z(B) \geq p$ (3)

where, z(X): alternative X performance; p: preference threshold.

3.2.2 Concordance index

The concordance index (Eqs. (4) and (5)) indicates the truth of the statement "alternative A outperforms alternative B" (A S B). C = 1 indicates the full truth of the assertion and C = 0 indicates that the statement is false.

Zone 1.$Z_i(B) - Z_i(A) \leq q_i$, alternatives A and B are indifferent, which means agreementon the statement "The alternative Aovercomes alternative B".Zone 2. $q_i < z_i(B) - z_i(A) < p_i$, the alternative B is weakly preferred to A, which means a partial agreement on the statement "The alternative A overcomes the alternative B". Zone 3.$Z_i(B) - Z_i(A) \geq p_i$, alternative B is strictly preferred to A, which means a false agreement on the statement "alternative A overcomes alternative B".

$$C(a,b) = \frac{1}{k} . \sum_{j=1}^{n} kj \, . cj(a,b) \quad (4)$$

Being for each criterion,

$$c_j(a,b) = \begin{cases} 1 \text{ if } g_j(a) + q_j(b) \geq g_j(b) \\ 0 \text{ if } g_j(a) + p_j(b) \leq g_j(b) \\ \dfrac{p_j + g_j(a) - g_j(b)}{p_j - q_j}, \text{ in all cases} \end{cases} \quad (5)$$

where, C(a,b): concordance index of actions a and b; K: sum of all weights of criteria; k_j: weight of criterion j, for j = 1, 2, 3, …, *n*; c_j: concordance index of actions a and b, under the criterion j.

3.2.3 Discordance index

If the difference in performances between alternatives A and B in a criterion i is greater than the veto threshold v_i it is cautious to refuse the statement "alternative A overcomes alternative B".The discordance index for each criterion i is given by Eq. (6).

Zone 1.$Z_i(B) - Z_i(A) \leq p_i$, alternative B is weakly preferable to alternative A, which means no disagreement about the statement "alternative A overcomes alternative B". Zone 2. $P_i < z_i(B) - z_i(A) < v_i$, alternative B is strictly preferred to alternative A, which means weak disagreement on the assertion "alternative A overcomes alternative B". Zone 3.$Z_i(B) - Z_i(A) \geq v_i$, the

difference between alternative A and alternative B exceeds the threshold for veto, which means total disagreement with the statement “alternative A overcomes alternative B”.

$$d_j(a,b) = \begin{cases} 1 \text{ se } g_j(a) + v_j \leq g_j(b) \\ 0 \text{ se } g_j(a) + p_j \geq g_j(b) \\ \dfrac{g_j(b) - g_j(a) - p_j}{v_j - p_j} \text{nos demais casos} \end{cases} \quad (6)$$

where: $z_i(X)$: alternative X performance in criterion i; p_i: threshold of alternative preference on the criterion i.

3.2.4 Credibility index

Considering the concordance (Eq. (4)) and discordance (Eq. (6)) indexes, the credibility degree (Eq. (7)) indicates whether the outranking hypothesis is true or not. If the concordance index (Eq.(4)) is greater than or equal to the discordance index on all criteria (Eq. (6)), then Eq. (7) is equal to Eq. (4). If Eq. (4) is strictly below Eq. (6) then the reliability degree (Eq. (7)) is equal to Eq. (4). Note the importance of the direct relationship of these indices.

$$S(a,b) = \begin{cases} C(a,b), \text{ se } d_j(a,b) \leq C(a,b) \ \forall_j \\ C(a,b). \prod_{j \in J(a,b)} \dfrac{1 - dj(a,b)}{1 - C(a,b)}, otherwise \end{cases} \quad (7)$$

Where: J(A,B): is the set of criteria for di(A,B) > C(A,B).

4. Results

4.1 Performance Matrix

In order to determine the sequence of alternatives using the processes assigned to the ELECTRE III, the performance matrix of alternatives for each criterion can be observed taking into account the evolution over eighteen years. For each criterion, thresholds and weights were assigned by experts through questionnaires and interviews conducted directly. In the case of weights, all these criteria at this first time, receive the same importance in the analysis,i.e., equal weights were assigned to all of them (kj ¼ 1). After calculating the indices of concordance and disagreement, the degrees of credibility are built and consolidated in the Matrix of Credibility. The degrees of credibility and indexed to each pair of alternatives do not produce a symmetric matrix. The next step is to explore this matrix. See Section 4.2.

4.2 Distillation

A graph can be drawn from the credibility matrix. Each alternative is connected with another one by two arrows, one in each direction indicating the credibility index. The graph for many alternatives is highly complex. An automated procedure named distillation, should be used to rank the alternatives. The name “distillation” was chosen by analogy to alchemists who distill mixtures of liquid to extract a magic ingredient. The algorithm to classify all alternatives can be divided into two pre-classifications. The first pre-classification is achieved with descending distillation by selecting the best ranked alternatives initially and ending with the

worst. The best alternative is extracted from the whole set by applying very strict rules (Eq. (8)). In this subset, the best alternatives are selected by application of less restrictive rules (Eq.(10)), and the same rules previously used would bring a different result. The procedure continues with less restrictive rules and a lower number of alternatives (subsets). The procedure ends when it remains only one alternative or a group of alternatives that cannot be separated. The second distillation uses the same procedure, but in the original set of alternatives removed, at first, the best results from the distillation. Thus, a new subset is obtained in each distillation, which contains the best alternative. In each distillation, the alternative extracted will be ranked at an inferior position. As an alternative is connected with each other by two arrows, one in each direction, but not necessarily with symmetrical credibility index; a second pre-classification is constructed with ascendant distillation. In this case, the worst alternatives are first selected and the distillation ends with the assign of the best alternative. For distillation, it is necessary that an alternative a preferred to b is defined as follows: the alternative a preferred to b if the degree of credibility that "A exceeds B" is superior to the threshold λ_2 and significantly higher than the degree credibility "B exceeds A" (Eq. (8)).

$$S(A; B) > \lambda_2 \text{ and } S(A; B) - S(B; A) > s(\lambda_0) \quad (8)$$

Where λ_2 is the highest level of credibility, which is slightly below the cutoff λ_1, as follows:

$$\lambda_2 = Max_{\{S(A,B) \leq \lambda 1\}} S(A,B) \forall \{A,B\} \in G \quad (9)$$

Where G is the set of alternatives.λ_1 is the next level:

$$\lambda_1 = \lambda_0 - s(\lambda_0) \quad (10)$$

where λ_0 is the greatest degree of credibility in the respective credibility matrix:

$$\lambda_0 = Max_{A,B \in G} S(A,B) \quad (11)$$

and $s(\lambda_0)$ is the following threshold discrimination:

$$s(\lambda_0) = \alpha + \beta \, . \, \lambda_0 \quad (12)$$

It is used a $\alpha = 0.3$ and b $\beta = -0.15$ since both values are recommended by Roy (1985).

By applying this procedure for all from 2005 to 2022, there are the distillations shown in Figs. 4 and 5. It may be noted that the result of descendant distillation in 2006 was similar to that in 2005, the company E2 had preference over the others followed by the company E4. The others did not receive preferences related, resulting in indifference between them.
In the years 2007 and 2008, results of descendant distillation were similar; the company E4 had preference over the others. Indifference, in these two years, was among four other companies, highlighting the strong preference for the company E4.
The result of descendant distillation showed preference for the company E4, followed by the company E2 in 2009. Regarding the companies E1, E3 and E5, there was no preference between them. Finally, in 2010 and 2011 the resultwas similar, and the company E2 had preference over the others followed by the company E4 (Fig. 4). The companies E2 and E4 were the most impact companies in 2016 until 2022. The companies E1 and E3 were the worst in 2019 until 2022.

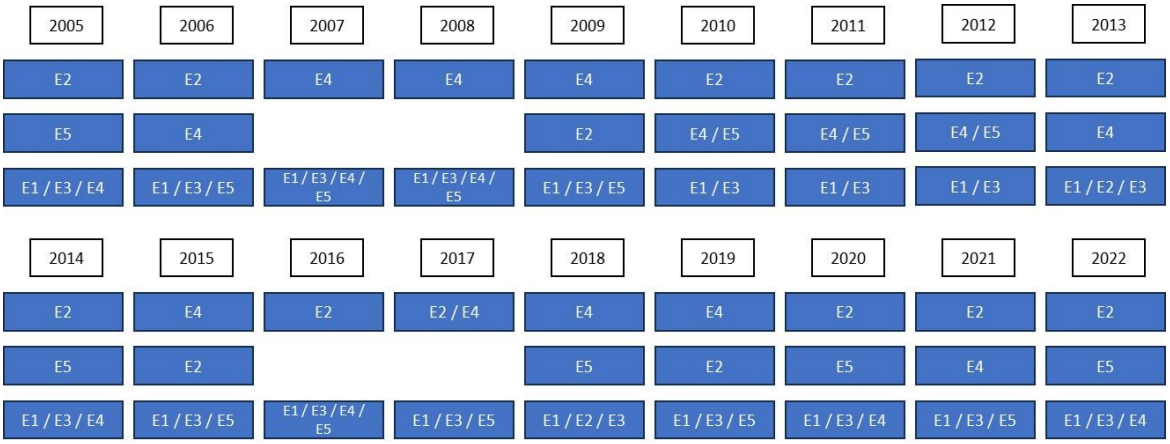

Fig 4 - Results from descendent distillations

The ascendant distillation showed that the company E1 got preference over the others, followed by companies E4 and E5 in 2006. The others did not receive preferences related, resulting in indifference between them.

In the years 2007 and 2008, the results of ascendant distillation were similar. For the former, companies E1, E2 and E5 were ranked as the best and the companies at the second best position were E1, E3 and E5. It is noticed that only the E2 company is not indifferent to the other in the second year analyzed. For other companies, there was no preference between them. In 2009, the result of ascendant distillation showed preference for companies E1 and E5, followed by the company E3. Regarding the companies E2 and E5, there was no preference between them.

Finally, in 2010 and 2011 the result was similar, and the company E2 had preference over the others followed by the companies E4 and E5 (Fig. 5). In 2012 and 2013 the result was similar to 2010.

The companies E1 and E5 were the most negative impact companies in 2016 until 2022. The companies E2 and E4 were the less impact in 2016 until 2022.

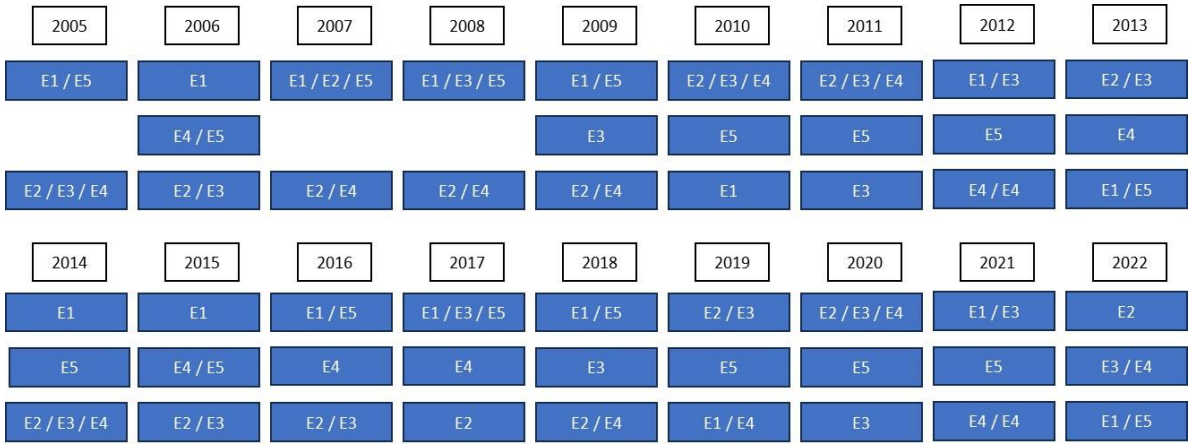

Fig 5 - Results from ascendent distillations

With successive distillations, the cutoff level λ_1 is gradually reduced, which makes it much easier to be preferred to B. However it contains some arbitrariness such as the recommended values of α and β (Takeda, 2001). Other values may be used, which can slightly change the classification.

4.3 Final Ordination

The final ordination (Fig. 6) is obtained by combining two preclassifications. Refer to Section 4.2. Partial results of preclassifications are aggregated in the classification matrix. There are four possible cases (Xu and Ouenniche, 2012):

i. The alternative A is better than B or in both distillations or A is better than B in one distillation and it has the same position in the other one, subsequently A is better than B: **A P^{+}B**;
ii. The alternative A is greater than B in one distillation, but B is better than A in another distillation, then A is incomparable to B: **A R B**;
iii. Alternative A has the same position that B in both distillations, therefore A is indifferent to B: **A I B**;
iv. A is smaller than B in both distillations or A is smaller than B in one distillation and it has the same rank in the other distillation, then A is worse than B: A **P^{-}B**.
v.

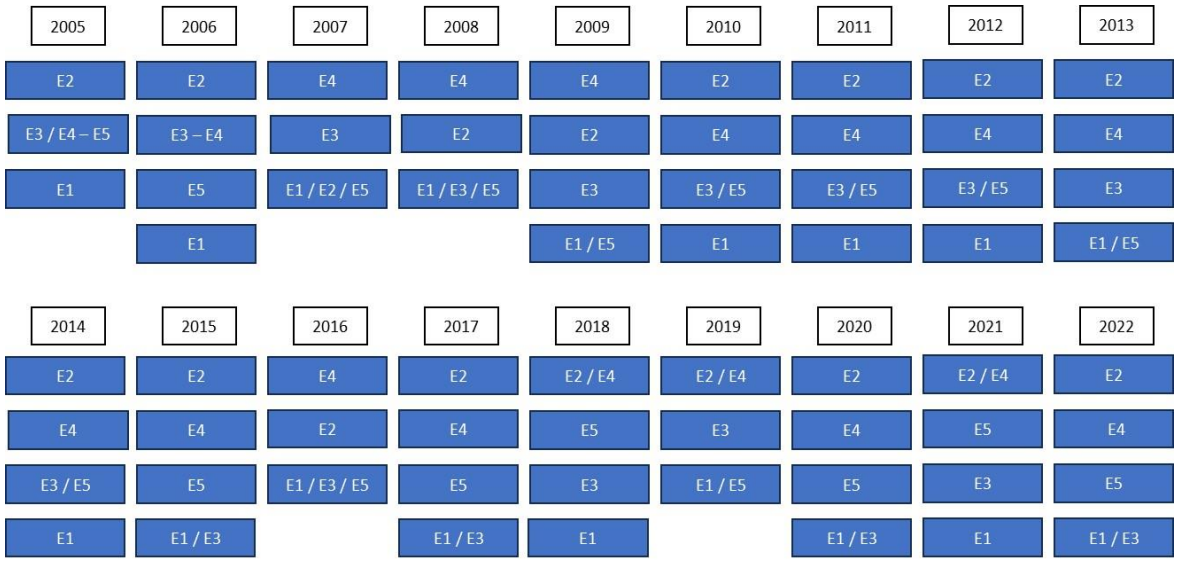

Fig 6 - Final Ordination

The company E4 had the best performance, considering its evolution. This companywas indifferent to E3 (E4I E3) and the incomparable company E5 (E4 R E5) in 2005 and 2006, and it obtained the second position in the ordination; however, in the following years its performance was considered more relevant, enabling a prominent position before the others;
The company E2 obtained the second best performance, considering its evolution. The company ranked first in the ranking in 2005 and 2006, only falling to second position in the other years, except 2010 and 2011, where E2 was first too. This favorable performance in seven years provided its effective implementation and criteria analyzed;
The company E3 has remained virtually constant in all years. In the years 2005 to 2007 it took the second position in the ranking, dropping to third in the years 2008 and 2009, which earned him third place overall. This company was considered indifferent to enterprises E1 and E5 (E1 I E3) and (E3 I E5) in 2008, which did not happen again in 2009.

In 2010 and 2011, the company E2 had the best performance, considering this evolution. Not the same was considered in 2012 and 2013, where this company was the second.
The company E5 began at second position in the ordination in 2005, just indifferent to companies E2 and E4 (E4 I E5) and (E5 I E2). In the years 2006e2008 it remained at the third position, being indifferent to the companies E1 (E1 I E5), E2 (E5 I E2) and E3 (E3 I E5). In 2009 it got the last position, being indifferent to the company E1 only. In 2010 and 2011, this company had the third best performance, being indifferent by E3. This low performance improvement for company E5 allowed its fourth position overall in the final ordination. This similar result could be analyzed in 2012 and 2013.
The company E1 got the worse evolution according to the criteria analyzed. This got the last position every year, being indifferent to companies E2 (E1 I E2) and E5 (E5 I E1) in 2007,E3 (E1 I E3) and E5 (E5 I E1) in 2008, only the company E5 (E1 I E5) in 2009, and in 2010 to 2013 this companywas the worst.
In 2014 until 2022, the company E2 and E4 were the better, therefore the companies E1 and E3 were the worst.
In order to analyze the robustness of results, the sensitivity analysis was performed, whose weighted values, thresholds and criteria arrangements were varied.

4.3.1 Sensitivity analysis

A sensitivity analysis was carried out varying the weights and some criteria arrangements. This analysis was performed to obtain a greater robustness of the results. At the stage of new criteria, arrangements resulted in eighteen important combinations in order to verify the accuracy of the final ordination. The change in weights of the criteria groups, i.e. economic, social and environmental groups was performed by assigning weights between 1.5 and 2.5 to each group, resulting in six combinations. It is important to remember that the weights of all criteria were equal originally. A total of twenty five new combinations were performed to assess the final ordination's robustness. Checking for the sensitivity analyzes performed for each year surveyed, there is consistency in the results, which according to the final ordination has prevailed. In 2005 the disparity in the new ordination after changes performed is negligible, as it can be seen in other years. The weights assigned confirmed that, even with the change in importance of the criteria groups, there is a big change in the ordination of companies, which features robustness to the final result.
It was observed that the criterion - EN30 e Total investments and operating costs - was significant in all years analyzed, since its withdrawal from the analysis directly impacted the finalordination, resulting in indifference between enterprises E1, E2and E5. In the years 2005 and 2006 the criterion of greatestimpact was EN 21 - Total water discharge by quality and destination - whose withdrawal from the analysis partially modifiedthe final ordination, causing incomparability of the E5 companyin relation to the others and indifference between companies E3and E4.
The variation of weights in the criteria groups had a major impact only in 2009, where amendments 15 and 16 partially modified the companies' final ordination, changing the indifference to companies E2 and E4, which was previously observed in companies E1 and E5.

5. Conclusions

The system application provided the ranking of companies, which proved to be little susceptible to the variation of criteria weights, as well as in changing the arrangement of some other criteria.
The application of the method ELECTRE III promoted working on the objective (criteria values) and subjective (weights and criteria thresholds) variables in combination,

characteristic that directs a hierarchy process understood as more sensitive to the complexity of decisions.
The criteria presented and discussed were adequate for evaluating the companies in the oil and gas sector, as they encompassed economic, environmental and social aspects for the study. It should be noted that, regarding the risks to the environmental criteria, there is need for a more accurate survey in the field, in order to evaluate all parameters that influence such a criterion, but for the present study, the evaluation performed was satisfactory. The study allowed analyzing the companies, strategically, checking for their development and performance in the years studied. According to the criteria selected, these companies were ordered to obtain comparisons and improvements in their production processes.

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