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Ecological Efficiency Evaluation in Petrochemical Enterprises Using Plithogenic-ARTASI Model

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Abstract: The application of the ecological carrying capacity theory to the assessment of petrochemical companies' eco-efficiency is the main goal of this article. This study deviates from previous research that examines company eco-efficiency from a strategic and behavioral incentive standpoint. This study uses the multiple-criteria decision-making (MCDM) approach, considering both qualitative and quantitative factors. Plithogenic sets are used to compute expert importance levels in a decision support system for choosing Petrochemical Enterprises. The suggested plithogenic-based alternative ranking methodology based on adaptive standardized intervals (ARTASI) method is used to determine the ranking of Petrochemical Enterprises. The plithogenic-ARTASI model is a combination of these techniques. For this hybrid model, an algorithm is also created. The plithogenic-ARTASI hybrid model's suitability for Petrochemical Enterprises performance calculations is illustrated through a case study. Tests of robustness are conducted using a variety of sensitivity analysis scenarios. The study's findings show that plithogenic-ARTASI is reliable and relevant. In-depth managerial consequences are discussed and given.

Keywords: Ecological Efficiency; Petrochemical Enterprises; Decision Support; Uncertainty; MCDM Methodology.

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1. Introduction

The Canadian Scientific Council (SCC) first put forth the idea of eco-efficiency in the 1970s. Ecological efficiency was added to the global conservation plan in the 1980s by the International Union for Conservation of Nature and Natural Resources (IUCN). Schaltegger and Sturn, two Swiss academics, defined ecological efficiency in 1992.One Several organizations and academics worldwide began researching ecological efficiency in the later 1990s, and they provided a variety of meanings for the term. The World's Sustainable Development of Industrial and Commercial Enterprises Commission (WBCSD) provided the most significant definition of eco-efficiency in 1995[1], [2]. Reducing the intensity of resource and energy usage, increasing the efficiency of using renewable resources, improving substance recovery, and lowering the emission of harmful compounds are the main goals of eco-efficiency[3], [4]. Throughout an enterprise's whole life cycle, the intensity of resource consumption and environmental pollution are decreased to a level consistent with ecological carrying. Three main objectives were established, and the connotation was further clarified in 2000. Reducing the impact on the environment and consuming less resources are the two goals. Increasing the value of the product is the third[5], [6]. The theory of natural ecology is the source of the idea of carrying capacity, which is the maximum amount of time an organism may survive in each environment. Ecologists first proposed the idea of carrying capacity in the study of human ecology in the 1920s. Park introduced the idea of ecological carrying capacity, or the upper limit of the number of individuals that can exist in a certain habitat and published the carrying capacity principle. As a result, the concept of carrying capacity keeps growing, as does the theory and practice of carrying capacity. The interaction between the industrial economy, resources, environment, and social conditions was then measured using the carrying capacity concept[7], [8].

Decision models by structure serve as the foundation for decision assistance systems. Decision-makers, selection criteria, and alternatives are all included in decision models. Determining the influence of experts on the decision-making process, assessing the significance of criteria, and prioritizing options in this manner are all essential for making the optimal choice. The MCDM approach is used in this study to create a sophisticated decision support system. Figure 1 shows the steps of the MCDM. Furthermore, because plithogenic sets are linguistically based, they are utilized for expert evaluations. Due to its benefits in stabilizing unstable structures in expert evaluations, plithogenic sets are utilized in this area[9], [10], [11].

Plithogenic set is used with the alternative ranking technique based on adaptive standardized intervals (ARTASI) method for the rating of alternatives. Because it offers a two-step standardization option based on absolute maximum and minimum values, the developed plithogenic-ARTASI approach is recommended[12], [13]. A plithogenic-ARTASI hybrid model and a decision support system for ecological efficiency evaluation are therefore established in this study[14], [15].

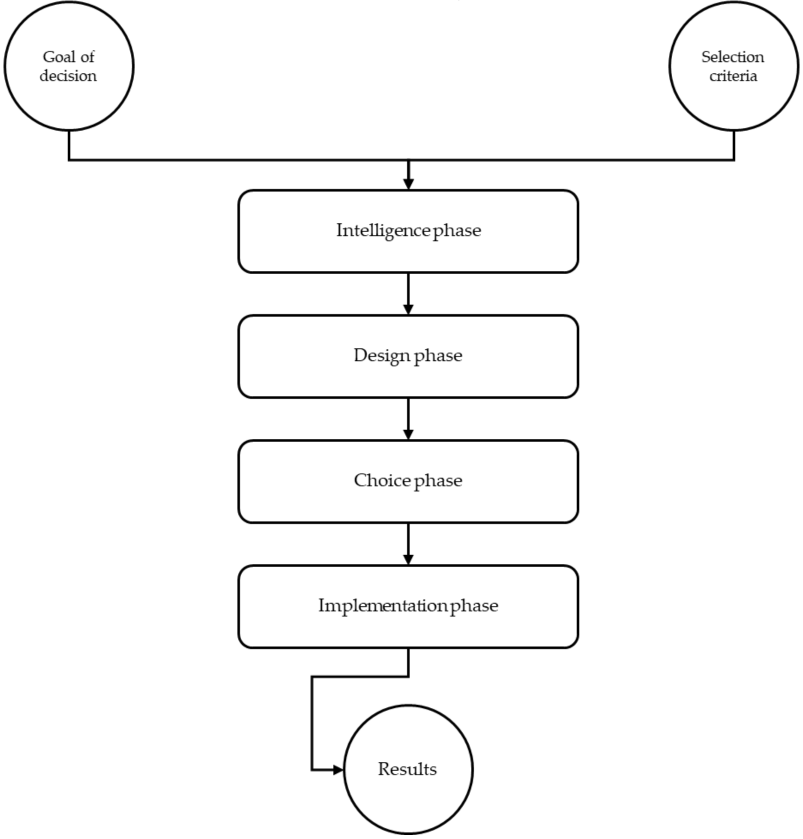

Figure 1. The steps of the MCDM problems.

1.1 Contributions of this study

The following summarizes the research' contributions to the body of literature:

- ✓ Determined a critical need for the creation of a decision support system in the context of ecological efficiency in Petrochemical Enterprises.
- ✓ Underlined the relevance of choosing the appropriate Petrochemical Enterprises to reach the best executive prospects and acknowledged the value of the Petrochemical Enterprises selection process.
- ✓ To raise executives' understanding of the Petrochemical Enterprises selection process, qualitative and quantitative criteria for Petrochemical Enterprises selection were included.
- ✓ Using an MCDM technique and plithogenic sets, the research creatively addressed the decision-making process, setting it apart from previous works.
- ✓ Broadened the decision-making process by combining qualitative and quantitative criteria, offering a more thorough viewpoint than traditional methods that frequently concentrate only on quantitative metrics.
- ✓ Created a new and creative method based on plithogenic sets for Petrochemical Enterprises: the plithogenic-ARTASI hybrid model. This paradigm offers a distinctive framework for decision support.
- ✓ Introduced the plithogenic-ARTASI technique for Petrochemical Enterprises and determining the most effective Petrochemical Enterprises. This approach's two-stage standardization process, which produces more effective results, is credited with its effectiveness.

2. Materials and Methods

Figure 2 shows the methodology used in this study, which was carried out to evaluate the effectiveness of ecological efficiency. The methodological framework was implemented using plithogenic sets and MCDM. Furthermore, the goal was to incorporate both qualitative and quantitative elements into the choice model. Four sections comprised the research approach in this context. The input parameters for measuring the performance of ecological efficiency were established in the first part. Experts, alternative Petrochemical Enterprises, and qualitative and quantitative criteria were among these considerations. The important levels of the experts' contributions to the decision-making process were ascertained in the second section. Alternative rankings were created while taking Petrochemical Enterprises performance levels into account. Furthermore, sensitivity analysis scenarios were used to apply robustness testing for the suggested model[16], [17], [18].

Step 1. Each alternative is evaluated by each expert with respect to each criterion. Initial decision matrices are constructed for the criteria and alternatives.

Step 2. We used the plithogenic operators to aggregate these decision matrices. The combined decision matrix is created in this step.

Step 3. Determine the crisp initial decision matrix between the criteria and alternatives by applying the score function.

Step 4. Compute the maximum and minimum absolute value in the initial decision matrix between the criteria and the alternative.

$$y_j^{max} = \left(\max x_{ij} + \max x_{ij}\right)^{1/m} \tag{1}$$

$$y_j^{min} = \left(\min x_{ij} + \min x_{ij}\right)^{1/m} \tag{2}$$

Step 5. Compute the normalization matrix by two steps such as:

$$R_{ij} = \frac{x_{ij}\left(B^{(u)} - B^{(l)}\right)}{y_j^{max} - y_j^{min}} + \frac{y_j^{max} B^{(l)} - y_j^{min} B^{(u)}}{y_j^{max} - y_j^{min}} \tag{3}$$

$$L_{ij} = \left(-R_{ij} + \max R_{ij} + \min R_{ij}\right) \tag{4}$$

Where $\left[B^{(u)}, B^{(l)}\right]$ is set to values [1,100]

Step 6. Compute the utility level of alternatives for positive and negative criteria such as:

$$P_{ij}^{+} = \left(\frac{L_{ij}}{\max L_{ij}}\right) w_j\left(B^{(u)}\right) \tag{5}$$

$$P_{ij}^{-} = \left(\frac{\min L_{ij}}{L_{ij}}\right) w_j\left(B^{(u)}\right) \tag{6}$$

Step 7. Compute the comprehensive assessment of the utility level of alternatives

$$N_i^{+} = \sum_{j=1}^{n} P_{ij}^{+} \tag{7}$$

$$N_i^{-} = \sum_{j=1}^{n} P_{ij}^{-} \tag{8}$$

Step 8. Compute the final utility function

$$N_i = (N_i^{+} + N_i^{-})(Q)\left(f(N_i^{+})\right)^t + \left((1 - Q)\left(f(N_i^{-})\right)^t\right)^{1/t} \tag{9}$$

$$f(N_i^{+}) = \frac{N_i^{+}}{N_i^{+} + N_i^{-}} \tag{10}$$

$$f(N_i^{-}) = \frac{N_i^{-}}{N_i^{+} + N_i^{-}} \tag{11}$$

Where $t \in [1, +\infty]$ and $Q \in [0,1]$

Step 9. Final rank of alternatives.

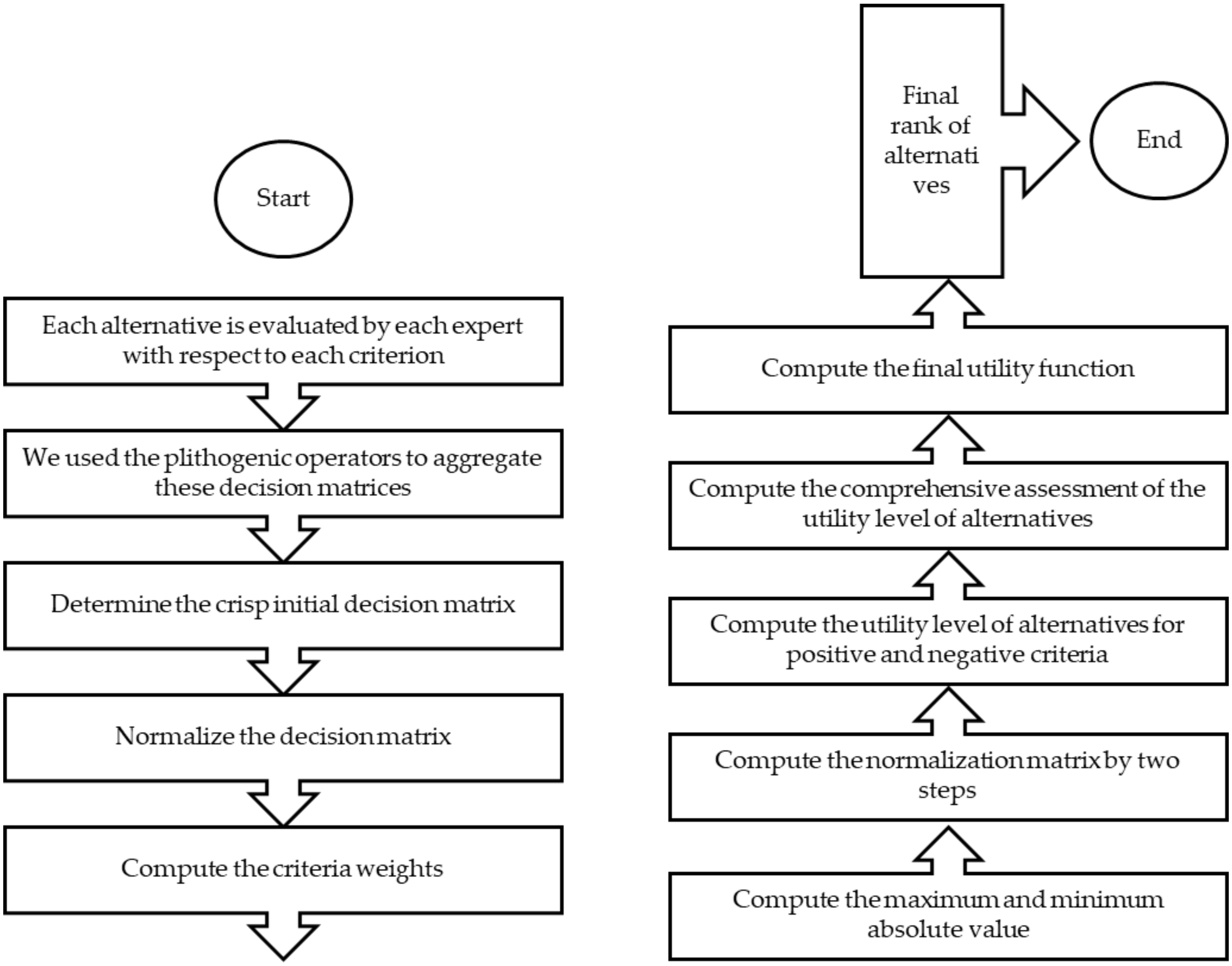

Figure 2. The Steps of MCDM approach.

3. Results and Discussion

Ecological efficiency evaluation in petrochemical enterprises focuses on promoting sustainable development by balancing economic performance with environmental responsibility. It emphasizes the efficient use of resources and energy while minimizing negative environmental impacts, such as waste generation and pollution. Petrochemical companies play a critical role in global industrial chains, and their operations significantly affect ecosystems and communities. Eco-efficiency evaluation helps these enterprises align with environmental regulations and societal expectations by fostering cleaner production and responsible resource management. Through this approach, companies can enhance their competitiveness, reduce operational risks, and contribute to a circular economy. This process is vital for achieving long-term environmental and economic sustainability in the petrochemical industry. This section evaluates the Petrochemical Enterprises to assess ecological efficiency based on a set of criteria. This study evaluated the criteria and alternatives by four experts and decision makers. Seven criteria and five alternatives (Petrochemical Enterprises) are used in this study as shown in Figure 3. All criteria are positive except the third criterion is negative.

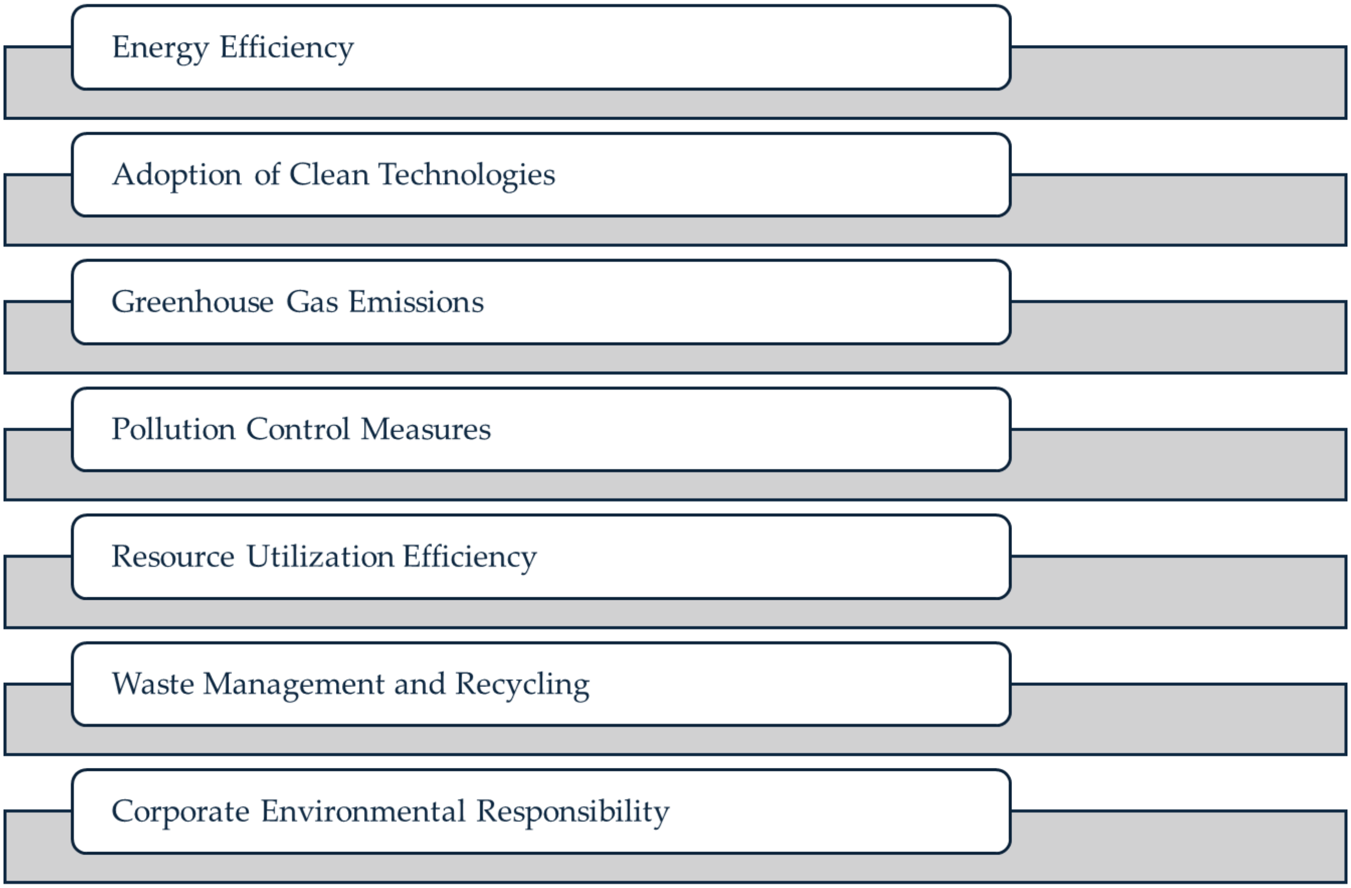

Figure 3. The criteria for assessment the ecological efficiency.

Step 1. Plithogenic numbers are used to evaluate the criteria and alternatives to build the decision matrix as shown in table 1.

Table 1. The decision matrix.

	A_1	A_2	A_3	A_4	A_5
C_1	(0.50, 0.40, 0.60)	(0.30, 0.40, 0.80)	(0.30, 0.40, 0.80)	(0.50, 0.40, 0.60)	(0.70, 0.30, 0.10)
C_2	(0.90, 0.10, 0.10)	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)	(0.30, 0.40, 0.80)	(0.50, 0.40, 0.60)
C_3	(0.50, 0.40, 0.60)	(0.90, 0.10, 0.10)	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)	(0.50, 0.40, 0.60)
C_4	(0.70, 0.30, 0.10)	(0.50, 0.40, 0.60)	(0.90, 0.10, 0.10)	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)
C_5	(0.90, 0.10, 0.10)	(0.90, 0.10, 0.10)	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)	(0.30, 0.40, 0.80)
C_6	(0.30, 0.40, 0.80)	(0.50, 0.40, 0.60)	(0.90, 0.10, 0.10)	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)
C_7	(0.50, 0.40, 0.60)	(0.90, 0.10, 0.10)	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)
	A_1	A_2	A_3	A_4	A_5
C_1	(0.30, 0.40, 0.80)	(0.30, 0.40, 0.80)	(0.50, 0.40, 0.60)	(0.90, 0.10, 0.10)	(0.10, 0.70, 0.80)
C_2	(0.30, 0.40, 0.80)	(0.30, 0.40, 0.80)	(0.30, 0.40, 0.80)	(0.50, 0.40, 0.60)	(0.30, 0.40, 0.80)
C_3	(0.10, 0.70, 0.80)	(0.30, 0.40, 0.80)	(0.30, 0.40, 0.80)	(0.50, 0.40, 0.60)	(0.10, 0.70, 0.80)
C_4	(0.30, 0.40, 0.80)	(0.30, 0.40, 0.80)	(0.50, 0.40, 0.60)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)
C_5	(0.90, 0.10, 0.10)	(0.30, 0.40, 0.80)	(0.30, 0.40, 0.80)	(0.50, 0.40, 0.60)	(0.90, 0.10, 0.10)
C_6	(0.90, 0.10, 0.10)	(0.10, 0.70, 0.80)	(0.30, 0.40, 0.80)	(0.30, 0.40, 0.80)	(0.50, 0.40, 0.60)

C_7	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.30, 0.40, 0.80)	(0.50, 0.40, 0.60)	(0.90, 0.10, 0.10)
	A_1	A_2	A_3	A_4	A_5
C_1	(0.50, 0.40, 0.60)	(0.70, 0.30, 0.10)	(0.10, 0.70, 0.80)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)
C_2	(0.70, 0.30, 0.10)	(0.50, 0.40, 0.60)	(0.70, 0.30, 0.10)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)
C_3	(0.50, 0.40, 0.60)	(0.70, 0.30, 0.10)	(0.50, 0.40, 0.60)	(0.70, 0.30, 0.10)	(0.70, 0.30, 0.10)
C_4	(0.70, 0.30, 0.10)	(0.50, 0.40, 0.60)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)
C_5	(0.90, 0.10, 0.10)	(0.70, 0.30, 0.10)	(0.50, 0.40, 0.60)	(0.70, 0.30, 0.10)	(0.50, 0.40, 0.60)
C_6	(0.70, 0.30, 0.10)	(0.50, 0.40, 0.60)	(0.70, 0.30, 0.10)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)
C_7	(0.50, 0.40, 0.60)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)
	A_1	A_2	A_3	A_4	A_5
C_1	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.70, 0.30, 0.10)	(0.90, 0.10, 0.10)
C_2	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.30, 0.40, 0.80)
C_3	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.90, 0.10, 0.10)	(0.90, 0.10, 0.10)
C_4	(0.10, 0.70, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.90, 0.10, 0.10)
C_5	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.90, 0.10, 0.10)	(0.70, 0.30, 0.10)
C_6	(0.30, 0.40, 0.80)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)	(0.90, 0.10, 0.10)
C_7	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.10, 0.70, 0.80)	(0.70, 0.30, 0.10)	(0.30, 0.40, 0.80)

Step 2. Then we combine these numbers into a single matrix using plithogenic operators.

Step 3. Compute crisp values between criteria and alternatives. Then we compute the criteria weights as shown in Figure 4.

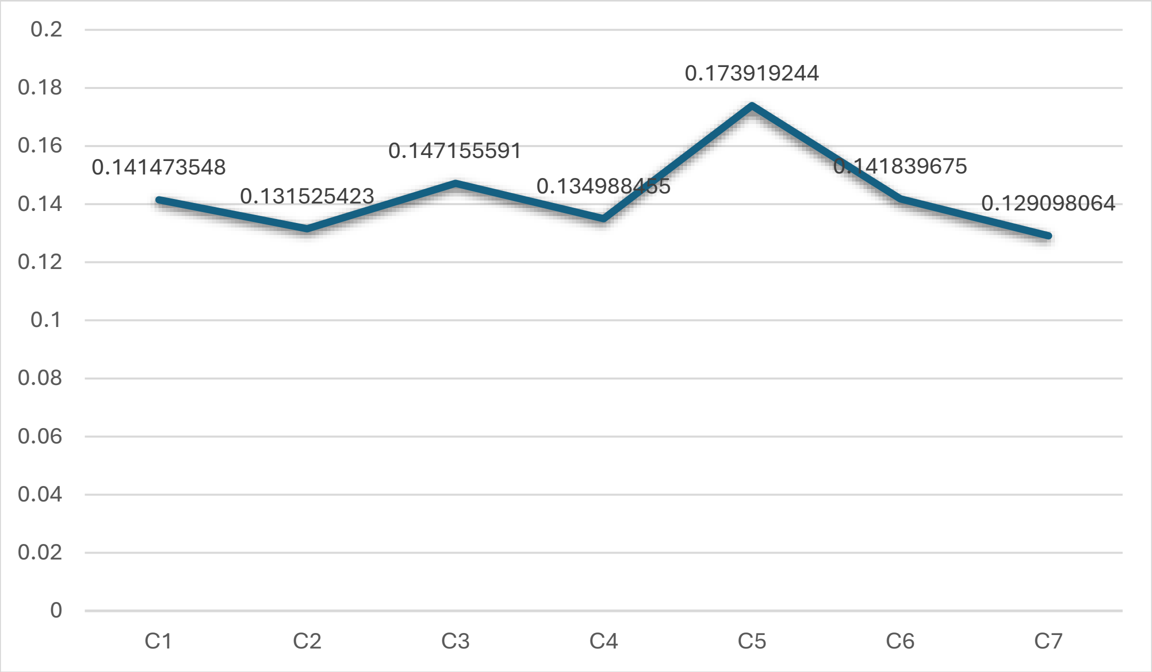

Figure 4. The criteria weights.

Step 4. Eqs. (1 and 2) are used to compute the maximum and minimum values.

Step 5. Eqs. (3 and 4) are used to compute the two-normalization matrix as shown in tables 2 and 3.

Table 2. The first normalization matrix.

	A_1	A_2	A_3	A_4	A_5
C_1	-213.724	21.8161	-275.89	124.2605	-60.4209
C_2	41.63347	-309.464	-21.9484	-10.943	-161.579
C_3	-249.589	155.7683	-235.508	56.25834	56.25834
C_4	3.428192	-91.8483	149.6393	-214.479	-2.10125
C_5	199.5484	142.0548	-225.615	48.54862	101.8798
C_6	86.60537	-141.642	138.548	-220.594	69.76501
C_7	-6.78208	138.548	-220.594	-81.3608	-69.332

Table 3. The second normalization matrix.

	A_1	A_2	A_3	A_4	A_5
C_1	62.09454	-173.446	124.2605	-275.89	-91.2087
C_2	-309.464	41.63347	-245.882	-256.887	-106.251
C_3	155.7683	-249.589	141.6882	-150.079	-150.079
C_4	-68.2684	27.00805	-214.479	149.6393	-62.739
C_5	-225.615	-168.121	199.5484	-74.6149	-127.946
C_6	-168.652	59.59518	-220.594	138.548	-151.811
C_7	-75.2644	-220.594	138.548	-0.68565	-12.7145

Step 6. Then we compute the utility level of alternatives for positive and negative criteria using Eqs. (5 and 6).
Step 7. Then we compute the comprehensive assessment of the utility level of alternatives using Eqs. (7 and 8)
Step 8. Then we compute the final utility function using Eq. (9). We put the value of $Q = 0.5$.
Step 9. Final rank of alternatives is shown in Table 4 and Figure 5.

Table 4. The rank of alternatives.

	N_i^+	N_i^-	$f(N_i^+)$	$f(N_i^-)$	N_i	*Rank*
A_1	-140.795	14.71555907	1.116716	-0.11672	-70.4559	1
A_2	-33.2649	-9.183987339	0.783646	0.216354	-16.5243	5
A_3	-75.1597	16.17790147	1.274286	-0.27429	-37.717	4
A_4	-91.449	-15.27345493	0.856886	0.143114	-45.6529	2
A_5	-77.488	-15.27345493	0.835347	0.164653	-38.6617	3

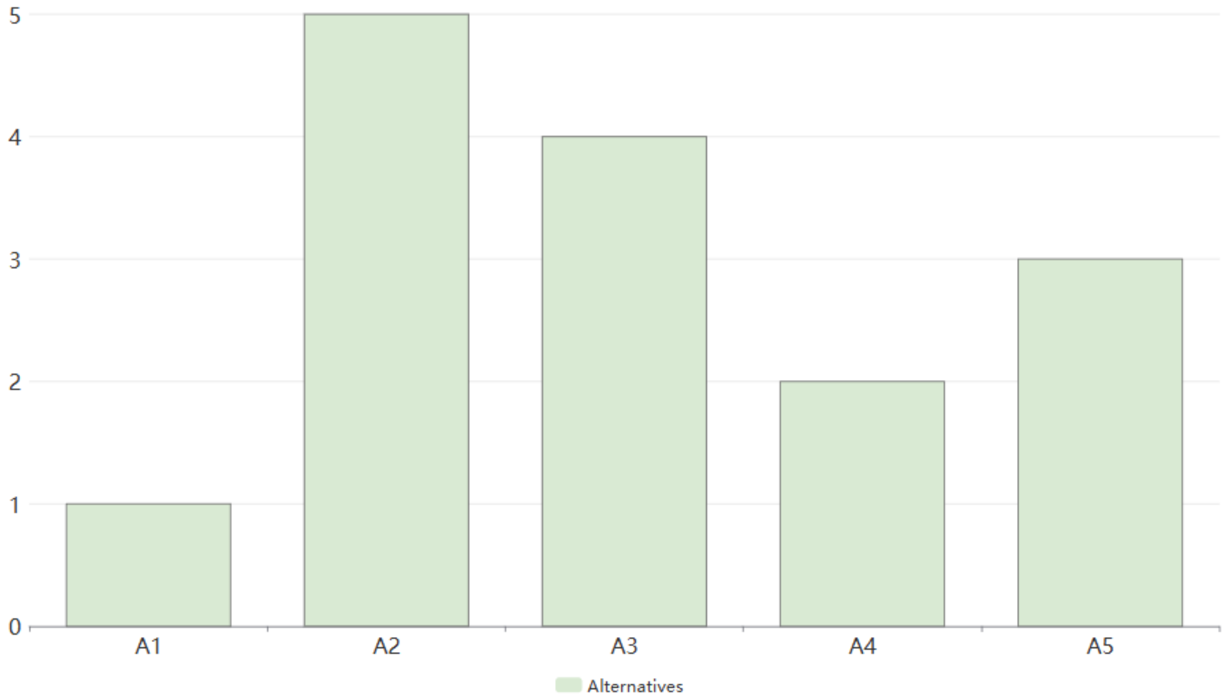

Figure 5. The rank of alternatives.

4. Sensitivity Analysis

This section performed the sensitivity analysis to show the different ranks of the alternatives. Sensitivity analysis shows the stability of the ranks under different cases and changes in each case of the best and worst alternative. This operation ensures the results is not sensitive to change in different cases. This study changes un value of Q between 0 and 1 with eleven cases. Then we applied the proposed approach under these cases as shown in Figure 6. The results show alternative 2 is the best and alternative 1 is the worst. The results show that the rank is stable under different cases.

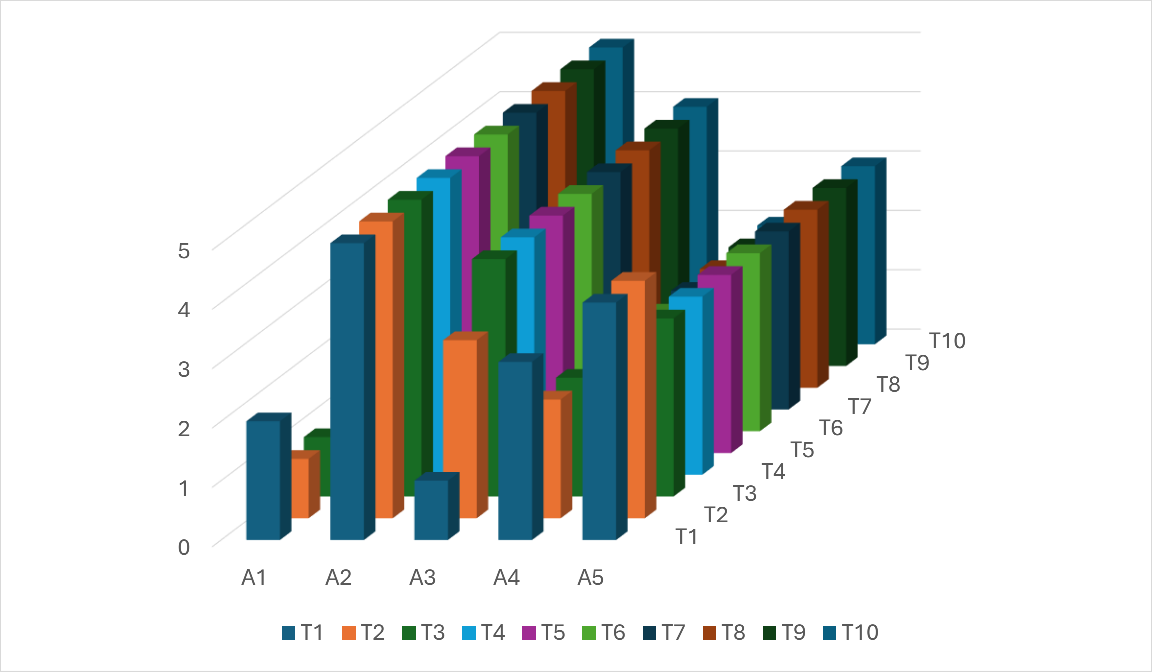

Figure 6. Th sensitivity analysis ranks.

In the second phase in the sensitivity analysis, we change the criteria weights under different weights and then rank the alternatives. Figure 7 shows the criteria weights under different cases. In the first case, we put all criteria weight the same weights. In the second case, we increase the first criterion with 25% and other criteria weights with the same weights.

Then we rank the alternatives under different criteria weights. We show all cases that accepting alternative 2 is the best and alternative 1 is the worst. Case 1, 3, and 4 have identical rank of alternatives. Alternative 2 is the best, followed by alternative 5, alternative 3, alternative 4, and alternative 1 is the worst. Cases 2, 5, 6, 7, and 8 have identical ranks. Alternative 2 is the best, followed by alternative 4, alternative 5, alternative 3, and alternative 1 is the worst. Figure 8 shows the different ranks of alternatives.

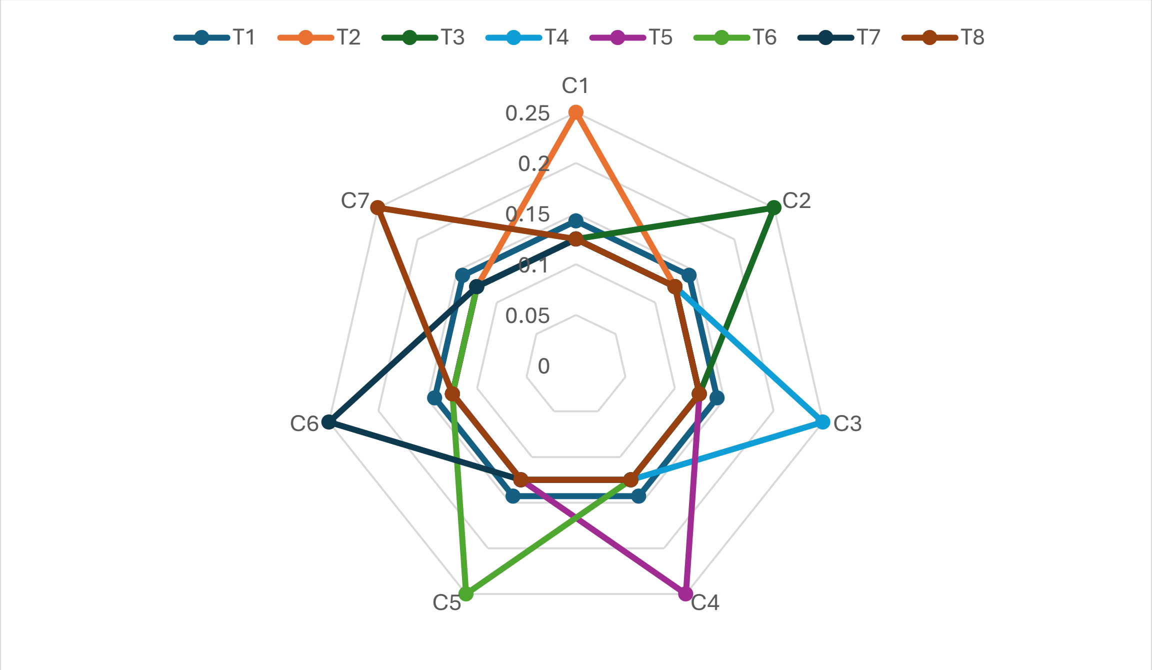

Figure 7. The criteria change under different cases.

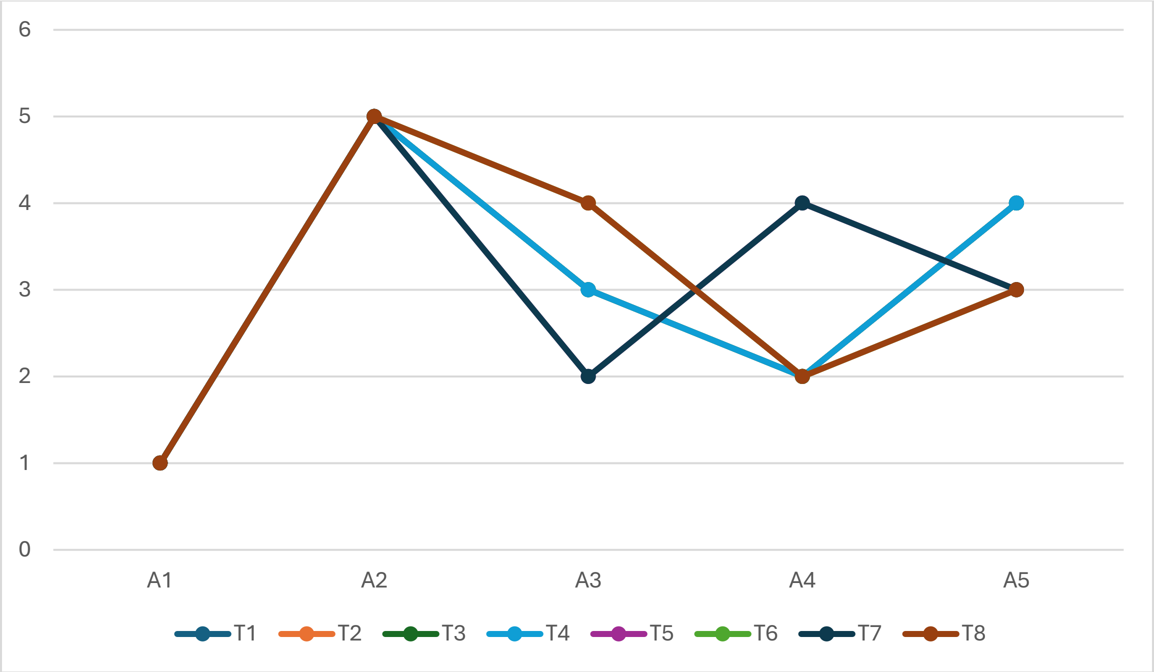

Figure 8. Rank of alternatives under different weights of criteria.

5. Conclusions

With emphasis on the executive selection Petrochemical Enterprises for ecological efficiency, this study tackled the necessity of creating a decision support system within the framework of ecological efficiency evaluation. In contrast to conventional decision support systems, this study offered a thorough viewpoint by integrating qualitative and quantitative criteria in a novel way. For the Petrochemical Enterprises performance analysis topic that was addressed, the suggested plithogenic-ARTASI hybrid model provided a strong foundation. The suggested plithogenic-ARTASI method showed promising results for evaluating Petrochemical Enterprises and determining which one was best. plithogenic aggregation operators were used to determine the weights of the expert opinions that went into evaluating the criterion. Following the presentation of the plithogenic-ARTASI hybrid method's step-by-step development. A case study that examined Petrochemical Enterprises selection for ecological efficiency evaluation was used to test the algorithm's resilience. The results of the study validated the new decision-analytic algorithm's dependability.

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